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Seminar on
"Construction Management Tools, Modern Technologies & Materials in Built Environment"

June 21-22, 2019
Pune

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FOREWORD

The construction industry of today is quite different from the one existing few years back. In the recent decade, there has been speedy growth in mechanization in the construction projects of buildings, infrastructural projects comprising of bridges, highways, ports and airports. The globalization in economy has brought in international competitiveness in the field of engineering projects where speed, economy, manpower optimal planning, quality assurance for durability, functional utility as well as serviceability have been the main considerations in project management. Advanced building technologies can contribute to the environmental performance, reduce defects in construction, improve health and safety on site, and increase overall efficiency.

It is heartening to mention here that with the concerted efforts put up by Government, now, we have a set of 17 such new emerging technologies which can bring in speed, safety, sustainability in the construction sector. The next biggest challenge is to mainstream these new systems in the construction sector and, therefore, there is need to create an enabling eco- system to facilitate use of these new systems. The Government has also setup a technology sub- mission which aims to encourage the use of sustainable & safe practices across states. Government of India has also provided incentives in terms of excise duty concessions on new building materials and custom duty exemptions on import of machinery and equipment required for manufacture of new and waste based materials and prefab components.

Construction projects have so many parties involved and so many moving pieces of data flowing at any given time that something may get missed. Effective project management means controlling the data flow and staying on top of transmittals, submittals, email communications, change orders, materials, inventory, job cost and reports for labour hours and wages, safety regulations, insurance etc.

We should make our best efforts to encourage use of best available management software, alternative green building construction materials, and innovative technologies in Civil Engineering projects for faster construction of stronger, sustainable, durable, user & environmental friendly and affordable buildings to minimise the demand —supply gap.

The Indian Buildings Congress has selected "Construction Management Tools, Modern Techniques and Materials in Built Environment" as theme of this Mid Term Session and Seminar in order to draw attention of all concerned with built environment on this vital topic. It is hoped that this seminar will generate sufficient interest among the professionals and come up with positive and practical recommendations for making speedy and construction an integral part of Built Environment.

(Dr. Anoop Kumar Mittal)
President, IBC &
Fmr. CMD, NBCC (India) Limited

PREFACE

Smart building design, innovative construction technologies and appropriate usage of building materials are tools for sharing knowledge of how various building technologies and materials can increase productivity using advanced communication, collaboration and management techniques. These advancements have paved the way for new construction methodology that makes buildings stronger, safer, durable, time and cost effective.

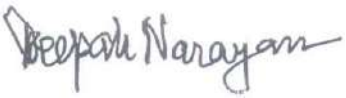
Monolithic Construction has RCC walls and framework with traditional steel shuttering, in which RCC walls, beams and slabs are casted monolithically using different types of formwork such as tunnel formwork, jump form shuttering, aluminium formwork and tunnel formwork. Pre-cast construction is carried out at factory or offsite and components are casted, transported to site and suitably assembled. Pre-cast sandwich panels are used for walling which can be made of different materials as well. Recycled waste materials like flyash bricks, AAC blocks and C&D waste blocks are used for masonry work.

Some other technologies include construction of large mass housing projects on turnkey basis, with precast elements and limited cast-in-situ concrete for wet jointing. Advantage of such construction is quality assurance of pre-cast components, faster construction and less storage space at site. Some other important technologies include high performance concrete, self healing concrete, ductile iron pipes for sewer network, aerogel insulation etc.

Modern construction technologies are also used in conventional construction and pre-engineered buildings. In conventional buildings, many new technologies are being adopted for faster and quality construction in different components like casting of concrete, flooring, connections, finishing and services. Such technologies include monolithic construction using different types of formwork, post tensioned concrete construction, stamped flooring, anchoring, robotics, trenchless technology etc.

In the present day context, the theme of the seminar during the Mid Term Session and Seminar on "Construction Management Tools, Modern Technologies and Materials in Built Environment" on June 21-22, 2019 at Pune is of great relevance. The technical papers received have been included in the Preliminary Publication of the Seminar. Efforts shall be made to include the maximum number of papers for presentation depending on the number of authors present.

The contribution of the various learned authors is gratefully acknowledged. It is expected that the deliberations would be very useful and important recommendations would emerge pertaining to theme of the seminar. I would like to thank all the members of the Technical Committee for rendering their invaluable help in screening and selection of papers. I also express my profound thanks to Shri M.C. Bansal, Advisor (Technical) and Shri P.S.Chadha, Consultant, IBC for their untiring efforts in bringing out this publication.



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TECHNICAL SESSION I:
MODERN TECHNOLOGIES

3S PREFAB BUILDING TECHNOLOGY - CASE STUDY

V.G. JANA* AND COL. SANJAY ADSAR**

Abstract

For mitigating the housing shortage through affordable as well as sustainable built environment, adoption of prefab mass housing movement is the only viable solution. The ambitious 'Housing for All' mission can be realised through capacity building for precast mass housing constructors by ensuring continuity of work besides proactive changes in the tendering system which exists today. The construction of mass housing through precast technology has been successfully implemented by BG Shirke Construction Technology Pvt. Ltd. The timely execution of large scale mass housing projects using 3S System on Design-Build turnkey basis has aptly justified it to be a time-tested and proven technology.

The benefits of 3-S prefab system; which is practiced for the past over 4.5 decades by the company makes it one of the versatile options for mass housing constructions with best quality in India. With the motto as 'Industrialization of civil engineering' this system, which uses total prefab elements, limited cast-in-situ concrete work for wet jointing and not requiring formwork, has been evolved and perfected to cater to the varying geophysical, climatic and seismic conditions prevailing in India. Being an open componentalised system, it enables flexibility for accommodating every possible architectural planning and aesthetic application for all types of dwellings, layouts and storey configurations.

INTRODUCTION

Our Hon'ble Prime Minister has already declared that by 2022, about 2 crore affordable houses for the needy will be constructed all over India. The basic need of human being is "Roti, Kapada and Makan". By and large, the Government has been successful in solving the basic issues, like Roti and Kapada, to some extent. However, as far as the "Makan" is concerned, there has been extremely slow progress in providing affordable housing mainly for Economically Weaker Section (EWS) and Low Income Group (LIG) categories. Our Hon. Prime Minister, a visionary, has appreciated the importance of providing the basic necessity to the common man, i.e. shelter in the form of affordable house and accordingly has prepared an ambitious programme in his own wisdom for providing affordable housing for the weaker sections of the society.

As per the Government's ambitious Housing for All Mission to be accomplished by year 2022, when independent India will be celebrating its 75th Independence Day, every Indian family should have a house of its own.

For fulfilling this ambitious program of our Government, such massive requirement of housing, particularly for EWS and LIG categories, cannot be met with by conventional methods and materials. This is so because, apart from being costly and scarce, these conventional materials and technology to a larger extent are not capable to meet even the fringe of the massive demand and supply situation prevailing in India, today. In order to meet this mammoth task of housing, we would require over 200 constructors, having capability to deliver at least 20000 houses yearly.

**Sr. Chief Executive & **General Manager, B G Shirke Construction Technology Pvt Ltd, Pune*

TRIED, TESTED AND PROVEN 3-S PREFAB TECHNOLOGY

The Founder Chairman, Padma Shri B.G. Shirke, a visionary and reformist, had visualized the burning problem of housing shortage in India about 45 years ago and decided to completely transform civil engineering into its total industrialization by innovating, developing and introducing new products, having scientific and objective quality controls and capable of being modularly planned for economy and standardization, which can cope up with future challenges for effectively solving India's acute and nagging problem of housing shortage and slum proliferation.

Technology

'Shirke' Group, the pioneer of Prefab Building System, using factory produced precast structural components for building construction since 1972. '3-S' (S-Strength, S-Safety, S-Speed) is the brand name of prefab building construction system, which is developed and perfected by 'Shirkes' after years of strenuous Research and Development supplemented by extensive field trials. 'Shirkes' have developed total technology for effective implementation of this '3-S' system of building construction for Mass Housing Projects. The '3-S' system is successfully used for the last about 45 years in India and abroad and have constructed over 2 lac houses in all types of climatic conditions including heavy rainfall areas and seismic zones.

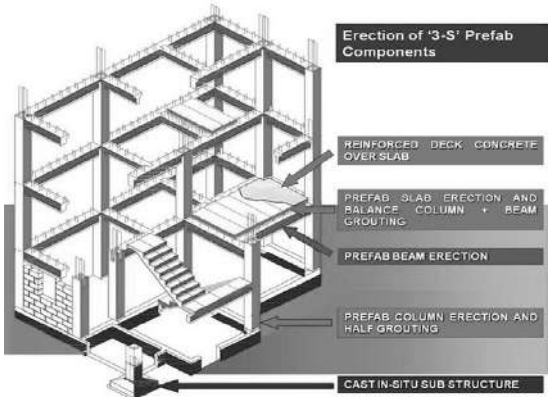

Fig.1: 3S Technology

The technology consists of foundation with conventional methods and superstructure frame with dense concrete hollow cored columns, dense concrete partially precast beams, lintels, staircases, chajjas etc. and autoclaved aerated cellular reinforced (AAC) Siporex slabs/RCC precast slabs and Siporex blocks for masonry, precast walls as shown in Fig.1. Reinforced screed is provided on slab to have monolithic construction. The Siporex Blocks and Slabs are manufactured in permanent factory and other structural components, like columns, beams; precast wall panels, precast slabs, staircases, lintels, chajjas etc, are manufactured at precast factories established at site under stringent quality control. The prefab components are erected, aligned and connected, using self-compacting concrete of appropriate grade and secured with embedded reinforcement. Various projects of buildings completed by adopting 3S technology are shown in Figs. 2 to 8.

Fig. 2: Completed Building

Fig. 3: Prefab Mass Housing Project at Delhi for DDA

Fig. 4: India's 1st High rise 25 Storeyed Prefab Residential Towers at Mumbai

Fig. 5: Conference Hall at Hon. Vice President Residence, New Delhi (Constructed in 82 days)

Fig. 6: Prefab Mass Housing Project at Delhi for DDA

Fig. 7: MIG & HIG Housing Project at Kharghar, Navi Mumbai for CIDCO

Fig. 8: 18 Storeyed Mass Housing Project for BDA at Doddabanahalli, Bangaluru

Successful Implementation of Technology for Mass Housing at Delhi-Case Study

Considering the volume of work, such as construction of about 55,000 houses at Delhi for Delhi Development Authority in a short period of 3 years, the state of the art plant and machinery has been established which is biggest such facility in Asia. The factory is laid out over 25,200 sq.m area with Storage/ Stacking area of 46,000sq.m for the precast components. The most modern sophisticated machineries as shown to Fig.9 to 13 being utilized for Prefab Housing Projects are as under:

- Computerized weigh batching and mixing plant for concrete.
- High capacity tower cranes for erection of structural components.
- High quality moulds for precasting of slabs, walls, columns and beams. The carousel system adopted for casting the walls comprises of 68 pallets. This reduces the cycle time, thereby increasing the rate of casting the walls.
- Automated system for moulding and demoulding of mould sides.
- Specialized vibration system for proper compaction of concrete.
- Automated overhead concrete transport and pouring system.
- Specialized magnetic shuttering.
- Specialized equipment for concrete surface finishing.
- Arrangements for modern ways of curing by hot water circulation, curing chambers with hot air circulation, vapour curing system for precast beams, sprinklers etc., which not only conserves water but also provides efficient curing.
- Specialized tilting, lifting and transportation equipment for early age concrete components.
- Most modern reinforcement steel cutting and bending machines.
- Reinforcement bar decoiler and straightening machine.

- Automatic slab and wall cage welding machine.
- Slab and wall cage bending machine.
- Automatic column cage welding machine (Capacity – 250 sq.m/Hr).
- Automatic stirrup making machine.
- Automatic raft steel binding machine.
- Automatic lattice girder fabrication machine

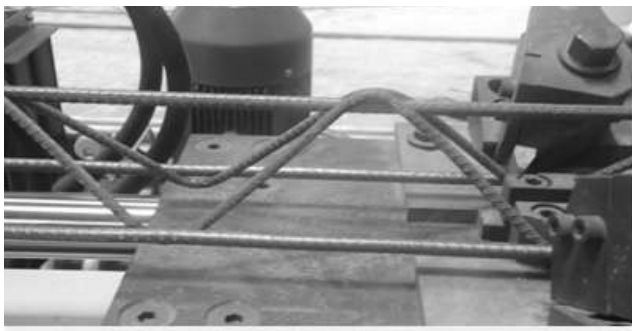

Fig. 9: Lattice Girder Manufacturing Facility for Precast Slabs (7500 m²/day)

Fig. 10: Precast Wall Panels (1400 Sqm/day)

Fig.11: Curing Chambers - for Accelerated Curing

Fig. 12: Precast Column Casting (130 Columns /Day)

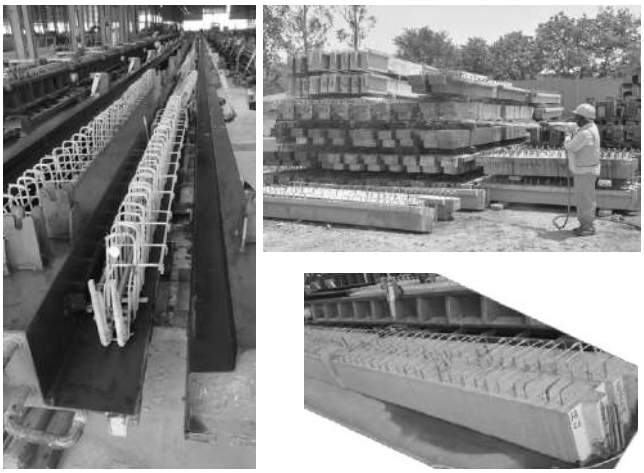

Fig. 13: Precast Beam Casting (1800 m /day)

Evaluation of Technology by Reputed Institutions

The Precast Technology (3S system) has been developed and perfected since 1972 by carrying out field and laboratory tests by many reputed organizations, which are as under:

- City Industrial Development Corporation (CIDCO) has carried out actual performance load test to check the safety and stability of the structure by loading the structure to destruction and found that the structural behaviour was most satisfactory.
- Tests were carried out by Indian Institute of Technology, Mumbai, and they have certified that the joints fully established the behavior in the elastic range with adequate safety margins; absence of any separation cracks or any structural distress in the joints; adequacy of the bare portal to offer resistance to horizontal forces; ultimate load is on the higher side and ductility ratio is more than what is specified and required; joints of the beam column connections have behaved as monolithic, as designed.
- TOR Steel Research Foundation of India has carried out the tests and concluded that there is no distress feature in any of the joints and assembly of precast units is safe for resisting the loads for which they are designed for.
- Tests were carried out by Prof. Haresh C. Shah, Head of Civil Engineering Department, Stanford University, and he certified that the design calculations and detailing of the structure are such that for vertical loads, seismic loads and the wind loads, the buildings should provide safe and desired performance.
- Central Building Research Institute (CBRI), Roorkee, has also carried out tests and experimental results on Full Scale Building Structure and established the desired performance and behaviour of '3-S prefab building system under all design load conditions, including seismic (Zone-IV) for high rise buildings. CBRI has also certified that protective treatment given to steel reinforcement in Siporex is quite effective compared to corrosion of steel in normal conventional concrete.

TECHNOLOGICAL AND FINANCIAL BENEFITS

Technological advantages

- Reduction in dead weight due to light weight prefab components is beneficial from seismic considerations.
- Use of fire resistant Siporex products enhances the safety of the buildings
- Thermal insulation properties of Siporex products leads to increased comfort levels inside the buildings.
- Due to use of precast structural members, cycle time required for each floor is reduced substantially.
- Elimination of plaster to precast units, such as slab, wall panel etc., since these components are form finished, which is similar or better than that of a plastered surface.
- Quality is ensured automatically as structural units have BIS(ISI) norm and markings and are manufactured in permanent / site factories with objective quality control.
- Considerable reduction in use of quantities of natural resources, such as sand, metal, water, wood etc, by optimum utilization of construction materials.

Financial benefits

- Due to turnkey, saving in planning and design fee.
- Reduction in dead weight results in saving in foundation and frame work cost.'
- Saving in cost due to elimination of slab, wall panel plaster.
- Due to early completion, financial benefits are as under:
  - □ Saving in interest on investment.
  - □ Saving in escalation cost
  - □ Saving in establishment cost
  - □ Early return on investments
- Cost saving in maintenance due to quality construction.
- Rapid Speed of erection and fast construction, resulting in earlier occupancy and reduced financing cost.

Due to technological advantages, there is time saving of 15 to 20% and cost saving of about 30 to 40%.

ENVIRONMENT FRIENDLY TECHNOLOGY

'3-S' Prefab Technology is eco-friendly due to judicious use of construction materials, reduction in wastage of materials, using more durable materials, use of energy efficient building materials, use of products that contribute to a safe, healthy built environment, use of construction system minimizing air, water and noise pollution during construction, use of fly-ash, very minimal requirement of water for construction, non-generation of construction debris, elimination of use of timber / wooden scaffolding, judicious use of scarce natural resources, use of eco-friendly products for walling, flooring and roofing.

CONCLUSION

There is huge shortage of affordable houses to the tune of 95% of total requirements [9] in the country particularly in LIG and EWS segments. Such massive requirements cannot be met with conventional construction methods. 3-S Prefab technology for smart construction, a brand name developed and perfected by Shirke has undergone the test of time in addition to rigorous tests and appraisals conducted at test houses of national and international repute. The 3-S system is thus, tried, tested and proven to suit the Indian climatic, seismic, rainfall and wind conditions. In addition to speed and several other sustainable benefits, there is cost saving of about 30 to 40% if tangible and intangible financial benefits are to be quantified due to technological advantages.

The uniqueness of the smart construction in the project is amply brought out right from inception itself by inviting Lump sum Turnkey tender, setting up a state-of-the-artonsite precast manufacturing unit, achieving full mechanization / automation, incorporating sustainable features and delivering on both parameters of quality and time. The 3-S (S-Strength, S-Safety, S-Speed and Sustainability) prefab technology for smart construction would thus go long way in mitigating the housing shortage through industrialization of civil engineering and Shirke has already taken lead on this front as is evident through the case study. This case study has been able to exhibit several unique features and demonstrate global best practices by introducing cutting edge technology which makes this project a model and trend setter that can be replicated to fulfil the Government's missions of 'Smart City' and 'Housing for All'.

Use of prefab construction has reportedly helped in saving almost 60% of time in completion of projects as compared to the conventional construction methods. To summarize, it can be said that the Industrialized manufacturing system using prefab technology such as 3-S for smart construction is the best solution to meet huge demand supply gap particularly in LIG and EWS category and to ensure sustainable and inclusive development. Such smart construction technology would also offer an economy of scale and hence reduced cost, greater speed and green construction.

STRUCTURAL SYSTEMS FOR SEISMIC RESISTANCE

VINAY GUPTA*

Abstract

As the time goes by, awareness of earthquake proofness of structures is increasing. There are even examples wherein occupants of buildings (residential as well as commercial) are asking the builder for a certificate from the respective structural consultant stating that the structural design adheres to the prevailing codes and standards for earthquake design and detailing. This has made it mandatory to incorporate up to date seismic provisions in the structure. Architectural and structural engineer have to work in tandem to see that architectural ambitions adequately camouflage the structural needs. On the other hand, seismic zones have been upgraded in some locations after occurrence of more sever seismic activity. A recent example is Killari earthquake in Maharashtra that has led to upgrading seismic zone I to III in the respective areas. Higher levels of seismic forces require techniques to reduce seismic demand of the structure and mitigate seismic effects.

Use of Base Isolation, Seismic Dampers, Shock Transmission Unit etc are some of the new techniques used for the purpose. It is said that a more rigid basic structure in combination with one of the anti-seismic devices stated above performs better than the one made structurally more flexible by reducing the member stiffness. Once the seismic related structural provisions are adequately camouflaged into architectural designs, undoubtedly an efficient structure is created.

INTRODUCTION

Earthquake acts in any possible direction, including vertical. Depending upon the considered return period of occurrence of earthquake, the design magnitude of earthquake varies. For a considered higher return period, design earthquake magnitude is higher and vice-versa. It is for this reason that a structure is typically designed to remain elastic for the magnitudes corresponding to 50 to 100 years return period (more frequent but smaller earthquakes) and avoid collapse for higher return period (about 500 years) of earthquakes which are much stronger. At this higher level of earthquake plastic hinges are expected to form at structural junctions, collapse of which is avoided by providing special confining transverse reinforcement at such junctions. Table 1 gives details of some of the recent major earthquakes in India.

Table 1: Major Indian Earthquakes in Last 100 Years

MAJOR INDIAN EARTHQUAKES IN LAST 100 YEARS

MAGNITUDE (RICHTER SCALE)	LOCATION	YEAR	DEATHS
>8.5	ASSAM	1897	1,542
8.0	KANGRA (HP)	1905	20,000
6.5	JABALPUR	1927	?
8.4	BIHAR-NEPAL	1934	14,000
8.3	ASSAM	1950	1,500
6.6	BIHAR-NEPAL	1988	1,000
6.4	LATTUR	1993	10,000
6.1	JABALPUR	1997	?
7.7	BHUJ	2001	20,000
7.8	S-W CHINA	2008 (KILLED/MISSING)	87,000
7.0	PORT-AU-PRINCE	2010 (KILLED/MISSING)	2,30,000
8.9	JAPAN	2011 (KILLED/MISSING)	20,000
7.8	NEPAL	2015	8,000

- EACH INCREASE OF 1.0 ON THE RICHTER SCALE IS A 10 FOLD INCREASE IN WAVE AMPLITUDE AND A 30 FOLD INCREASE IN ENERGY RELEASED.
- OVER 60% OF INDIA IS EARTHQUAKE PRONE

There is a common terminology called Richter Magnitude, which defines the level of earthquake near the point of origin. It is defined as "A number, which is a measure of energy released in an earthquake, defined as log(10) of the maximum

* *Director & CEO, Tandon Consultants Pvt. Ltd, New Delhi*

trace amplitude (microns) measured by a standard short period torsion seismometer with its period of 0.8 sec, magnification 2800, near critical damping at an epicentral distance of 100 km."

STRUCTURAL CONCEPTS

It is a well-known principle that configuration of a structure in high seismic zone should be as simple as possible, i.e. no or negligible plan and elevational irregularities, no abrupt change of stiffness, no weak storey as far as possible, minimum plan torsional effects etc. However, a congenial working between the architect and the structural engineer can still provide an aesthetic structure within the acceptable premise of seismic norms. A structure shown in Figs.1, 2 & 3 located in a very low seismic zone of Thailand has no seismic issues and can assume any shape. Whereas a structure shown in Figs. 4, 5 & 6 located in India's highest seismic zone no. V needs every precaution to be taken against seismicity.

Fig. 1: Atrium Hotel, Bangkok

Fig. 2: Banded Slab PSC Floors

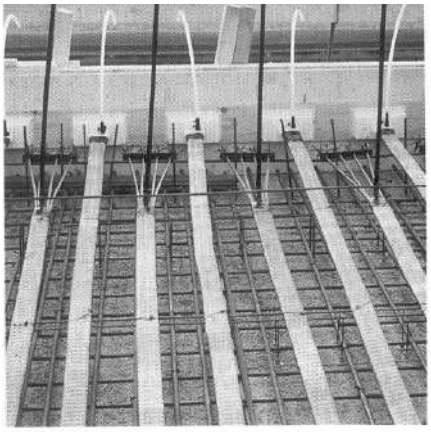

Fig. 3: Flat PT System

Fig.4: Khalsa Heritage Complex, Punjab

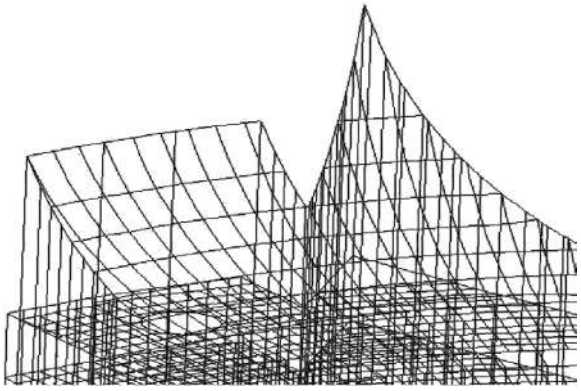

Fig. 5: 3D Grillage Analysis of Khalsa Heritage Complex

In case of plan/elevation irregularity, one of the basic and simple rules is to divide the structure into building blocks, using expansion joints, maintaining a regular structure between consecutive expansion joints. Radisson Hotel, Delhi (Fig.6) has several plan and elevation irregularities. These have been handled by incorporating several expansion joints (almost at every 20m), Fig. 7.

Fig. 6: Radisson Hotel, Delhi

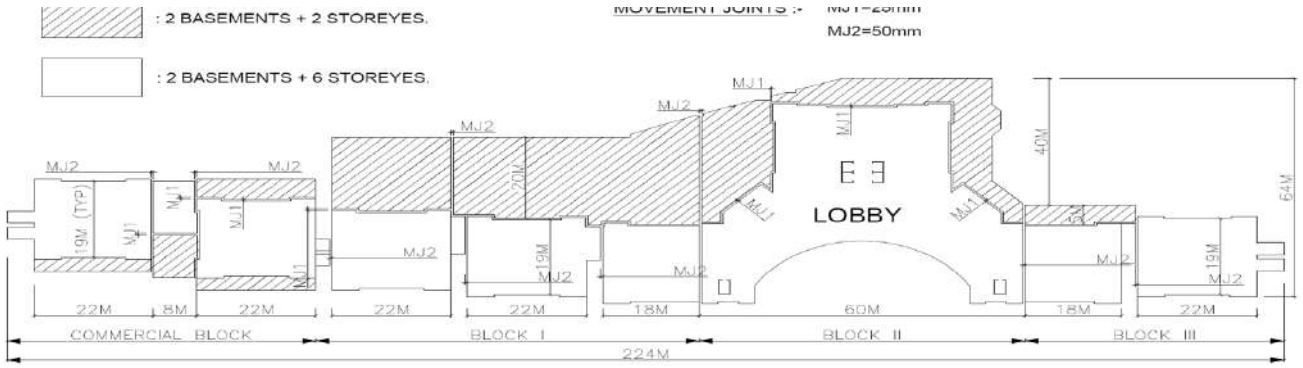

Fig. 7: Separation Using Expansion Joints

In order to negotiate better with the architects, most of the expansion joints were provided with corbels and continuous ribs to support beams and slabs, respectively with elastomeric bearing sandwich to permit movement (Fig.8), thereby avoiding twin columns.

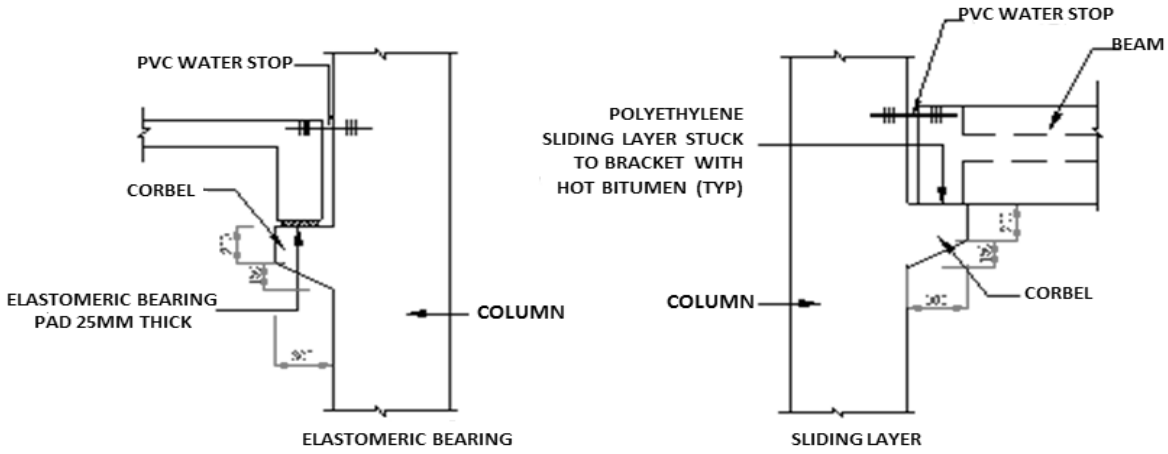

Fig.8: Detailing at Expansion Joint

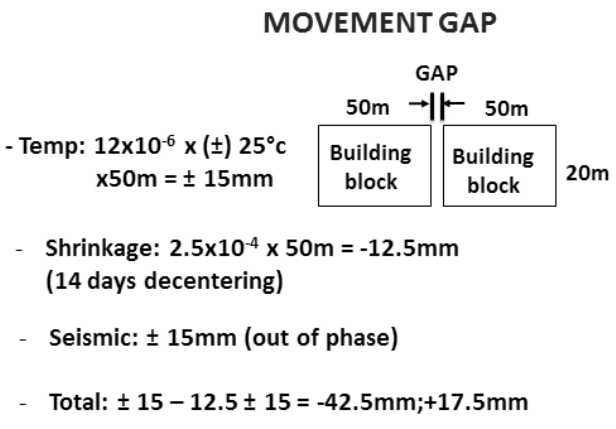

Fig. 9: Movement at Expansion Joint

One of the issues about expansion joint that bothers designers is about the gap. The gap movement depends upon several factors, such as thermal movement of the adjoining building blocks, creep and shrinkage movements, seismic out of phase movement, structural deflections etc. (Fig.9). Hence, a taller structure requires a larger expansion gap. Similarly, a more rigid structure will entail smaller expansion gap.

Eurocode EN-1998-1:2014 states "Structural Simplicity Incorporating Clear and Direct Paths for Transmission of Seismic Forces is an important aspect as Simple Structures are subject to much less uncertainty of Seismic Behaviour".

STRUCTURAL DESIGN FOR EARTHQUAKE

For the reasons explained above, designs are performed for two levels of earthquake, viz Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE). They are defined as:

DBE: Maximum Earthquake that can be expected to occur and structure would undergo permissible deformations and repairable damages during economic life of 50-100 years of structure.

MCE: Maximum earthquake motion capable of producing most severe ground motion under the currently known Seismo-Tectonic Framework. Significant cracking/irreparable damages can be expected to occur.

However, for regular design purpose, DBE forces are used and the method as given in Figs. 10 & 11 is used.

EARTHQUAKE EFFECTS

The horizontal seismic coefficient for Design Basis Earthquake is given by

---------- (7)

$$A_h = \frac{(Z/2)(Sa/g)}{R/I}$$

Here Z = Zone Factor depending on the location of project in India

I = Importance Factor, taken as 1.5 for Reinforced Concrete Chimneys

R = Response Reduction Factor taken as 3, ***Ref 5***

Sa/g = Spectral acceleration for 5% damping and as a function of period of vibration and sub-strata below the foundation.

Dynamic analysis using response spectrum method is generally recommended for tall structures in consonance with equation (7). The no. of modes to be considered in the analysis should be such that about 90% of the modal mass is excited. The modes are then combined for response (shear, moment, etc.).

Fig. 10: Earthquake Design

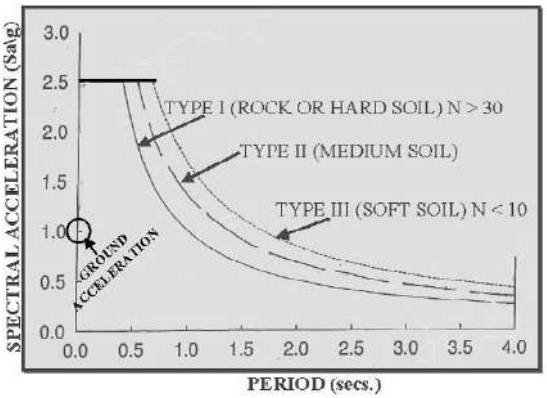

Fig. 11: Response Spectra

Codal requirements for lapping of column reinforcement and special confining reinforcement are indicated in Fig.12. The detailing poses a difficulty of having to stabilize as much as 8m to 10m long vertical reinforcement above the foundation level, as lapping is permitted in only the middle half of storey height and not more than half the bars must be lapped at a section. This necessitates use of reinforcement couplers as in Fig 13, which enables splicing of all the vertical reinforcement within one floor, because length of reinforcement couplers is 100mm – 150mm and stagger required is only 600mm, entailing splicing all the bars within about a meter distance. This reduces length of bars above foundation to be stabilized to 5m to 6m.

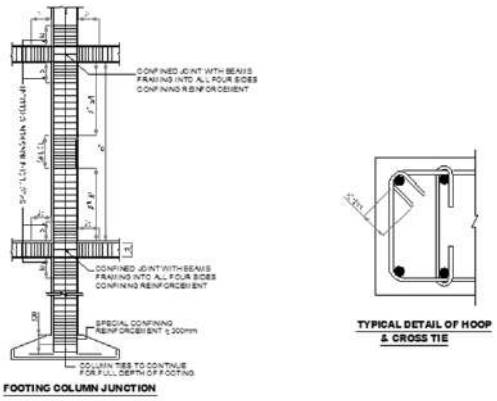

Fig.12: Ductility Requirements

Fig. 13: Splicing using Reinforcement Couplers

Reinforcement couplers work on nut-bolt concept as shown in Fig 14. IS:13920 dictates detailing of column stirrups/ties to engage the other encountered stirrup/tie passing above and below it, as in Fig 15. This is difficult, but not impossible. The Fig 15 shows picture of an actually executed project this way.

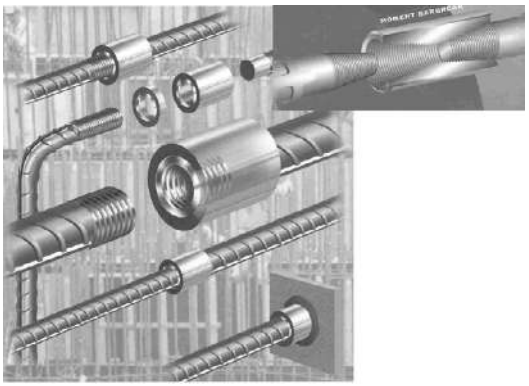

Fig.14: Reinforcement Couplers

Fig.15: Seismic Detailing of Transverse Reinforcement

It is a common practice to provide large span girders (for large open areas) in lower floors to support closely spaced columns above for the guest rooms in case of hotel buildings. In such cases, we get into an undesirable situation of unpredictable locations of plastic hinges. For one such case, (Figs. 16 & 17), we provided special confining reinforcement throughout the respective members to substantially improve seismic performance of the structure.

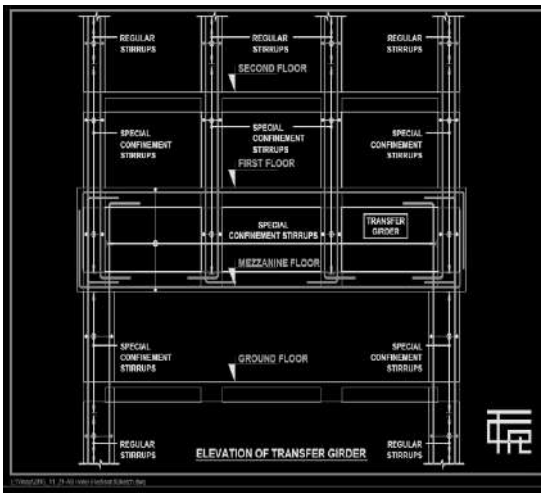

Fig.16: One Floor Deep Transfer Girder

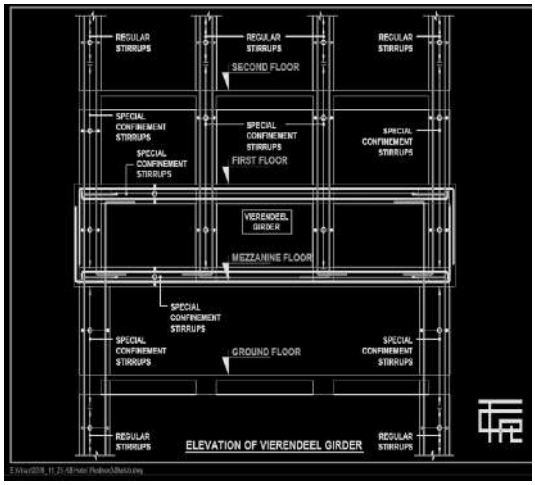

Fig. 17: One Floor Deep Vierendeel Girder

In case, such provisions are not followed, damages as in Figs. 18 & 19 may take place.

Fig.18: Damage During 2001 Earthquake

Fig. 19: Damage During 2001 Earthquake

ANTI-SEISMIC DEVICES

In order to mitigate high levels of earthquake forces, several methods have been devised. One of them being reduction of stiffness of structure. This method entails larger structural deflections and

more density of reinforcement. Other option is to provide suitable anti-seismic devices, such as base Isolators, friction dampers, lead-rubber bearing (Isolators), shock transmission unit (STU), etc.

The factory building of Samtel Color Ltd incorporates precast post-tensioned concrete roof trusses resting over RCC columns with elastomeric rubber isolator sandwich, reducing earthquake forces to less than half (Fig 20). Friction Dampers as shown in Figs. 21& 22 are used in building frames to reduce the seismic demand. Hydraulic Dampers as in Fig. 23 have been used in Apollo Hospital, Delhi and few other buildings.

Fig. 20: Use of Elastomeric Isolators

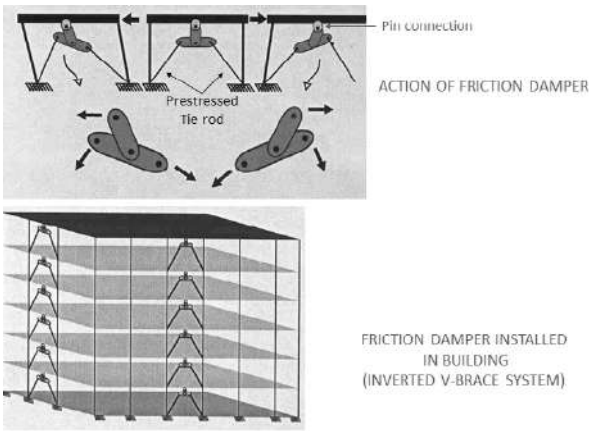

Fig. 21: Use of Friction Dampers

The elastomeric isolators used in Samtel Color Ltd use low damping elastomer which is same as the conventional elastomer used for bridges and other structures and it has damping ratio of about 6%. If the requirement of damping is high, lead rubber bearing as indicated in Fig. 24 may be used. In this case, lead plug is sandwiched within low damping elastomer. This system provides a damping ratio of about 30%. For further damping ratio of 60% to 70%, Hydraulic Viscous Dampers may be used. In nutshell, anti-seismic devices reduce the seismic demand substantially.

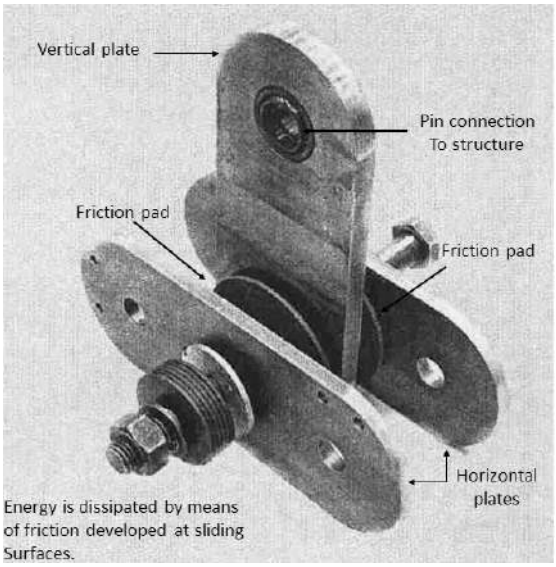

Fig. 22: Friction Damper

Fig. 23: Use of Hydraulic Dampers

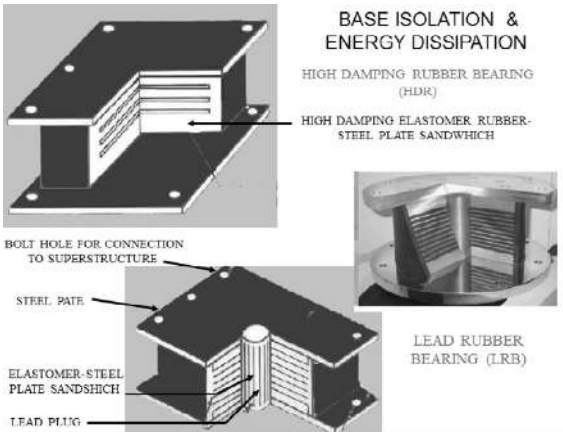

Fig. 24: Lead Rubber Bearing

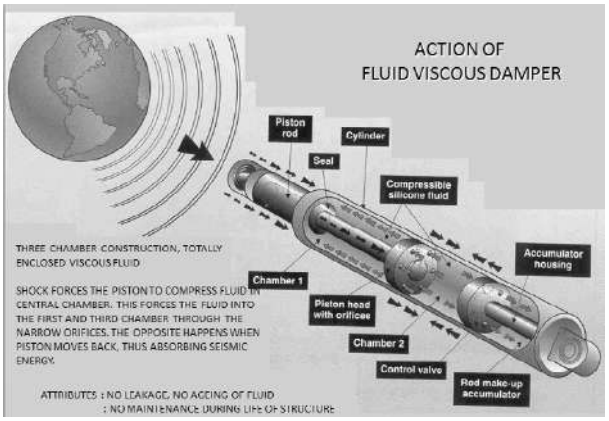

Fig. 25: Shock Transmission Unit

It is a common practice (mostly abroad, some in India) to provide Shock Transmission Unit (STU) (Fig. 25) in long continuous bridges, wherein one restrained pier is required to carry all longitudinal forces of the entire continuous superstructure length, making it difficult to design. In such cases STUs are provided at some of the free piers enabling them to become restrained piers during quick acting forces such as braking and Earthquake. The longitudinal force is shared among more than one pier and design of restrained pier becomes feasible. Figs. 26 & 27 for one such bridge.

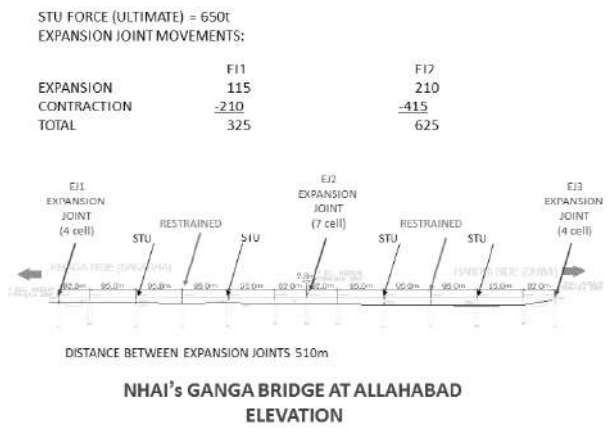

Fig. 26: Bridge with STUs

An example of camouflaging architecture with structural needs, especially earthquake is eminent in AIIMS-Safdarjung Hospital flyover in Delhi (Figs.28,29&30) wherein plan curvature, curved surface of superstructure and curved surface of piers have been provided with aesthetic matching. At the same time, seismic attachments have been provided between piers cap and superstructure.

Fig. 27: STUs in Place

Fig. 28: AIIMS- Safdarjung Flyover

Fig. 29: Aesthetic Matching

Fig. 30: Seismic Attachments

CONCLUSION

A properly conceptualized structure requires constant interaction between the architect and the structural engineer. Each one needs to understand and respect other one's requirements. These days, neither a structurally deficient structure with very good aesthetics is acceptable, nor is structurally sound structure with poor aesthetics acceptable. Hence, both need to work hand in hand. While low seismic zones can be taken care of with ease, high seismic zones require special precautions. Several Indian codes are being developed to design and provide anti-seismic devices for the use in buildings and bridges to mitigate the seismic forces. It is our joint responsibility to provide a structure that is structurally sound as well as aesthetically beautiful.

EMERGING CONSTRUCTION TECHNOLOGIES IN INDIA

Dr. K.M. Soni*

Abstract

Speed, quality and durability are going to govern the construction process in the country due to large requirement of housing. Construction technologies which qualify for speed, quality and durability will last longer and others may not.

Large numbers of construction technologies are available in the country and globally but many are with slight innovation or being used for some parts or applications of construction but RCC and steel still remain main construction materials.

CPWD is involved in planning and execution of buildings and preparation of engineering documents. CPWD adopts new technologies in its projects and then incorporates them in its Schedule of Rates. These are discussed in the paper alongwith other technologies.

INTRODUCTION

Many organizations now arrange the financial resources through loans or grants which are provided for a fixed period. Hence, such funds are limited and mostly not carried forward during next financial year. Such organizations are asked to construct the buildings or create infrastructure within the time allotted to them. Any cost or time overrun puts them in difficulty as either they do not get funds or are required to pay additional interest on the loans taken by them. Hence, completion of works in time or before time has become priority of such organizations and so of the government also.

CPWD has approved new and emerging technologies which help in faster construction. Such technologies are in different fields like materials, formwork, components, or processes. Some technologies contribute to faster construction and some to utilizing waste materials and few use innovative and new materials or processes. Overall 17 technologies have been approved by CPWD for construction in CPWD works.

Apart from the technologies approved by CPWD, many other technologies are available, some of which are briefly discussed.

TECHNOLOGIES APPROVED BY CPWD

The following technologies have been approved by CPWD;

- Monolithic construction using aluminium formwork
- Monolithic construction using plastic aluminium formwork
- Pre fab or pre cast construction
- LGFS construction
- Hybrid construction
- Expanded polystyrene core panel system
- Speed floor system
- GFRG panel building system
- Non asbestos fibre reinforced aerated sandwich wall/roof/floor light weight solid core panel
- EPS cement sandwich wall/roof/floor light weight solid core panel
- Block masonry using AAC blocks
- Block masonry using Flyash bricks

**Addl. DG, CPWD, Delhi*

- Reinforced soil technology using technical textiles
- Use of self compaction concrete
- Use of confined masonry
- Use of C&D recycled waste products in construction
- VRF system in air-conditioning

Above technologies can be grouped broadly in the following categories;

- Monolithic construction
- Pre fab/pre cast RCC construction
- LGFS construction
- Hybrid construction
- Pre-fabricated sandwich panel system
- Masonry with recycled waste technology
- Reinforced soil technology
- High Performance concrete
- Energy efficient technologies

Monolithic construction has RCC walls and as such it is similar to RCC framework construction except it uses new type of formwork than the traditional steel shuttering in which RCC walls, beams and slab are casted insitu and monolithically using different type of formwork such as tunnel formwork, aluminium formwork, jump formwork, plastic or plastic - aluminium formwork. Prefab or pre cast construction is carried out at factory or off site in the yard where structural components are casted, transported at site, and assembled with or without any cast in situ construction. LGFS uses light gauge steel structure which is then covered with different types of materials and buildings erected. Hybrid construction uses two different types of materials like LGFS and steel particularly to suit design requirements. Pre cast sandwich panels are used for walling which can be made with different materials. As they are to be transported from the factory to site, they are made of lighter materials for ease of transportation and erection. Recycled waste materials like flyash bricks, AAC blocks and C&D waste blocks are used for masonry works. Reinforced soil technology is used for retaining walls, roads and slope stabilization. Confined masonry is similar to RCC construction and reduces column sizes and performs better under seismic conditions. VRF is used for air-conditioning, normally in place of window or split air-conditioners.

MONOLITHIC CONSTRUCTION TECHNOLOGIES

Monolithic construction means in situ casting of slab, beams and columns/walls simultaneously. Such construction is carried out by specialized shuttering/ formwork after placement of reinforcement and service lines hence all the designs and drawings must be available before taking up the construction. As the construction of the structure is with RCC walls, wall thickness is less than masonry members or columns resulting into higher carpet area. Also, it has few construction joints and even does not require cement plaster on the walls. It provides better seismic resistance due to monolithic action. Main advantage is speed and quality. It is highly suitable for repetitive multi-storeyed construction which may compensate to the extra cost due to economy of scale.

Limitations of such construction include limited modular sizes in some cases, high cost in case of non-repetitive units, high initial cost, skilled labour requirement, changes not feasible after casting or during life time of the building, feasibility of limited architectural features, less energy efficient due to external walls having low insulation properties, and difficulty and higher cost in repair and rehabilitation of services and structure during its life time. Due to advantage in repetitive type of construction, such technique is being adopted in residential units, hostels and hotels having similar modules.

Monolithic construction can be adopted using various types of shuttering as given in the following;

JUMP FORM SHUTTERING

In this technique, central core generally for housing lifts or staircase is constructed first using a climbing or jump formwork system and thus the name. A frame is constructed over the central core and steel formwork hung from it. Once the climbing formwork is in position, the formwork panels are

closed and concrete wall casted. After the walls are casted, the formwork is released. Jacks then lift the whole frame up to next level. All the formwork panels are then attached to the frame and the process continued. The formwork gets supported on the concrete casted earlier and thus does not rely on supports or access from other parts of the building or permanent works. This is suitable for multi-storeyed vertical concrete such as shear walls, core walls, lift shafts and stair shafts in buildings. Advantage in high rise construction is that central core can be effectively used for other activities.

With little difference in operations, three types of such formwork are in general use known as normal jump form in which units are individually lifted off the structure and relocated at the next level using a crane, guided climbing jump form in which units remain guided by the structure also using crane, and self climbing jump form, which does not require crane as it climbs on rails by means of hydraulic jacks. Guided formwork also known as slip formwork is similar to self climbing formwork but moves continuously when pouring/ casting is being done instead of periodically static self climbing formwork.

Such formwork has the advantage of faster construction and can be used only for central core while for other parts of building, normal RCC construction can be taken up.

ALUMINIUM FORMWORK

Monolithic construction is also carried out by using aluminium formwork system (Fig.1) which allows casting of a floor in single operation. Mivan is the name of Malaysian company who invented it first in 1990. Advantage of such formwork is that architectural features like projections, cornices, planters, curved beams etc can also be casted in one operation though it cannot be combined with other formwork materials such as plywood and steel. The formwork is largely hand held and does not need the services of a crane for movement either vertically or horizontally. These can be effectively used for repetitive works like multi-storeyed construction or row houses (Fig.2).

Fig. 1: Aluminium Formwork

Fig. 2: Multi-Storeyed Construction

Limitation of the technology may be holes caused by wall ties which are to be taken care to avoid leakage/seepage. Number of times such formwork can be used is less than tunnel formwork. It is said that it can be used 250 times while tunnel formwork can be used for more than 500 times though being aluminium, it can be recycled. Suppliers of such formwork are available in the country.

TUNNEL FORMWORK

Tunnel formwork was invented about 50 years back in Turkey for multi unit residential apartments and is said to be useable from 500 – 1000 cycles. It comes in half units in the form of an inverted "L". When two halves are bolted together at the top, they form the tunnel (Fig.3) hence the name. The inbuilt wheels and the jacks help the formwork move in and out of the position and adjusted to the final height to cast walls and slabs in one operation in a daily cycle. In casting process, prefabricated wall reinforcement is placed by crane along the entire wing prior to casting the kickers used to position wall formwork then two and a half tunnel placed in position also by crane, bolted together

and ties added. The formwork system provides for a pour to be wrapped in tarpaulins and for the use of butane heaters to maintain a sufficiently high temperature for the concrete to reach its desired strength overnight for removal of formwork next day thus working on 24 hours cycle. The process is repeated for the next two bays. Apart from limitations described earlier, in tunnel formwork, walls are to be planned in same alignment of the formwork (Fig.4), external projections avoided and shaft openings to be provided from inside. CPWD has taken up such construction in Chennai (Fig.5).

Fig. 3: Tunnel Formwork

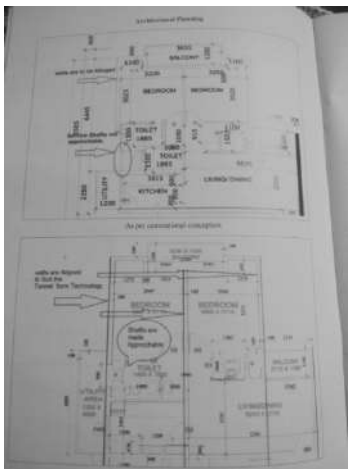

Fig. 4: Alignment of Walls

Monolithic construction can also be achieved using plastic, aluminium-plastic and formwork of similar other materials. Such formwork is cheaper but cannot be used for those numbers of repetitions as aluminium or tunnel formwork and has to be checked for uniform surface without any bulging. Maini scaffold systems, MFS formwork systems Pvt. Ltd., Bajaj products, Uday structural and engineers Pvt. Ltd., Prime Steeltech (I) Pvt. Ltd., RGVR constructions India Pvt. Ltd., Royal technocrafts, Wonder moldplast Pvt. Ltd., and Global industrial suppliers are some of the suppliers of different formworks for monolithic construction.

Fig. 5: CPWD Construction

PRE FABRICATED CONSTRUCTION

Pre-fabricated construction may be with pre-cast concrete or steel. Precast concrete buildings use precast RCC structural members such as beams, slabs, columns, walls, staircases, individual isolated footings etc (Fig.6). Normally such members are fabricated at the casting yard or in the factory with in-situ jointing. Connectivity of pre fabricated members is to be ensured and members designed suiting to seismic/ lateral loads, if any. Advantage of such construction is in pollution and dust control, quality assurance, faster construction and less storage space required at the site. Limitations are of module sizes, limited architectural features, constraints of service lines and assurance of monolithic action during lateral loads. CPWD has recently constructed multi level car parking block for SBI data centre at Hyderabad (Fig.7) in which precast external and internal wall panels, precast parapet wall panels, precast pre-stressed beams, precast hollow core slabs, precast staircase, precast columns and precast solid slabs for ramp landings have been used. Cost analysis indicated that such construction is costlier than conventional in situ construction for individual buildings however for large number of buildings, the cost may be comparable. Also, the speed of construction is faster compared to conventional construction. Such

technology is recommended upto seismic zone IV however analysis of seismic loads may be made before adopting such technology.

Fig. 6: Precast Slab

Fig.7: Building with Precast Members

Some of the technology providers are M/s B G Shirke construction technologies Pvt. ltd, Moducast Pvt. Ltd, Magicrete Building Solutions, Elematic India, P G Setty Construction Pvt. Ltd., Teemage, Nordicflex, William Ling, and Adalakha associates Pvt. Ltd.

LIGHT GAUGE FRAME SYSTEM (LGFS)

LGFS technology uses cold formed steel as the construction material for wall, floor and roof system. LGFS cold rolled steel sections are galvanized for corrosion resistant property, have less weight, and helps in faster construction. Since inside structure is with LGFS, external panels both from outside and inside are used like pre cast concrete panels and polyurethane based panels. Since the system is light, it can be used for low rise structures though with steel structures, LGFS can be used in high rise structures i.e. with hybrid structures. LGFS construction is recommended for G+3 structures. Advantage is that the structure is light, construction is faster and chances of corrosion are less compared to RCC structures. Precautions are to be taken in design and connections of foundation with LGFS components, their maintainability and durability. Impact resistance to such structures may also be less compared to conventional ones.

In hybrid steel structure, a combination of LGFS and steel structure can be used and then any number of storeys can be constructed however cost may not be economical substantially but speed is faster than conventional RCC structures. Since, LGFS structures are light, load on the structure is also less compared to conventional construction.

Some of the agencies in this technology are Mitsumi housing Pvt. Ltd., Everest industries Ltd., MGI infra Pvt. Ltd., RCM prefab Pvt. Ltd, Visakha industries Pvt. Ltd., Jindal Steel & Power Ltd, and HIL Ltd.

STAY IN PLACE FORMWORK SYSTEM

Stay in place formwork, as the name suggests, stays with the structure and thus not taken out as done in case of conventional shuttering or tunnel/aluminium formwork system. Since the formwork remains, it is of light weight like EPS. J K Structure, FACT RCF building products Ltd., Coffor Construction Technology Pvt. Ltd., Reliable Insupack and FTS Buildtech Pvt. Ltd. are some of the technology providers.

PREFABRICATED SANDWICH PANEL SYSTEM

Sandwich panels are used for walling and can be made from different materials such as EPS, cement based materials, fibre glass, or any other light suitable material. Such panels are sometimes used for load bearing construction, which are used for low rise structures varying from as G+1 to G+3 structures. Such panels can also be used in conventional RCC framed construction and walls made of such panels in place of brick/block work. Such construction needs to be ensured for seepage and connectivity when used in RCC construction.

Such technology for high rise construction is only for wall panels and as panels are precast, they save the time of construction.

Some of the agencies providing such technologies are Worldhaus, Rising Japan infra Pvt. Ltd., Bau Panel Systems India Pvt. Ltd., B K Chemtech Engineering, Beardshell Ltd., and Covestro India Pvt. Ltd.

CONFINED MASONRY CONSTRUCTION TECHNOLOGY

Concept of confined masonry construction (Fig.8) is similar to Assam walling or ekra walling construction used long time back in semi permanent buildings in north eastern part of India, difference being that in place of wooden vertical and horizontal members of ekra walling construction, members in confined masonry construction are casted in reinforced concrete while infill walls are replaced with masonry work in place of bamboo mat. Such construction has higher seismic resistance and provides higher carpet area due to lesser sizes of columns.

Fig. 8: Confined Masonry Construction in IIT Gandhinagar

HIGH PERFORMANCE CONCRETE (HPC)

HPC is a high strength concrete made by lowering the water-cement (w/c) ratio than 0.35, utilizing fine pozzolanic materials. Low w/c ratio and the use of silica fume makes concrete mixes significantly less workable. To compensate the reduced workability, super plasticizers are commonly added to high-strength mixtures. Thus, HPC has high workability, high durability and high strength. Self compaction concrete is normally used in post tensioned construction, and even in monolithic construction which is also HPC and does not require compaction.

REINFORCED SOIL TECHNOLOGY

Reinforced soil concept is based on the principle of friction between soil and the reinforcement. Geosynthetics are being used in various applications like separation, reinforcement, filtration and drainage, moisture barrier. Government is giving a lot of emphasis on use of technical textiles. Geosynthetics are now being used in reinforced soil of retaining walls and approaches of bridges/ flyovers.

OTHER TECHNOLOGIES

There are many emerging technologies being used in different components of building construction. There are few which are in research stage and being experimented and may be adopted after they become technically and economically viable.

3 D construction printing technology is another technology being researched for implementation in building construction which is going to be the integration of owner's design acceptability, architect's vision with on site but mainly off site fabrication enabling one to get house in less than 24 hours and as per the demand. Thus, robotics and Artificial Intelligence (AI) are the future technologies for use in civil engineering fields, both in construction and maintenance.

Trenchless technology largely avoids cutting of roads and paths to pass through utility services in soils avoiding disruption of traffic and also helping in pollution control and uses micro tunnelling, horizontal directional drilling, pipe ramming, auger boring, moling etc.

Large numbers of energy efficient technologies are available now for E&M services also such as LED technology, solar power generation, regenerative

lifts, IBMS, occupancy and other sensors, smart meters, energy efficient chillers and geo thermal heat exchange system for energy efficient air-conditioning.

Technologies are also available for time saving and quality work in flooring, paneling, false ceiling, painting, plastering, slab casting, anchoring etc.

CONCLUSION

New and emerging technologies helping in execution of structures with speed, quality and durability have become essential for the development of the country hence are going to come in India from all over the world due to large scale requirements in the country. At present, limited technologies with limited entities are available but with the government's support, such technologies will not only be available but will be developed suiting to country's requirements.

CPWD has approved new and emerging technologies for speedy construction and also the technologies which are green and sustainable. These technologies are also being included in Delhi Schedule of Rates (DSR) for the benefit of engineers in the construction industry.

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INTEGRATED TRANSIT CORRIDOR DEVELOPMENT IN AND AROUND PRAGATI MAIDAN, NEW DELHI – CASE STUDY

PRADEEP KUMAR PARMAR* **AND DHIRAJ AGGARWAL****

Abstract

Pragati Maidan is bounded by Supreme Court Land in North, Bhairon Marg (60m RoW) IN South, Railway Line in East and Mathura Road (45m RoW) in west and covers an area of 123.5 Acres. The Land Use plan of ITPO area has been changed from recreational (district Park) to Public and Semi Public Facilities (international Convention Centre). This ITPO area is being re-developed into a world class Integrated Exhibition-cum-Convention Centre. The redevelopment of Pragati Maidan as a modern, up-to date centre for holding global conference and exhibitions is under progress.

This is a rare project with several unique features, requiring creative and innovative solutions. This technical paper highlights some of the salient features of the project.

INTRODUCTION

Over the years, the need for expansion of the facility and its modernization has been felt due to various compelling reasons (i.e. inability to host international level large exhibitions; Low exhibition area density; 33% of existing exhibition space non-usable during most of the year; Over-utilisation in peak season; Presence of few regular, large events lead to capacity short fall; Declining market share etc.). Accordingly the Government of India decided to redevelop the facility into a global level iconic, self-contained, totally integrated, state-of-the-art infrastructure for organizing international exhibitions, business events, meetings, and conventions. The various components along-with its objectives are given as under:

- State of the art Conventions Centre with combined capacity of 13,500 people, which is many a times the capacity of Vigyan Bhavan.
- Exhibition Halls: There are a total of 11 exhibition halls proposed in the main redevelopment strategy.
- Basement: Designed over total built-up area of 1,68,305 sq. mtrs. Which is divided in two parts – Administration Basement ad General Basement, meant for parking facilities of 4800 ECS, which will be connected to the Ring Road through a series of tunnels, thereby freeing traffic on Mathura Road.
- Administrative Block: the administration Building is designed over a total area of approx.. 8857 Sqm. With all modern amenities and basement having parking facility for 180 cars.
- 3.7 acres land for a star hotel – Future provision.
- Ticketing Plaza and Gate Houses with large LED digital walls
- Food and Beverage Kiosks
- Skywalk from Pragati Maidan Metro Station
- Covered Walkways
- Extensive landscaping and water bodies
- Musical Fountains
- Amphitheaters – which will seat 3,000 people, is touted to be one of the largest single-gathering space.

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- Integrated infrastructure development to decongest traffic in and around Pragati Maidan Complex (i.e. Mathura Road, Purana Quila Road and Ring Road connectivity)

The project is planned to be executed in two phase. The Phase-1 redevelopment is expected to cover approximately 3,82,188 m^2 of built-up area, which will cover Convention Centre, Administrative Block, 6 nos. of Exhibition Hall, Basements including the integrated transit corridor connecting Mathura Road with Ring Road. Phase-I is scheduled to be completed by March 2020. Phase-II will cover balance 1,96,000 m^2 of built-up area comprising of remaining exhibition halls (5 Nos.). The total cost of the Pragati Maidan redevelopment project is estimated to be Rs. 2,600 crore for phase-1. Fig. 1 shows the layout plan of the integrated Exhibition cum Convention Centre (IECC).

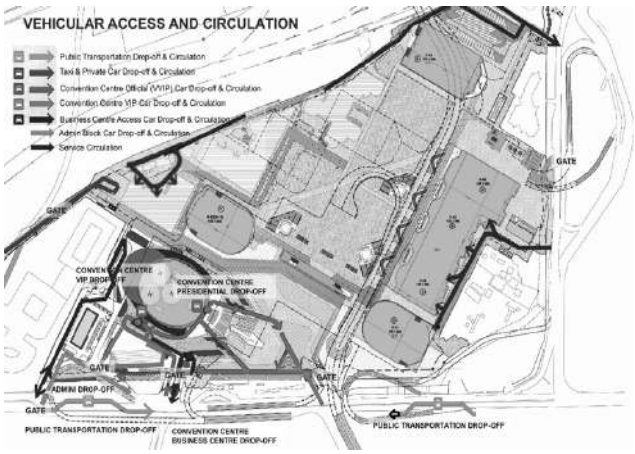


Fig.1: Vehicular Access and Circulation Plan to Parking Area of ITPO

The project taken up by PWD involved Integrated Infrastructural development to decongest traffic in and around Pragati Maidan complex which would result from the construction of such an iconic exhibition center in the heart of Delhi.

The work started with detailed traffic analysis which would help in preparing the best possible solution for decongesting the traffic along 3 major roads viz. i) Mathura Road, ii) Bhairon Marg, iii) Ring Road.

TRAFFIC ANALYSIS

Detailed traffic analysis was done to study each and every aspect of the traffic mix for obtaining a more comprehensive solution for traffic. The hourly variation of traffic illustrated the distribution of traffic over the entire period of survey for a particular day with respect to different hours of a day and the peak hour is the maximum traffic that was observed on the road in one single hour of the day. It is of significance as highway capacities and design calculations are based on Peak hour traffic in urban situations where the traffic peak hour has got significance.

From Hourly variation it was concluded that morning and evening peak hours vary marginally but with clear trend. People travel to be able to participate in activities. Possible explanations for variations in the amount of traffic can therefore be found in variations in activity patterns and timings. Moreover, variations in travel behaviour (modal split, route choice, departure time) can also contribute to variations in traffic flows.

PROPOSED INTEGRATED TRANSIT CORRIDOR

After a rigorous traffic survey and study a proposal was made for decongesting the major roads around Pragati Maidan, which would not only suffice current demand, but also serve for the coming 15 years and the traffic growth thereafter.

The final proposal comprised of construction of the following major structural components:-

- A divided 6 lane highway tunnel of about 1.1 Km long, passing through the Pragati Maidan.
- 3 Nos. of 2 lane U-turn Underpasses (No. 1, 2 & 4) along Mathura Road between Pragati Maidan Station and DPS.
- 1 No. of 3 lane underpass (No. 3) near Purana Quila Road.
- 3+2 lanes underpass no. 5 near Bhairon Marg and Ring Road T-Junction.
- 2 lane Underpass no. 6 at Bhairon Marg.
- Widening and strengthening of existing roads around Pragati Maidan and allied works.

The 1.1 Km main tunnel has a divided 6 lane configuration. Main entry to this tunnel is through the Purana Quila road towards Pragati Maidan. Vehicles travelling on Mathura Road towards

Nizamuddin can enter this tunnel through its branch tunnel. The tunnel runs below the Pragati Maidan area and culminates at Ring Road and has 4 connecting branch tunnels ramps/loops which takes care of traffic in all directions of the Ring Road. This tunnel also has a 140m long box pushing section under 7 railway tracks just beyond there Pragati Maidan Boundary towards Ring Road. The tunnel will also provide access to the new parking lots of Pragati Maidan's International Exhibition cum Convention Center (IECC) from branch tunnels connected to it. Apart from this, passenger cars can also commute from one side of the basement to the other from underneath the tunnel through 2 cross tunnels which are integrated with the main tunnel.

Apart from this 6 lane main tunnel, 4 Underpasses are proposed at various locations on Mathura Road over 3 Km stretch between Pragati Maidan Metro Station and Delhi Public School. 2 Underpasses are also proposed at Bhairon Marg providing connectivity to underground parking inside Pragati Maidan. In addition there are 2 sets of Underpasses proposed Connecting Ring Road and Bhairon Marg.

Fig. 2 shows the layout plan of the various infrastructures planned around the Pragati Maidan for decongestion.

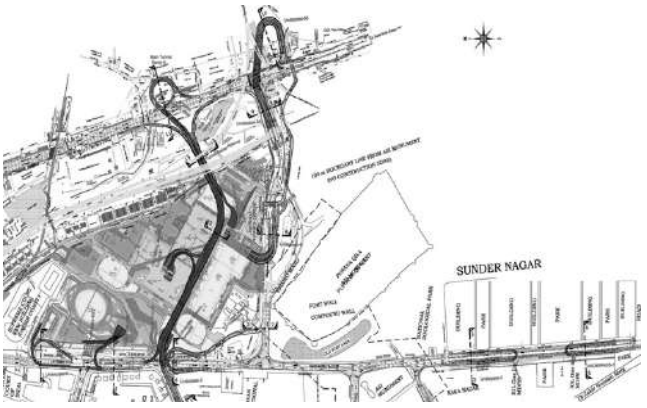


Fig.2: Infrastructure Planned

SPECIAL FEATURES OF THE PROJECT

The unique feature includes Box Pushing of twin box, 3-lane each (approx. 14.6m x 7.945m) dimension, 140m length below 7 railway tracks. Such massive size box is one of its kind in Box Pushing technology.

Another unique feature is construction of 6 lane wide, 1.1 Km long tunnel from Purana Quila road to Ring Road running below Pragati Maidan. This tunnel will also give access to the parking lot inside Pragati Maidan. Apart from this main highway tunnel, 6 road underpasses are also proposed in Mathura Road, in the vicinity of Pragati Maidan. The infrastructure development thus planned is expected to take the huge traffic related pressure off the ITO and Bhairon Marg intersections and make the surrounding area signal free. A large portion of east bound traffic will use this tunnel for a quick gateway. With Mathura Road also becoming signal free traffic situation will improve leaps and bounds in the surrounding area.

The project is being funded entirely by the central government. Delhi government's Public Works Department is entrusted with this part of the project and the contract was awarded to Larsen & Toubro Limited (L&T) on EPC mode at a cost of Rs. 777.00 Crores. The work commenced in November 2017 and is planned to be completed in August 2019. The percentage break-up of the cost (Approx.) in various components are in given in Table 1 below.

Table 4.1: Percentage break-up of Project cost (Approx)

Sl.	Particulars	Approx. % of Cost
1.	Main Tunnel; with 6 Lane divided carriageway	40%
2.	Connecting Branch Tunnels from Main Tunnels to Underground parking of Basement of Pragati Maidan	10%
3.	Underpasses (6 Nos.)	36%
4.	MEP (including Fire Fighting)	8%
5.	Miscellaneous (Consultancy maintenance during project period, Art Work, FOB, Shifting of Storm Water Drain, Handing over of Site and Construction of offices	6%
	TOTAL	**100%**

MAJOR CHALLENGES IN THE PROJECT AND STRUCTURAL DESIGN

- **High Ground Water Table:** The project site is very close to the Yamuna bank, so the GWT is varying from as low as 25.m to 7.5m below the NGL, whereas the bottom level of box is approx. 8-9m below NGL, thus the structure will always be exposed to the massive uplift pressure from the GWT. Such uplift force is being considered in the design which resulted in bigger sizes of structural members to counter balance the uplift presence. The span being large without intermediate support resulted in greater depth of slab, which subsequently caused the reinforcement structure to be casted under such conditions of water table was a challenge. Fig. 3 below shows the condition of ground water and constructional challenges.

Fig. 3: Site Condition

- **Box Pushing Technology:** The project includes pushing of twin box each of size approx. 15m wide and 8m height under the 7 important railway tracks connecting Howrah-Delhi and Mumbai-Delhi of total length 140m. The major challenge in this arises due to the high GWT level, and sandy strata of soil making it difficult to push the box without causing soil failure and subsequently affecting the track. To avoid collapse of earth, the soil nailing technology has been used and nearly 200 nails of 32mm dia and 9m length is embedded at interval of 400mm to 800mm to avoid soil failure and collapse. Track is further protected by placing additional steel girders 6m length at every alternate railway sleepers to distribute the axle load and avoid stress concentration. Such huge size of box has rarely been pushed inside railway embankment with such long stretch. The box pushing consists of pushing from two sides (Pragati Maidan end and Millennium Park end) of the track along with stitching cast-in-situ portion in the middle portion. This involves precise alignment and level of boxes from both ends to avoid misalignment at middle portion.

SALIENT DESIGN FEATURES OF THE PROJECT

Geotechnical Aspects

The geotechnical investigations was carried out at site in and around November 2017. A total of 86 bore holes were done to have a clear picture of the ground strata. Bore-hole depth varying from 15m of ramp location to 45 m at raft portion. The investigation indicates that the sub-soil is primarily a mixture of various layers of non plastic sandy silt / silty stand / fine sand / clayey silt / sandy clay / silty clay of low or medium plasticity. Ground Water Table is observed at a depth of 2.30m to 7.5m below the existing ground level at the time of investigation.

Liquefaction potential of the sub-soil is also assessed. For the purpose of liquefaction potential assessment, the peak ground acceleration values are taken from the published micro zonation maps for NCT Delhi prepared by National center for Seismology, Ministry of Earth Science, Govt. of India. The sub-soil is found to be in loose condition and is prone to liquefaction up to 6 to 7.5m below the existing ground surface at some locations near the main tunnel portion. Wherever, the founding level of the structure lies above potentially liquefiable soil, ground improvement and soil replacement is being carried out.

The RCC Box structures or the RCC U-trough structures are proposed to be constructed in-situ by cut and cover method in a bottom-up sequence. A net safe bearing capacity of $10t/m^2$ is considered for design purpose as per recommendations by the Geotechnical Expert. This SBC is derived based on an assumed allowable settlement of 75mm for the foundation. Photo 4 to 6 shows various stages of construction of the main tunnel.

Highway and Drainage Design Philosophy Highway Geometrics

Geometric design of the highway for all Underpasses, Tunnels, Ramps, and existing roads are designed in accordance with Schedule B provisions of the contract and the relevant IRC standards and MoRTH specifications. Following geometric design parameters have been followed in this project:

- Design Speed : 80 Km/Hr for the main tunnel
  : 40/30 Km/hr. for the ramps of Underpass and Tunnel portion
- Curve Radius : Varies from 50m to 300m for Main Tunnel + Ramps
  : 50m to 112m for Branch Tunnels
  : 36.5m to 500m in Underpasses
- Vertical Gradient : Varies from 0% to 3.3% for Main Tunnel + Ramps
  : Varies from 0% to 4.0% for Branch Tunnels
  : Varies from 0% to 3.84% in Underpasses
- Super elevation : Provided as per provision of IRC:86-1983
- Vertical : Main Tunnel – 5m, clearance Underpasses 1,2 & 5- 5.5;
  Underpass 3,4 & 6 - 5.0m
- Design Criteria Design Loads : Dead Load, Live Load, Seismic force, Earth Pressure

Drainage System

Surface drainage on roads are provided on its side in conformity with the provisions of IRC:SP:50- 2013.For the super elevated portion of the roads,median drains are also provided.For tunnel /underpasses a drainage system is installed to divert surface run-off.The surface run-off from each ramp and open to sky portions is collected in the sumps through longitudinal drains, provided on the sides. Sumps are designed for 5 minutes retention of run-off. The collected run-off in sumps and discharged to the nearest surface level drain or manhole. 2 submersible pumps are provided in each sump. Design of pump capacity is based on the assumption that only one pump capacity is based on the assumption that only one pump will be operational at a time.

Pavement Design Philosophy

Flexible pavement is proposed for area / location where road widening, road strengthening, re-construction is to be done in the surrounding area around Pragati Maidan. Concrete pavement proposed in ramps and covered tunnel portion. Flexible pavements are designed for a minimum design period of 15 years. Design life of concrete pavement is 30 years. The minimum design traffic considered for pavement is 50 Million Standards Axle (MSA) for main road, 30 MSA for slip roads and 10 MSA for service roads.

STRUCTURAL SCHEME FOR THE MAIN TUNNEL, UNDERPASSES AND RAMPS

Salient Structural Scheme

The covered portion of 3+3 lane main tunnel is a 2 cell RCC box structure which is being constructed cast-in-situ, using cut and cover method, except below the railway portion, just beyond the Pragati Maidan boundary, where box pushing technique is used. The ramps/loops at entry/exit of the tunnel consists of RCC U-Trough structure. The tunnel is provide with a clear height of 5m and its width varies from 28m to 38m. The entire carriageway is divided for traffic partly by intermediate wall and partly by RCC column. The thickness of wall varies from 0.8m to 1.2m. Wherever columns are provided, they have a typical square dimension of 1.00 x 1.00 m with a spacing of 5.75m along the length of the tunnel.

The buried tunnel portion inside Pragati Maidan area has landscaping on top of it. The filled up soil thickness over it varies from 0.3m to 1m. However, it has been designed for a minimum thickness of 1

m as per the provisions of the contract. Although there is no provision for vehicular movement over the tunnel, except at Mathura road, the tunnel is designed for a static live load of 4 t/m^2, to cater for possible movement of fire tenders over it in case of emergency.

A portion of main tunnel lies directly beneath the exhibition Hall A-6 of IECC project, which makes the structural scheme very complex and challenging, since the structure is split into two separate units with two different agencies involved in design as well as construction. Different design philosophies involve different settlement criteria for raft foundation of tunnel and pile foundation of the hall structure. To overcome this, common settlement has been considered in the design along with pre-stressing to limit the depth of slab, supporting heavy loads. Columns of this hall directly rests over the top slab of the tunnel. Therefore, in orders to design this portion of the tunnel, pre-stressing has also been introduced along with pile foundation to transfer load vehicular loading as per IRC:6 has been considered. A 100m stretch of the tunnel just beyond the Pragati Maidan boundary passes below 7 railway tracks of the Northern Railways from New Delhi to Mumbai. Construction of this length is being carried using box pushing technique and is being carried using box pushing technique and is being looked after by the Indian Railways.

Apart from the main tunnel, 6 underpasses are also being built in the surrounding area which have similar structural configuration as the main tunnel. The highway geometrics of all tunnels are based on the provisions of IRC:86. The structural modelling and analysis has been done using software like STAAD Pro and LUSAS. Structural design has been done as per the provisions of IRC:112.

Design Philosophy

The design service life for all structural components (RCC Box structures as well as U-troughs) is considered as 100 years. Salient features of the structural design are as follows:

- **Minimum Grade of Concrete:** M45 for RCC; M20 for Levelling Courses.
- **Minimum Grade of Reinft:** Fe 500D. The reinforcement shall be corrosion resistant steel (CRS).
- **Exposure climatic condition:** "Severe" for outer faces in contact with earth and "Moderate" for inner faces.
- **Cover to Reinforcement:** 75mm for foundation and outer face of RCC Box/U-trough; 45 mm for inner faces.
- **Design Ground Water Level:** For the stretch of the Main tunnel from Mathura Road to Railway Boundary, the GWT is considered as 204.55m. For all other locations, it is considered as RL 206.30 or the existing ground level, whichever is lower.
- **Vehicular Live Load:** For the underpass, live load shall be considered as per IRC:6 or the roof of underpass.

Fig.4: Various Stages of Construction

Fig.5 : Various Stages of Construction

Fig.6: Various Stages of Construction

Construction Scheme for Tunnel under Railway by Box Pushing Method

Cut and cover method or diaphragm wall method cannot be used under railway track as it will disturb and destabilize the railway track and rail traffic movement. Therefore, the method of box pushing is the ideal method for construction of tunnel or RUB under railway track. Box pushing Technique is developed where in R.C.C. Boxes in segments are cast outside and pushed through the heavy embankments of Rail or Road by Jacking. Construction methodology for box pushing method is briefly described below (ref. Fig.7-11)

Methodology

- Excavation
- Casting of thrust bed
- Fabrication of front and rear shield
- Box casting and placing
- Pushing-shifting-pushing operation
- Precautions
- Excavation and casting of thrust bed

A properly designed RCC thrust bed is cast at appropriate location. Open excavation is carried out for construction of Thrust bed. Generally the top layer of 50mm is finished with screwing layer to obtain a perfect level surface. This thrust bed along with the connected thrust walls and shear keys serves the purpose of forming the base to the casting of the box segments and also enables jacking of the segments. It acts as a medium to transfer the entire jacking force into the ground. The auxiliary thrust bed also may be constructed depending upon site requirement, which in turn helps in saving of reinforcement, time, labor and expenditure.

Fabrication of Front Shield

— Front Shield is fabricated for cutting action and to provide support, to prevent caving in of soil.

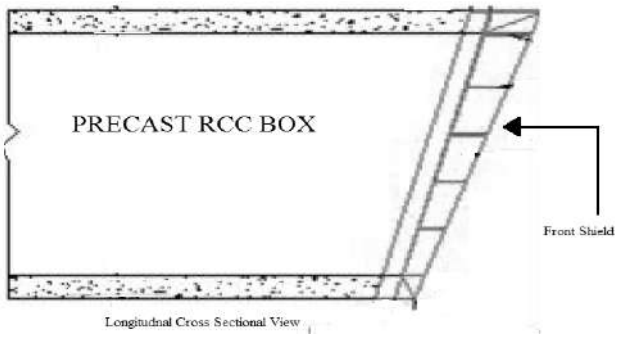


Fig.7: Cross Section View

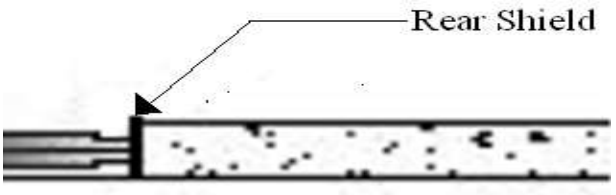


Fig. 8: Fabrication of Rear Shield

Casting of RCC Box Segments

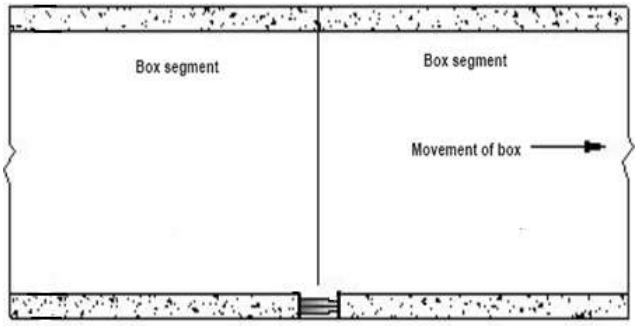
Over the well set and leveled thrust bed, RCC box segments are cast in segments of convenient length of total pushing length. The front face of the box will be cast in a slope to match with the shape of the cutting edge which is fabricated from structural steel and is integrated into the concrete. The cutting edge is provided all round the box and it also acts as a shield preventing soil from top and sides from slipping. A rear shield is provided which houses and guides the subsequent segments while supporting the soil. In case of more than one segment in a span, the necessary recess arrangement with MS plate is provided at pre-determined locations while casting the boxes for accommodating the jacks during pushing. An intermediate cutting shield with MS plate is also required to be provided depending upon site conditions, type of soil, size of box etc. The Box section is designed as per IRS / IRC codes of practice for loading. Concrete grade normally kept as M-40.

Fig.9: Reinforcement for Box Section

Pushing of Box Segments

Under suitable speed restriction, the segments are jacked into the embankment by means of hydraulic jacks of suitable capacity installed at the rear end of the segment taking reaction through an assembly of steel pins and beams. Measures like GI drag sheets are provided to reduce drag effect and lateral movement of overburden. Further epoxy coating on sides and top of the box segments is also applied to reduce the soil friction. In order to reduce the friction between the thrust bed and box segment, two layers of polyethylene sheet sandwiched with a coat of grease is provided. Grid arrangement with rails/channels/timbers etc. was also provided at needy locations to ensure the safety especially in non-cohesive type soils. The box is jacked into the embankment in a controlled and phased manner with simultaneous excavation of material from inside manual/machinery after every stage of jacking. Throughout the entire process of jacking, alignment is monitored by optical instruments at regular intervals. Rectification of alignment is achieved through jacks. The jacking of segments, in case of more than one in a span, first segment will follow the second segment for each stroke.

Fig.10: Pushing of Box Segments



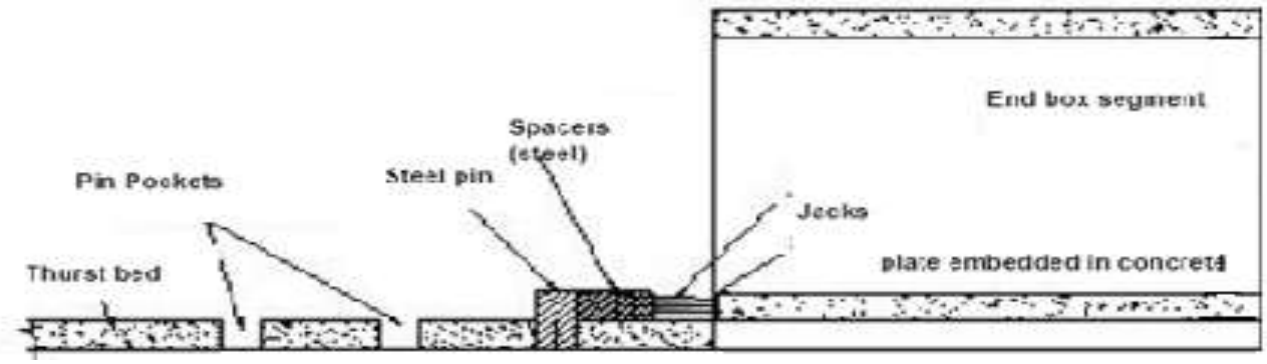


Fig.11: Box Casting and Box Pushing

Precautions

- Cutting edge of front shield is fabricated with adequate thickness of steel plate and the front edges of the steel plate are sharpened to facilitate penetration into the soil.
- To prevent caving of earth during excavation quantity of earth is being removed to barest minimum duly following the slope of cutting edge.

- Guide channels have been provided in the thrust bed to guide the segments to ensure straight alignment
- The level of the boxes is continuously checked.
- The Speed limit is set to 20 km/h at the site of construction
- Soil Nailing is done inside the embankment to protect the soil from collapsing, as the soil is sandy with nil cohesion.
- Proper track protection arrangement is done by providing additional steel sleepers at alternate locations to provide extra safety and distribute the axle load on the rail track.

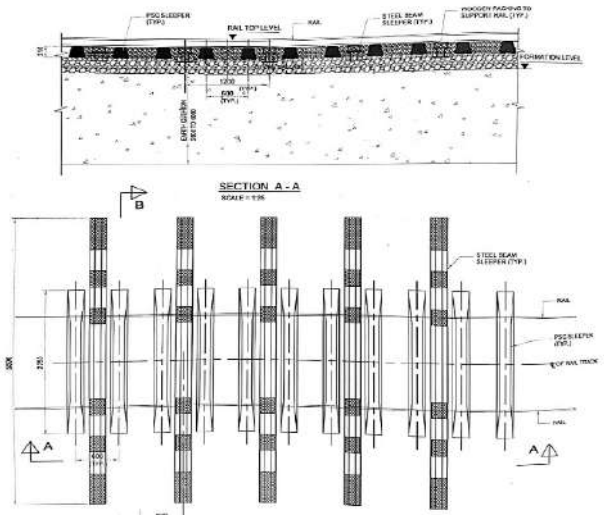


Fig. 12: Track Protection System

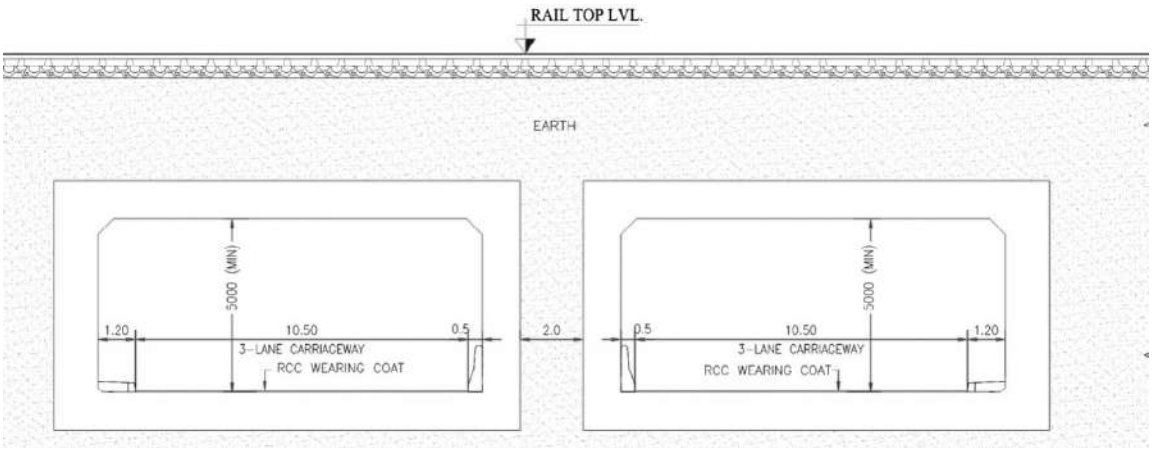


Fig. 13: Final Section

Waterproofing System

Stringent waterproofing system is proposed for this structure. This includes providing and mixing of integral crystalline admixture for waterproofing treatment to RCC structure, which is mixed at the time of transporting of concrete. The crystalline admixture shall be capable of self-healing of cracks upto a width 0.5mm. The material used as crystalline admixture shall conform to ACI-212-3R-2010, with minimum dosage of 0.8% to the weight of cement per cubic metre of concrete and shall reduce the permeability of concrete by more than 90% compared with controlled concrete as per DIN 1048.

In addition to the above, following waterproofing system is proposed to be used for raft, retaining wall, basement roof and water stop at construction joints:

- For Base Raft / Base Slab

  Pre-applied water proofing membrane should be having a minimum thickness of 1.2mm. Fully bonded membrane shall comprise of HDPE layer of not less than 0.8mm strong adhesive and protective layer:

- For Retaining Walls

  Cold applied, flexible self-adhesive polymer modified asphalt waterproofing membrane with laminated HDPE film. Membrane should be of minimum thickness of 1.5mm with HDPE layer of minimum 0.2mm.:

- For top slab of tunnel / Underpass

Single component, environment friendly, water based, non-toxic, with low VOC, polyurethane membrane in minimum 1mm thickness has been used:

TUNNEL LIGHTING SYSTEM

Tunnel lighting criteria conforms to CIE guidance (CIE 88). The lighting system is specially designed such that there is more lighting at the entry and gradually reducing inside the tunnel with an increase at the exit point.

For planning the lighting of tunnel, the tunnel length is divided into four zones. They are: a) Threshold zone, b) Transition zone, c) Interior zone and d) Exit zone.

Integrated Tunnel Control System

An integrated tunnel control system will be installed in the project that will remotely monitor one or more tunnel controls. The tunnel lighting falling in the Threshold and Transition zones are to be controlled by the Tunnel Control Unit placed inside the feeder pillar with the help of Photometer through SCADA Tunnel Management System for remote monitoring. There are provisions for emergency override switch, a digital input that forces the full tunnel lighting to the maximum light level in case of emergency switch shall be manually operated at each Feeder Pillar and can also be operated remotely from the Tunnel Control Room workstation.

TUNNEL VENTILATION SYSTEM

Longitudinal Ventilation System is proposed in tunnel due to space constraints. The ventilation system for the tunnel comprises unidirectional jet fans with silencers. Though the jet fans are unidirectional, these operate in the reverse direction also in case of emergencies. The motors are provided with moisture oil and fungus resisting insulation of a type specifically designed and constructed to withstand severe humid condition and to operate after a long period of idleness without drying out.

The whole tunnel is divided into 15 zones as shown in Fig. 14-15.

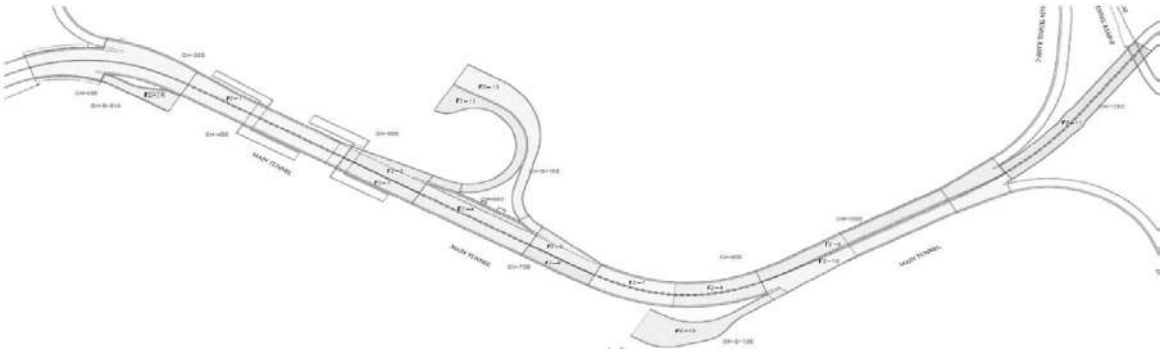


Fig.14: Ventilation Zones

The zone schematic diagram is shown below for better understanding:

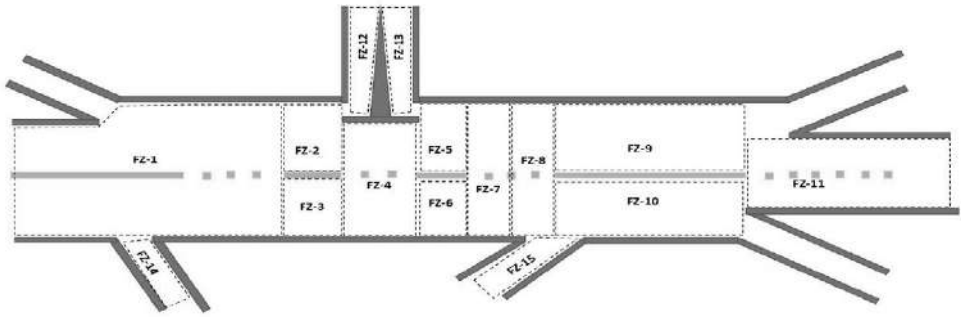


Fig. 15: Ventilation Zones

Sensors and Detectors

CO and Visibility-Opacity Sensor are provided at 3 locations inside the tunnel. If the CO concentration increases more than the accepted pre-set limit or the visibility decreases to less than 30 meters, it will give an alarm in the control room and the operator will turn on the congestion mode of ventilation. The Mode table is given in the DBR along with the schematic drawings. Air Flow Meters are provided at 6 locations to monitor the air flow inside the tunnel.

Linear Heat Sensing (LHS) Cables in 2 independent and redundant loops are provided to detect fire over each carriageway at tunnel crown. The maximum height of these cables shall be 5.3m from finished road level. These cables can detect and give alarm at any temperature (Pre-set at the time of commissioning) above 57.2 °C. The zoning of these sensors are done in accordance with the ventilation zones.

Cross Tunnels are provided with addressable Multi-Criteria sensors looped from Fire Alarm Control Panel located in Control Room.

Modes of Operation

- Normal Operation – Traffic is freely flowing.
- Congested Operation – Traffic is slow moving due to vehicle build up.
- Incident Operation – Traffic is slow moving or stopped due to accidents or breakdown in or beyond the tunnel.
- Emergency Operation – These are operations that requires the intervention of emergency services.

Design Criteria

The basic principle of tunnel ventilation is dilution of vehicle emissions by providing fresh air and then removing the exhaust air from the tunnel. The exhaust air can be removed via a portal (a location where the tunnel carriageway opens up to the surrounding environment), via a ventilation outlet (such as a stack), or via a combination of both. This objective can be achieved by the following:

- Preventing the dangerous accumulation of vehicle-emitted pollutants (i.e., carbon monoxide CO, and oxides of nitrogen, NOx)
- Maintaining visibility in the tunnel by preventing the accumulation of haze-producing pollutants.

System Design

Simulation analysis including 1-dimensional and 3-dimensional (CFD) analysis has been performed for the ventilation design of tunnel. Numbers of cases were performed and only Longitudinal ventilation system with Jet Fans is found possible. The main tunnel shall be equipped with 28 jet fans (16 jet fans of type – 1,804mm dia and 12 jet fans of type-2,630 mm dia). The branch tunnels connecting basements shall be equipped with 8 jet fans of type-1 (2 fans in each connecting branch). This leads to a total of 36 jet fans in tunnel.

FIRE DETECTION, ALARM AND ELV SERVICES

Fire Detection and Alarm System with voice evacuation in accordance with NFPA 72 has been proposed to provide a complete operable and intelligent analogue addressable Fire Alarm and Detection System with associated communication and notification systems. The system includes interfaces for foreign systems in all applicable Codes, Standards and local Regulations.

The system comprises of two types of Detection systems:

- Linear Heat Sensing Cables
- Addressable Multi Criteria Sensors

In addition to that, following Extra Low Voltage (ELV) services shall also be provided inside the tunnel for traffic control, fire detection, notification and evacuation:

- CCTV
- Public Address System
- Emergency Call Network (or SOS)
- Telephone System (or PABX system)
- Traffic Management System

Following functional systems are provided, in compliance with listed reference standards:

- Piping System: Piping system confirming to IS: 1239, ASTM A53B – MS Heavy Class.
- Fire Water static Storage (above ground): Fire water static storage (above ground) has been provided in accordance to NFPA.
- Fire Pumping System: Pumping system comprising of independent pumps for hydrant sprinkler and jockey application has been provided.
- Hydrant system: Hydrants complete with hose reel.
- Sprinkler System: Sprinkler rating and type shall be selected for respective areas.
- Hand held fire extinguishers: Strategically placed at designated areas as per NFPA-502 and IS Standards. The installation is also to have consent of Local Fire Service Authorities.

The entire fire safety installation is made compliant to ensure the highest safety standard uniformity of system. Further, the fire protection system is planned to be fully tested under simulated conditions before the tunnel is opened to traffic.

Agencies Involved

- Owner Client : Public Works Department, GNCTD
- Proof Consultant : B&S Engineering Consultants Pvt. Ltd.
- Contractor (EPC) : Larsen & Toubro Ltd.
- Design Consultant : Ramboll India Pvt. Ltd.

CONCLUSION

Execution of such complex mega projects on a fast track requires a good team work between all the stake holders. The design of structural components for this project focused on adoption of innovative engineering solution using location material and available equipment's with the contractor. It is expected that the project will be completed within the stipulated p eriod. Once operational, this project will not only bring considerable relief to the commuters in Delhi, but also bring down the pollution level in the area by reducing the idle time of vehicles on signals.

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REINVENTING CONSTRUCTION SECTOR IN INDIA

Jit Kumar Gupta*

Abstract

Construction, as a sector, is known for its role, importance and value in leveraging economies, promoting industry, generating employment and ensuring development of any community, state and nation. Construction sector is also known to be large consumer of energy, resources, promoter of global warming and responsible for creating large carbon footprints besides making people healthy and sick. Despite innovations made, construction sector in India continues to be opaque and inefficient, driven largely by waste, cost-overrun, time-overrun and poor quality. Based largely on human intervention, construction sector deploys large manpower which is qualitatively poor and lacks basic skill and knowledge of principles and techniques which define quality construction. Machinery deployed in construction remains minimal and outdated. Construction practices are largely obsolete, inefficient and least productive. Research and development for promoting efficiency and economy remain elusive and conspicuous by its absence. Accordingly, cost, time, quality and environment have emerged as major casualties in the construction sector. Estimates made by the McKenzie Global Research Institute have defined urban India's annual requirement of built space at 700- 900 million sqms and large infrastructures. For achieving this, construction sector needs to be made more effective and efficient. In search for appropriate solutions to make construction sector more effective, efficient, productive and sustainable; paper looks at the options of sustainable construction, using state of art materials; evolving innovative construction technologies; leveraging prefabrication; using Robotics/ drones; promoting Research and Development; skilling manpower involved in construction industry.

INTRODUCTION

It is said, "History of construction industry is the history of growth and development of human civilisations, building materials, construction tools and technologies. Construction starts with planning, designing, and financing; it continues until the project is built and made ready for use. Large-scale construction requires collaboration across multiple disciplines involving project manager, architect, design engineer, construction engineer/architect to supervise it. Evolving design and execution need consideration of zoning, environmental impact assessment, scheduling, budgeting, construction/site safety, availability and transportation of building materials, logistics, site management, manpower/machinery deployment, delays and bidding".

Construction sector is known for its dualities and contradictions. Construction, as a sector, is known for its role and value in leveraging economies, promoting industry, generating employment and ensuring development of any community, state and nation. Construction sector is also known to be large consumer of energy, resources; promoter of global warming and responsible for creating large carbon footprints besides making people healthy and occasionally causing health hazard. 11% of India's GDP is contributed by the construction sector besides 1/6th share (35 million) in the total employment generated in the country. Sector ranks

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second in terms of total value output in the country. In the year 2015, India ranked fourth globally in the construction output after China, United States and Japan with total output placed at 333 billion US dollars. In India, construction has accounted for around 40 per cent of the development investment during the past 50 years and created assets worth over ₹ 200 billion. Considering ever increasing number of construction projects, their complexity and role and importance in community and national development, it becomes critical that construction sector is made more effective, efficient, productive and sustainable through advanced technologies and integration of many sub-systems so that full potential of the sector is realised to make India global leader in the sustainable construction practices.

SUSTAINABLE CONSTRUCTION

Construction industry, known for its energy, resource and environmental implications has to be sustainable in order to minimise the adverse impact of global warming, carbon emission and ozone depletion. Studies made by United Nations Environment Programme (UNEP), has stated that "the increased construction activities and urbanization will increase waste which will eventually destroy natural resources and wild life habitats over 70% of land surface from now up to 2032". Study further states that production and transport of building materials are known to consume 25 - 50 percent of all energy used, whereas construction industry counts for 47% of CO2 emission. Therefore looking at global warming and other environmental issues, construction sector has to be sustainable. In 1994,Professor Charles J. Kibert, called for construction industry to be sustainable during the Final Session of the First International Conference of CIB TG 16 on Sustainable Construction. He defined it as "The creation and responsible management of a healthy built environment based on resource efficient and ecological principles". Comparing with the traditional concerns in construction (performance, quality, cost), he said concept of sustainable construction revolves around; minimising resource depletion, environmental degradation and creating healthy environment. Six principles which define sustainable construction include;

- Minimize resource consumption (Conserve)
- Maximize resource reuse (Reuse)
- Use renewable or recyclable resources (Renew/ Recycle)
- Protect the natural environment (Protect Nature)
- Create a healthy, non-toxic environment (Non-Toxics)
- Pursue quality in creating the built environment (Quality)

Sustainable construction, creates a win-win situation for owners, users, occupants, community, state and nation by lowering the life- cycle cost, promoting environmental protection, reducing waste, conserving resources, minimising energy consumption, promoting economy, generating employment; promoting choice of more sustainable, locally sourced products and materials; minimize amount of waste and water pollution; using rainwater and recycling waste water etc.

PREFABRICATION

Looking at the fact that India is passing through an era of rapid and massive urbanisation coupled with government launching number of missions and yojnas involving, 'Housing for all by 2022'; constructing millions of latrines pan India under Swatchh Bharat Mission; creating space for millions of street vendors and homes for houseless in urban centres under National Urban Livelihood Mission; developing 100 cities under Smart City Mission besides taking up development under HRIDAY and AMRUT; India needs to create large built space, to take care of its needs of shelter, healthcare, education, industry, trade and commerce, entertainment, leisure, transportation etc. Considering the huge task of creating enormous built space and its physical, environmental and economic implications, construction sector needs to be made more effective and efficient by using state of art construction technologies to promote cost- effective, resource–efficient, sustainable and eco-friendly construction. Pre-fabrication, as an approach, can go a long way in making construction sector more rational in terms of cost, time,

economy, quality, sustainability, resources, material etc. Looking at the fact, that pre-fabrication/ modular construction has proved its worth globally, it will be appropriate that this technology is also made operational in India on large scale. Despite limitations, prefabricated and precast construction methods offer numerous benefits involving optimal materials usage, recycling, freedom from pollution; improved construction efficiency and safety; year round fast construction, reduced pilferage; better quality control besides providing a real alternative to on-site processes. With improvement in manufacturing technology, prefabricated construction is proving to be an extremely viable option. Use of prefabrication can significantly improve the efficiency and competitiveness of the construction industry. With construction industry facing acute shortage of onsite quality skilled labour and challenge of making structures leaner, it is time ripe enough to promote adoption of large scale offsite prefabrication/modularization solutions'

NEW TECHNOLOGIES

Considering the magnitude of construction to be undertaken in the urban and rural sectors, putting in place new state of art technologies will be critical to redefine the construction sector in India and to make it more productive and efficient. New technologies will have great relevance if the construction sector is to be made cost-effective, time-efficient and providing best of quality besides generating minimum waste. Despite rapid strides made in the infrastructure construction, building construction remains a laggard so far new technologies are concerned.

Globally, new techniques of building construction including 3D printing technology, in the form of "additive building construction", similar to the additive manufacturing techniques for manufactured parts, has already revolutionised the construction sector. It is making possible to construct small commercial buildings and private habitations in around 20 hours, with built-in plumbing and electrical facilities, in one continuous operation, using large 3D printers. Working versions of 3D-printing building technology are already printing 2 metres (6 ft 7 in) of building material per hour as of January 2013, with the next-generation printers capable of 3.5 metres (11 ft) per hour, sufficient to complete a building in a week.

Over the years, the construction industry has seen a trend in IT adoption, Nowadays, construction is starting to see the full potential of technological advancements, moving on to paperless construction, using the power of automation and adopting BIM, the internet of things, cloud storage and co-working, and mobile apps, implementation of surveying drones, virtual reality, augmented reality, project management etc. Looking at the emerging challenges of rapid urbanisation and globalisation, Construction industry is trying to come out of its past shadow. With science and technology leveraging the construction industry the pace of change in construction practices is progressing and accelerating. India needs to adopt these emerging technologies for making construction sector vibrant.

INNOVATIVE BUILDING MATERIALS

Materials are known to have critical role in determining the future of the construction industry, design and structure of buildings. Innovations are being made on sustained basis to search for new materials which would facilitate the construction of cost-effective and sustainable buildings. Since buildings consume more than 30% of total materials sourced from nature, accordingly, there is an urgent need to minimise this exploitation and create materials which are lightweight, small in dimension, requiring minimum resources and minimum energy for its production and are stronger, resistant to pollution, heat and cold, having minimum wear and tear requiring minimum maintenance and upkeep. Researchers and various institutes are taking materials and technologies to the next level. Development in concrete and various other construction materials has been aggressive and intense. Few innovative construction materials that could revolutionize the building sector have been detailed below;

- **Translucent wood as construction material**

  Stockholm's KTH Royal Institute of Technology has invented Translucent wood that can be

mass produced and used commercially to develop windows and solar panels. It is created by first, removing the lining in the wood veneer and then through nano-scale tailoring. The resulting effect creates translucent wood that has various applications in the construction industry. As a low-cost, readily available and renewable resource, it has enormous capacity to make projects cost-effective by reducing cost of resource.

- **Hydro-Ceramics**

  By combining clay and hydro-gel (group of polymeric materials), students at the Institute of Advanced Architecture of Catalonia have created a new material that has a cooling effect on building interiors. Hydro-ceramics have the ability to reduce indoor temperature up to 6 degrees Celsius. Its cooling effect comes from the presence of hydro-gel in its structure which absorbs water, up to 500 times its weight. The absorbed water is released to reduce the temperature during hot days. Incorporating an innovative cooling system in the current building structure has made Hydro-ceramics into one of the coolest building materials to revolutionize construction. More progress in this direction may make household air conditioners obsolete.

- **Bricks made out of Cigarette butts**

  6 million cigarettes, manufactured annually produce 1.2 million tonnes of cigarette butt waste, impact environment through arsenic, chromium, nickel and cadmium which enter the soil and harm nature. To reduce the impact on the environment, researchers at RMIT developed lighter and more energy efficient bricks by infusing cigarette waste in fired-clay bricks This helps in not only reducing waste, but also producing bricks that are lighter and requires less energy for manufacturing.

- **Martian Concrete**

  North-Western University has created concrete that can be made with the materials available on Mars. The new concrete which doesn't require water, as an ingredient to be formed, can make this innovation truly beneficial for the development of structures in Mars. For making the Martian concrete, sulphur is heated at 240° Celsius which melts it into a liquid. The Martian soil then acts as an aggregate and once it cools down we get Martian concrete! According to the researching team, the ratio of Martian soil and sulphur needs to be 1:1.

- **Light Generating Cement**

  Dr. Josй Carlos from UMSNH of Morelia, has created low energy smart cement with ability to absorb and radiate light. Considering the fact that construction industry is fast moving towards resource and energy efficiency, the implications of cement acting as a 'light bulb' have great potential by using them in swimming pools, parking lots, road safety signs etc Cement is produced by the process of poly-condensation of raw materials such as river sand, industrial waste, silica, water and alkali at room temperature.

- **Biologically Produced Furniture**

  Biologically produced furniture made by a material called Mycoform, by combining wood chips, gypsum, oat bran together with a fungus called Ganoderma lucidum, has capacity to create furniture from waste, when used commercially. Fungus is added, as it has the ability to disintegrate waste products and leave a strong structural material. This combined effect creates plastic furniture that through time combusts. Process is low energy, pollution free requiring low technology for its creation.

- **Pollution absorbing bricks**

  Pollution absorbing bricks, sucks in pollutants in the air and release filtered air. Designed to be part of a building's ventilation system, it has a two layer facade system, with the specialist bricks on the outside and standard insulation on the inside with central cyclone filtration system that separates out the heavy air particles from the air and collects them in a removable hopper. Its design is very similar to a vacuum. This technology can be easily applied to the current construction processes. By performing wind tunnel tests, it was proven that the system

can filter 30% fine particle pollutants and 100% coarse particles such as dust.

- **Self healing concrete**

  Dutch civil engineer, Dr. Schlangen has invented a self healing concrete which involves heating the broken pieces together for joining. Once the melted material cools down, it joins together. In case of concrete roads, the broken concrete can be made to heal by making a special vehicle pass on the road every four years. It is estimated that this innovative technology could save millions annually.

SKILLING CONSTRUCTION INDUSTRY

Despite employing one-sixth of total workforce of country, involving huge money and consuming largest proportion of resources, construction industry remains highly unskilled. Majority of workforce has no formal knowledge and experience of complexities of construction industry. Accordingly, majority of maladies in the industry are primarily the outcome of this lack of skill. In order to make construction industry more efficient, productive and innovative, it becomes critical that only quality and skilled manpower is deployed. Manpower should be adequately equipped with knowledge and understanding the processes and the products involved in the industry to make it vibrant and productive. Government of India and state governments must take the initiative of creating skilled manpower for construction industry by promoting dedicated institutions, which would impart necessary experience and practical knowledge to individuals in various trades involved in the construction industry. It needs to be done in collaboration with and involving all the stakeholders. Building Centres need to be created at the local level for imparting skill and hand on experience to rural/urban workforce for employment in the industry. HUDCO once started this project which need review with appropriate modification to make it more effective and efficient. ITI's and polytechnics, being run at local level, must be asked to start vocational courses relevant to the construction industry. In addition, funds available under National Urban Livelihood Mission must be used for imparting skill in the construction sector to create large skilled workforce. This will not only help in overcoming the problems of unemployment and poverty in the country but will also go a long way in making building industry more innovative and efficient. Engineering colleges and institutions imparting higher education, like NITs and IITs, should be leveraged to create new construction technologies and building materials from waste to make industry more cost-effective and resource efficient. Continued training of in-service professionals engaged in the construction sector (PWD/CPWD) should also be made mandatory so as to make them more skilled and innovative. PWD Codes should also be reviewed periodically to make them more inclusive and supportive of the innovations in construction industry. For skilling construction industry, government must mandate that only skilled manpower shall be employed for certain tasks in the construction projects. Initially, it could be limited to the larger projects but gradually it must be made mandatory for all projects.

BEST CONSTRUCTION PRACTICES IN SINGAPORE

For construction sector to be really effective and efficient, it must ensure not only structural integrity and stability of buildings but also their functionality besides safety of both users and occupiers. In majority of cases there does not exist any well defined mechanism to keep a check on the quality of building during designing, construction and maintenance. For promoting quality built environment, Singapore has put in place a detailed mechanism of checks and balances which not only provides best construction practices but also ensures continued adherence to process improvements. This mechanism is the outcome of learning made from the collapse of Hotel New World, Singapore in March 1986 and the findings which came out of the enquiry conducted about the collapse of hotel building. Enquiry revealed that the building's structure was not only grossly under-designed but also quality of construction was very poor. In addition, it was found that building was poorly maintained because there were plenty of warning

signs which indicated a possible collapse during the 13 years of existence of building. In 1989, Singapore passed a legislation, which mandated all construction projects to undergo mandatory checks at the stages of design, construction and completion of buildings. It has been made mandatory for all construction projects to seek certified design reviews prior to the commencement of construction; independent construction supervision during the construction and periodic structural inspections of buildings, after completion of construction. As per the law, buildings are required to be designed by duly qualified professionals. In addition, building design is to be reviewed by an Accredited Checker(Senior professional engineer), before building is constructed. Design Review Certification which helps in providing structural integrity, building stability and user and occupier safety costs about 0.15% of the total construction cost. In addition to looking at the safety of design, Singapore law also provides for Mandatory Testing during construction through engaging professionally certified Engineers, costing not more than 1% of the overall cost of the construction project. In addition, law also mandates the periodic certification of building with regard to its usability and safety which is carried out through the process of Periodic Structural Inspections (PSI). Conducting PSIs ensures early detection of structural defects, wear and tear of building which normally goes undetected and which ultimately leads to eventual partial or full collapse of building. Globally, it has been observed that there have been ample cases of building collapses in the past few years, leading to a tragic loss of lives. It has also been observed that If certification of buildings is conducted based on highest professional standards at the design, construction and post construction phases, then any subsequent rectification work becomes minimal. Periodic checks are also known to help in making buildings more cost- effective over its entire life span because of low cost of maintenance and longer life of building. Based on the Singapore experiences, it would be desirable that similar legislation in India also needs to be put in place to ensure that construction of buildings is carried out in a most professional manner and only buildings of appropriate quality are constructed.

REDEFINING POLICY FRAMEWORK FOR CONSTRUCTION

With a view to make construction sector more productive and sustainable, it will be appropriate that Government of India should immediately come out with a policy framework and blueprint to evolve a long term strategy for the construction sector. The policy framework should be evolved by involving all the stakeholders including industry, builders, developers, construction companies, corporate houses, CREDAI, CII, development authorities, academic institutions of excellence including IITs, NITs, research institutes etc. For promoting research and development, Government of India should create a dedicate agency at the national level besides a dedicated fund for promoting Research and Education for the construction industry on the pattern followed in Singapore, where in the year 2007, Government launched a $50 million "Research Fund for the Built Environment" to kick-start R&D efforts in sustainable construction. The agency, in addition to doing research should come out with publications in collaboration with academic institutions for guiding the various stakeholders involved in the construction sector to make it more efficient and productive. States should also be encouraged to create such dedicated agencies and dedicated funds for promoting research in the construction practices. All development authorities should be mandated to earmark dedicated funds in their annual budget for promoting research in construction methodologies and creating innovative building materials, looking at the local available resources and the industrial waste. By promoting sustainable methods and products, people can be demonstrated the positive outcome of sustainable construction. Consequently, there would be potential to expand the market of sustainable concepts or products. According to a report published by USGBC, "The global green building market grew in 2013 to $260 billion, including an estimated 20 percent of all new U.S. commercial real estate construction."

WAY FORWARD

Construction sector (public and private) makes both direct and indirect contribution to

the economic output of a country as this sector has strong linkages to several other sectors of the economy. India is projected to become world's third largest construction market by 2025 and thereby construction sector will be a key driver for the Indian Economy. The Construction Industry in India is highly fragmented. It needs to be made globally competitive, more productive, cost-effective, efficient and sustainable. Therefore, there is an urgent need to carry out an in-depth study and analysis of the prevailing gaps in the international and national standards regarding construction practices and technologies so that Indian construction industry is also put on the global standards by aligning national standards for design, construction, maintenance and operation with the global standards, This would go a long way in not only bringing down the cost of construction besides maintaining high standards of quality through adoption of innovative technologies and materials for construction. There is also a need to evolve a strategy to transform construction industry and make it more sustainable, from focusing not only on the traditional concerns of "cost, time and quality", but also to include "construction products and materials", to reduce natural resource consumption and minimize waste on site.

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3D CONSTRUCTION MIX PRINTER (3DcMP) FITTED WITH A DISPOSABLE, DISPENSER CUM EXTRUDER UNIT - A MODERN TOOL IN BUILT ENVIRONMENT

Dr. K. Kamal* **and Pulkit Tiwari****

Abstract

Concrete objects in 3D can now be printed-out using construction mix materials through a suitably sized, disposable, dispenser cum extruder unit that is designed and developed here while exploring the possibility of applications of Rapid Prototyping Technology in the form of 3DcMP as a tool in built environment. With deployment of this interchangeable dispenser/extruder unit, 3DcMP extrudes now any paste like cementecious construction materials. This extruder so developed works also as a dispenser unit since it dispenses successfully in a controlled way, the powder like dry materials which get sprayed layer by layer through its suitable nozzle and when a suitable binding liquid is pored intermittently over each of the powder mix layers, the desired 3D objects prints out employing any such '3DcMP's.

Highlighted here in this paper are the salient features of this 3DcMP which include a small disposable, construction mix dispensing/extruder unit that can be fitted and removed as and when desired, in replacement to any thermoplastic polymer extruder that usually comes with an FDM based 3D printers. With invent of such cost effective 3DcMP, real estate developers may be encouraged to readily adopt it as a tool in their future built environment.

INTRODUCTION

One of the effective tools in iterative design, inspection and quality manufacturing of prototypes has been the Rapid Prototyping (RP) and one of the most used methods in this has been the traditional machining which has undergone continuous advancements. With the advent of computer aided design (CAD) / computer aided manufacturing (CAM) workflow, CNC subtractive manufacturing came into existence and on mere following its invert process, a very popular technology that is Additive Manufacturing (AM) has then rolled out. Till very recently, this AM was looked upon by the industries as a technology not able to process materials having higher mechanical and physical properties, however, with usher in digital era having huge digital modeling and data handling possibility together with development of newer composite materials, this AM got re-defined further as a tool that offers ease in production of any engineering objects, suiting any application environment and handles any customized materials.

Fig. 1: Meeting with Prof. Behrokh Khoshnevis of University of Southern California, USA& CEO and Founder, Contour Crafting Corporation pioneered 3D printing in construction.

**DRDO Scientist, Ex-Principal JSSATEN, Ex-Adviser MoS&T, GoI, Dean (R&D) AKGEC **CED Faculty at AKGEC.*

Fig. 2: DST Supported National Seminar held which addressed the theme

AM can now produce 3D objects in materials like ceramics, metals paste and also those in polymeric composite materials possessing adequate mechanical strength properties. Researchers are now working to adopt AM interfaced with the laser devices to handle molten glasses whereby, it will become possible to create huge glass. Growing interest in the concrete construction industry has also been found to adopt the AM technologies as soon it starts dealing with ease, any construction mix/paste like concrete materials.

Fig. 3: 1st International Conference on 3DcP held at SwinBurne University of Technology, Melbourne, Australia

Worldwide efforts have therefore been made (some of these are depicted here in Figs.1, 2 & 3), to identify and resolve those various design and operational constraints which may arise on attempting 3D printing in construction. Needless to say here that once developed, any shapes can uniquely be printed out layer by layer using any 3DcMP in future, without incurring prohibitive costs on moulds and formworks which otherwise remains essential in constructions. Study has revealed that two of the constrains on application of 3D printing in any construction elements have respectively been as clearly identified are (1) non availability of suitable concrete/construction mix design and (2) non availability of any suitably designed extrusion/dispenser unit to fit onto any commercially available 3D printers for example and thus extrude out concrete mix. Having identified some suitable cementicious material mix and also created and deployed the effective dispenser unit for such mixes, it is opined that any 3DcMP so developed will readily be deployable as future tool in construction at sites as well.

Reported here is therefore one such design and development effort in which a construction mix dispenser cum extruder unit is successfully produced. The entire effort began with selection of a suitable geometry of this dispenser unit, part by part creating and then assembling them within the software, leading to generation of a 3D model on 'CREO' software, where a simulation study was conducted and modifications needed were also then carried out to meet virtually on this software its functional requirement fully. The details of this software generated 3D model and its functional simulation process has already been reported in the literature [1]. Every part of this unit subsequently has been printed out as hardware, all these hardware parts physically assembled as a unit and the same could successfully then be mounted initially onto a 3D printer using a suitable anchor and then subsequently fitted the same on a scaled up version of this existing 3D printer frame. This is how the required 3DcMP system got successfully produced and also functionally demonstrated.

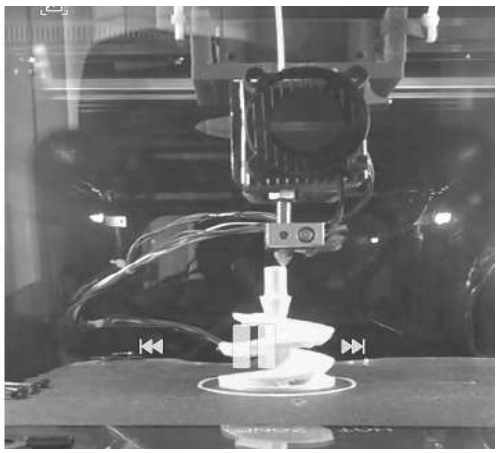

Fig. 4: Printing 3D Parts for a Concrete Mix Dispenser/Extruder Unit

In what follows are the complete descriptions of this developed hardware and 3DcMP system which is now available for use in printing 3D elements in construction.

DISCRIPTION OF '3DcMP' SYSTEM

Product here is a 3DcMP system, which is a computer software aided hardware complete 3D printing system, developed for construction industries. This 3DcMP system so developed composes of the four main components as-(i) the concrete mix tank, (ii) pumping mechanism,(iii) a small cylindrical shaped dispenser/extruder having print nozzle and (iv) a computer controller that is coupled to frame to give accurate tri-axial (x-y-z) plane movements to the extruder unit since the same is mounted over a gentry that moves over an x-y frame, which in turn moves in z plane within a fixed, rigid outer frame. Construction mix material starts the journey at the tank and is pumped (or may possibly flow under gravity)through the dispenser to reach this nozzle and it is the auger rotations which is responsible to control extrusion /dispense of this mix material which passes through nozzle and thus this extruder unit prints out any 3-dimensional construction elements, layer by layer in required dimensions. For use in construction, the frame of 3DcMP was needed as a scaled up version of any existing 3D printers available commercially so that the printer could accommodate the objects of any adequate dimensions.

3D object printing process in construction using 3DcMP begins with the illustrations of the object as to first be embodied in a software which remains installed on an electronic device/ computer. Subsequently, a soft solid model of the same is generated with the help of computer aided design (CAD) software which is converted further into a standard format such as Stereo-lithographic file (.STL file), a Virtual Reality Modeling Language (VRML) file, etc. The said file of the model contains a mesh, or series of triangles oriented in space but encloses the 3D volume of this object on which a slicing algorithm is implemented. In this file the instruction for sliced model get stored as thin cross-sectional layers and based on this information only, any hardware layers get extruded of 3D printed objects through any 3DcMP hardware. In order to print the 3D object for civil engineering, 3DcMP controller operates the printer to initially extrude the first layer of material through its nozzle and deposits this cementicious materials at the base of fixed outer frame of this 3DcMP. Once this layer hardens, next layer is laid and the process is repeated until the entire 3D object is printed out.

DISPOSIBLE DISPENSER/EXTRUDER UNIT

A suitably designed and developed extruder cum dispenser unit was needed to successfully create any 3D objects using various construction mix materials. This dispensing system was also required to be held by a suitable anchor to the gentry bar (Fig. 5), designed in a way as to allow easy fitting and removal of this dispenser unit in place that of alternately available extruder in the existing commercial 3D printers which otherwise extrudes the polymers material for any mechanical applications (depicted in Fig. 4).

Fig. 5: Anchor, Extruder, the Gentry Bar over an xy Frame.

For construction work, initially this dispenser/ extruder unit was fitted onto a commercially available FDM based 3D Printer itself and three dimensional controlled built-in movements of the same printer was utilized for proof of concept, however, as the 3D objects used in construction are fairly of big dimensions, a scaled up version of this printer frame as needed was created.

Disposable, easily interchangeable type dispenser unit so designed and developed here(Fig.6a) extrudes any paste like cementecious materials of construction and it as well works as control dispenser for any powder materials that could be sprayed layer by layer through its nozzle to print the desired 3D solid objects out of any powder materials. The unit possesses an interchangeable nozzle as well, so as to facilitate choosing of the shape (Fig.6b) and size of the nozzle according to requirements.

Fig. 6a : Parts of Extruder Units so Printed in PLA

Fig. 6b: Disposable Extruder/ Dispenser Unit without anchor

Complete dispenser hardware unit has been made out of PLA material and it consists of a cylindrical tube, housing therein a shaft with an auger along its length, this shaft gets its rotation from fitted pulley at its top which is driven through rotating belt passing over a stepper motor attached to the side wall of the cylinder outer face. The auger runs along this shaft is formed as continuous twisted blades that properly supplies the material mix to flow from top till end at the nozzle. There is a sidewise pipe coupled to cylinder wall that continuous supplies the construction mix material into the auger. While conducting the trial runs, it was observed that as wet construction material was used for printing through these extruders, the material generally found to clog the cylinder and nozzle as soon material gets hardened therein. This unit therefore was to be thoroughly cleaned which remains a tedious and time consuming process. This extruder unit developed here is of very low cost material, yet this unit serves effectively and it could easily be fitted and removed after its use. The polymer material PLA, used in its body may also easily, if need be extracted to recycle it by printing out a fresh unit through FDM technology extruder unit fitted over the same 3D printer as illustrated above. Relacing the clogged unit by new unit offers time saving in printing the 3D objects for construction application. This type of dispenser cum extruder unit thus remains an essential part of any 3DcMP to be readily employed in construction.

SCALED UP VERSION OF FRAME FOR 3DcMP

One 3DcMP has therefore been developed to successfully offer extension of Rapid Prototyping technology in construction. The outer frame of this 3DcMP acts as a structural framework for supporting/mounting all the above said components of any 3DcMP. Fig. 7 illustrates an exemplary architecture of this developed 3DcMP frame which is a modular assembly, can easily be assembled and dissembled. This frame need be a compact, rigid and a light weight assembly because 3DcMP uses precision positioning system e.g.. Corexy as its method of motion. Further, the said motion is driven by driving mechanism comprises of a set of stationary stepper motors mounted on the x-y frame. Both the frames include a plurality of aluminum extrusion sections which are connected together to form the frames utilizing the aluminum fixtures in T slots of the aluminum extrusions of suitable cross sections. 3DcMP rigid outer frame encloses the extruder assembly, moving gantry, an x-y rectangular frame that also move in z direction within this frame.

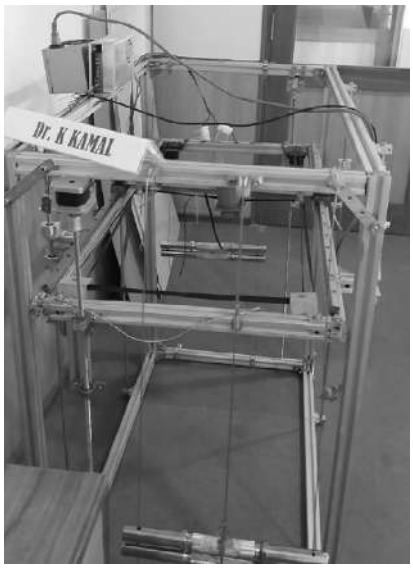

Fig. 7: An Exemplary Architecture of 3DcMP

As shown in Fig. 7, the extruder unit is attached with the help of an anchor, facing downwards towards the bottom end of the xy frame. The extruder assembly being coupled to the anchor that slides over a rail with the help of a linear bearing block fitted underneath this gantry bar. The extruder unit here is a light weight assembly which significantly reduces the motor power required for its movement, thereby rendering the 3DcMP cost effective. Each threaded rod placed with outer frame act as lead screw and help x-y frame to slide over it since coupled to the stationary stepper

motors as driving mechanism to the threaded rods. Counterweights to this movable x-y frame are attached through pulleys respectively on each side of top of the fixed frame. The x-y frame moves laterally (up and down) while the counterweights attached to it, move laterally in reverse. Such an arrangement assists the driving mechanism to operate this 3DcMP with ease and still remain economical. Movements of extruder assembly and/or the gantry and x-y frame all are controlled through a controller which receives instructions from a computer installed with software with which, this 3D printer communicates (either wired or wirelessly).All these moveable components of this 3DCMP operate in a synchronized manner and print the desired 3D objects. Soon switched on this printer for operation, the x-y frame, together with the gantry and the extruder assembly unit, move in downward z direction to get initially positioned close to the base. The construction mix is then dispensed on the base of this fixed frame, resulting in formation of very first layer of the 3D object, once this first layer is completely laid, the x-y frame then moves equal to layer thickness upwards, Additional layers of the mix are subsequently deposited layer by layer to eventually print out a complete 3D object for use in the construction.

CONCLUSION

A three-dimensional portable, sturdy 3D Construction Mix Printer namely '3DcMP' system with all its hardware comprising of an outer frame; a stationary driving mechanism fixed on this frame to move in z-plane the entire assembly of extruder, rectangular x-y frame with two stationary motors on it; a gantry bar with extruder assembly unit along with its driving mechanism to the extruder auger shaft that rotates inside a small lightweight cylinder provided with top caps, auger supporting rings and the nozzle cap, all these are developed in-house. Material feeding mechanism to the cylinder are separately developed and coupled to the cylinder of the extruder. Here the extruder unit developed here is of low cost material, it is detachable and disposable type having provision to choose type of nozzle depending on the material to be dispensed. On activating the driving mechanism through controller and giving regular feed of mix material into the cylinder, this dispenser in a very controlled environment prints out the first layer of material. The x-y frame along with all attachments is then moved upwards by a predefined distance for next layer and the same is than laid thereby repeating these steps, 3DcMP system thus generates successfully any three-dimensional elements for civil construction application of any suitable dimensions.

ACKNOWLEDGEMENT

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INNOVATIVE SANDWICH PANEL TECHNOLOGY AND CONSTRUCTION MATERIALS

USHA BATRA*

Abstract

New technologies are requiring attention globally for efficiencies and better-quality outcomes. With changing needs, manufacturers have created remarkable tools and technologies to attain quality and increased efficiency. Countless resources go into major construction projects. It is estimated that a large part of construction project expenses go into material waste and rectification of work. Therefore efficiency, analysis, and accountability are paramount to financial success. New technologies streamline construction project management processes and reduce waste. They ensure resource scheduling, tracking performance, equipment maintenance, and collaboration between teams, saving time and money.

Many developers have started using self-climbing formwork, aluminum shuttering, tunnel formwork for monolithic construction, precast concrete techniques and drywall systems as some of the new and innovative technologies.

Green and innovative materials are a must for quality and sustainable development. Sustainable development has also raised the need for net zero and energy plus buildings, necessitating the use of solar and wind energy, which now are making their way into mainstream construction as well.

Augmented reality is transforming the ways in which professionals interact with their tasks. It allows them to analyze problems and find solutions before implementation, which helps in making suitable decisions. Robots are being used for some processes. They may soon replace partly construction workers as well. Smart materials, roads, cities and new concepts for sustainability are being used and experimented for future use.

INTRODUCTION

The construction industry is changing rapidly, and new materials and technologies are being introduced on a regular basis. Execution of construction projects and their timely delivery has become a prime concern, emphasizing need for use of new technologies. Rising growth in residential and commercial properties is driving demand for faster construction methods and world-class quality. It has become imperative to use new materials /products and technologies to meet this increasing demand.

The construction industry in India is at the cusp of important change with new materials, building technology, software, digitization and artificial intelligence changing the way we conceptualize, build and use our buildings. Construction industry is exploring new technologies that improve the quality, durability and safety of the buildings. These technologies are not only cost-effective, but offer advantages such as minimal labour required, higher earthquake resistance, greater durability, larger carpet area, smooth finish on walls, and lower maintenance cost. Such technologies reduce the construction time as well.

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Many other technologies like Drone, BIM modeling, 3D printing, construction-site robots, virtual reality, augmented reality construction site robots and tree transplant machine etc. have also been used which help in expediting the planning and construction of projects.

Innovations are necessary for new materials to meet the challenges of speed, quality, disasters and sustainability. Precast and prefabrication methods and materials are suitable for future constructions.

PREFABRICATION COMPONENTS

Precast and prefabrication components improve speed of construction, quality, uniformity, consistency, build ability, reduces C & D waste, mitigates material failures and brings unskilled labor inside where work is supervised, monitored and controlled. The precast system consists of both structural and architectural elements such as partition walls, facade walls, floors, staircases, meter compartment and planter boxes.

Prefabrication technology requires greater precision compared to cast in-situ concrete construction. In precast construction, only limited tolerance is acceptable. Greater amount of accuracy must be achieved early in the design stage. Prefabrication may be in carried out in terms of columns, beams, slabs, 3D modular construction, EPS modular panels and EPS sandwich wall panels. EPS sandwich panels and modular panels being light weight, strong and having high insulation properties, are gaining importance in mass housing. The technology is discussed as EPS modular panels below.

EPS MODULAR PANELS

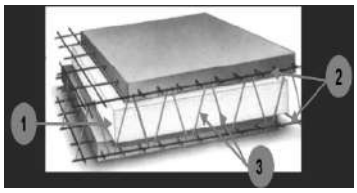
The product is manufactured by many companies. Variety of panels with little difference in manufacturing process and specifications are available e.g. solid, hollow, reinforced and sandwich panels.

One such material is modular panels formed from EPS and galvanised wire mesh and is suitable for speedy construction.It can be used for walls, roof, chajjas, domes, curved roof etc. upto G +3 storey structure and infill walls in case of multistorey structure. Any kind of exterior finish can be applied on it including stone cladding. Once finished, it is difficult to make out the basic construction material used. Location of services needs to be predetermined as well as details for location of windows, skirting etc, must be decided upfront to ensure proper alignment during construction stage.

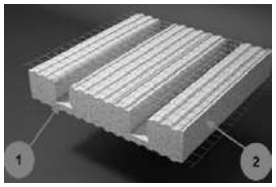
The technology has been in use abroad but has been used in Gujrat, Uttrakhand and Tamilnadu in india from 2013 onwards for residential and school buildings.

EPS panels are strong, light weight, eco friendly, safe against theft, easy to handle and assemble and reduce C & D waste. They have design flexibility and can be moulded in any shape and form especially good for domes or curved structures. They are safe against earthquake, cyclone, hurricanes. These can also be used in black cotton soil.

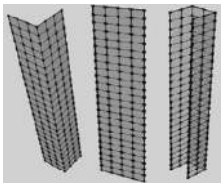
These modular panels are used to build frame for the structure and concrete or plaster is applied on both sides of panels to finish the structure. The panels consist of (1) Polystyrene Core (2) Galvanised Wire Mesh – two outer layers (3) Galvanised Wire Trusses pierced through the Polystyrene Core and welded to each of the outer layer sheets of Wire Mesh. as shown in Fig.1&2.



Wall Panel



Roof Panel



Mesh Joining Accessories

Fig.1: Different Components

Variety of polystyrene core thickness, mesh configurations and wire diameters are available. Specifications for wall and roof panels of quickbuild system are as under;

Wall Panel

(2.5mm Wire, 50x50mm Mesh, 50mm EPS Panel + 1" plaster both sides) Self Load – 120 kg/ m2 Load Bearing – 350 kN/m Plaster Ratio –

1st Coat 15mm of 1:2:3 (Chips mix – 100% of size < 6mm)

2nd Coat 10mm of 1:5 (Cement/Sand only)

Roof Panel

(2.5mm Wire, 50x50mm Mesh, 80mm EPS Panel + 1" plaster + 3" concrete)

Self Load – 280 kg/m2 Load Bearing – 10 kN/m2

Concrete Ratio – 1:2:4 (Chips mix - 50% of size < 10mm + 50% of size < 18mm)

Tongue and Groove joint (Approx. 2" deep) are available for Micro Beam (with or without steel rod) as shown above.

Panels are available in the following sizes:

Width – 1200 mm
Length – 2000 ~ 6000 mm
EPS Slab Thickness – 50, 80, 100, 120, 150 mm
EPS Slab Type – Plain or Corrugated
Mesh Spacing – 50 x 50 mm , 100 x 100 mm
Mesh Wire Thickness (dia) – 2.5 mm , 2.0 mm, 3.0 mm

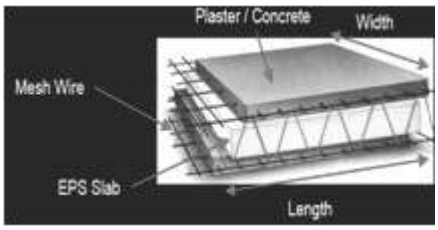


Fig. 2: Panels

Benefits

Low cost: The technology reduces labor, material and requires less construction equipments leading to saving in cost. Logistical costs are also reduced due to low weight of the product.

Structural integrity: The monolithic form of the panel and light weight enables the structure to withstand earthquakes, hurricanes and high winds.

Design and construction flexibility: Panels have the advantage of suitability of same material for walls, roof, chhajja, partitions and architectural features including concealed wiring and plumbing.

Speed of construction: Simple design process, ready made panels, easy transportation and quick erection of the building unit reduces construction time up to 60%.

Uniform quality: It brings simplicity, uniformity and high quality of construction. It consolidates masonry, insulation, plastering and addition of services thus reducing the complications in construction.

Thermal insulation: The core material being EPS is thermal insulator. It maintains indoor temperatures and lowers HVAC costs by 50%-70%.

Fire proof: It works very well as a fireproofing material for internal and external construction.

Moisture proof: The panel is excellent for preventing condensation/absorption on interior walls. Waterproofing mortar can be used in walls / roofs for additional protection.

Sound proof: The panels have superior sound dampening capability compared to masonry walls which can be further enhanced by increasing the core thickness.

Light weight: It is only 25% of the weight of a regular masonry wall, which alleviates the fixed load of a structure. This also facilitates its use in additions/alterations to existing buildings.

Flexible design: The panels can be easily used in a variety of forms like domes, curved roofs, curved facades, on site by removing mesh, bending EPS and re installing mesh.

Construction Method

Chronology of construction steps is as under;

- **Plinth Beam:** Steel reinforcement for plinth beam is laid and rebars are provided and 1½ feet, all along the plinth beam to hold the panels and concrete is poured to form the plinth beam.
- **Wall Panel Erection:** Panels are placed in between the re-bars on the Plinth beam. Erected panels are then bound to the re-bars with binding wire.
- **Wall Panel Joints:** Two panels are joined with a joining mesh, I-mesh (Fig 3) is used for a flat joint. I-mesh is overlapped over the two panels and is bound with a binding wire or

stapled using a clinching tool. At every 100 mm span the joining mesh is bound to the panels.

- **Corner Joint:** Panels at the corners are joined with a L-mesh (Fig 3). The Mesh is placed over the joint at the corner and is bound with a binding wire or stapled using a clinching tool to the panels. All corners of the building panels are joined from both inside and outside with the L-mesh.

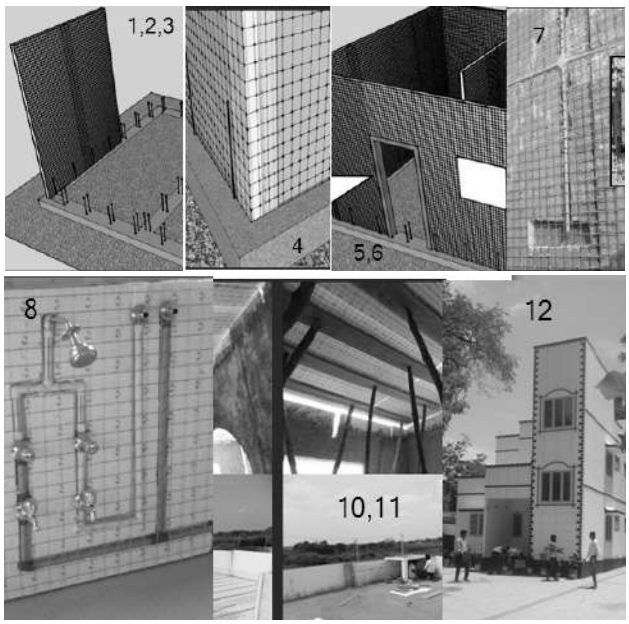


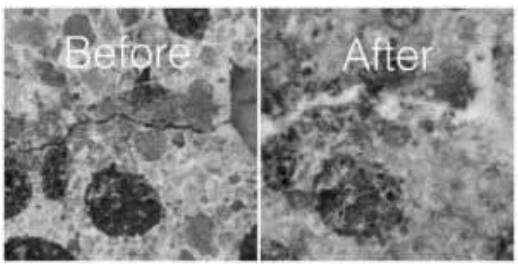
Fig. 3: Step of Construction

- **Wall Panel Erection:** Complete erection of all wall panels leaving space for the doors or other openings.
- **Window/Door Cutouts:** Opening for windows are cut with the help of a cutter. Frames for doors and windows are fixed to its corresponding opening. Window frames are fixed with a help of a C-clamp. One side is screwed to the wooden frame and the other end is fastened to the panel with binding wire.
- **Concealed Wiring:** Grooves are made in the EPS core using hot air gun and necessary PVC pipes are inserted into the grooves. Switch Boxes are fixed by cutting the mesh where the boxes are to be fixed.
- **Concealed Plumbing:** Piping is placed in the core material behind the Wire Mesh. No chipping and rework is required afterwards.
- **Plastering/Shotcreting:** Both sides of the wall panels are plastered with mortar (1:4). The plastering can be applied manually or with a shotcreting machine. First coat of plaster called rough plaster is 15 mm thick up to mesh level.
- **Roof Panel Fixing:** Roof Panels on the walls are erected with wall panels and joined using L-mesh on all the corners where wall panel and roof panel meet. L-mesh should be on inner and outer side of corners.
- **Roofing Work:** Roof panels are fixed and supports are placed under panels at 2ft. spacing. Rebars are added in Microbeam grooves if needed. Concrete is laid on the roof up to a thickness of 3 inches and allowed to cure for 15 days.
- **Finishing:** Finishing is carried out with fine plastering. Tiles, decorative POP, etc. are fixed on walls/roof as needed. AC's, stabilizers, wash basins, etc. can be fixed as done in the conventional type of building.

Some other innovations in the construction materials are descrbed below and shown in Fig. 4 to 8.

SELF-HEALING CONCRETE

Huge amounts are invested in maintaining, fixing and restoring roads, buildings, tunnels and bridges annually because unsatisfactory concrete cracks and needs to be restored. Self healing concrete can add years to a building's life saving time and money required for repairs. Science behind this technological marvel shows itself when water enters a crack and reactivates the bacteria that was mixed in it during the mixing process. When the bacteria is activated, it excretes calcite which then heals the crack.



Self- Healing Concrete

Aerogel Insulation

Smart Roads

AEROGEL INSULATION

Sometimes known as 'frozen smoke', aerogel is semi-transparent and is produced by removing the liquid from a gel, leaving behind the silica structure which is 90% air. Despite being almost weightless, aerogel holds its shape and can be used to create thin sheets of aerogel fabric which can be used in insulation. Aerogel insulation makes it extremely difficult for heat or cold to pass through and has up to four times the power of fibreglass or foam insulation.

SMART ROADS

Also known as smart highways, smart roads are the future of transport and involve using sensors and IoT technology to make driving safer and greener and generate energy from running vehicles on the road. They give drivers real-time information regarding traffic (congestion and parking availability for example) and weather conditions. This innovative technology can generate energy for charging electric vehicles on the move, as well as for street lights.

VERTICAL CITIES

Vertical cities may soon become reality as the world's population grows and land increasingly becomes scarce. They are tetris-like buildings of towers for thousands of people to inhabit. Supporting a blooming population, vertical cities are a space-saving solution to preserve land for food, nature and production.

Vertical Cities

Pollution Fighting Buildings

3D Printed Building

POLLUTION FIGHTING BUILDINGS

Also known as 'vertical forests', they are high-rise forest buildings designed to tackle air pollution. Pollution fighting buildings will be home to over 1,000 trees and 2,500 shrubs to absorb pollution in the air and to help filter it to make the air cleaner. Trees are highly productive in absorbing carbon dioxide, making this a cost-effective construction innovation for preventing air pollution.

3D PRINTING

3D printer construction technology can fabricate in-situ ceramic bricks with structural function and customized design and even construct houses as per the design requirement, making each house a unique one without extra time or effort. These bricks are fabricated in 15-20 minutes and once hardened it is possible to stack them and create walls, vaults or pillars.

COOLING SYSTEM IN BRICKS

Through the combination of clay and hydrogel, students at the Institute of Advanced Architecture of Catalonia have created a new material that has a cooling effect on building interiors.

Hydro ceramics have the ability to reduce indoor temperature by up to 6 degrees celsius. Its cooling effect comes from the presence of hydrogel in its structure which absorbs water, up to 500 times its weight. The absorbed water is released to reduce the temperature during hot days.

LIGHT GENERATING CEMENT

Dr. Josй Carlos Rubio Бvalos from UMSNH of Morelia, has created cement that has the ability to absorb and radiate light through the process of polycondensation of raw materials such as river sand, industrial waste, silica, water and alkali and can be used in swimming pools, parking lots and road safety signs etc.

Light Generated Cement

Martian Concrete

Floating Piers

Tesla Solar Tiles

MARTIAN CONCRETE

It is concrete that can be used to build structures in Mars now. It doesn't require water as an ingredient to be formed. In order to make the martian concrete, sulphur is heated at 240° celsius which melts it into a liquid. The martian soil then acts as an aggregate and once it cools down we get Martian concrete.

FLOATING PIERS

Over the water of Italy's lake Iseo, one can see another great innovation in the construction industry Floating piers by artists, Christo and Jean-Claude.

The floating dock system is composed of 220,000 polyethylene cubes of high density. It is a three kilometer long walkway with 100,000 square meters of yellow cloth wrapped around it. The cubes undulate along the waves of the lake.

COATED TITANIUM DIOXIDE NANOPARTICLES

For application to glass, steel, paper, and other materials, a new coating from researchers at the University College London resists moisture even after being scratched or exposed to oil. Made from coated titanium dioxide nanoparticles, the finish rejects water, oil by bouncing the invasive substances off its surface and removing dirt in the process and thus useful for maintenance of glass and other structural materials in high rise structures and solar panels.

TESLA SOLAR TILES

Tesla solar tiles can replace the regular roofing materials to produce energy. These solar tiles will be a profitable and economic investment for homeowners along with helping to produce its own green energy and save money. These tiles will prove to be more durable than any existing hard roof tiles in the market, thus being sustainable and efficient at the same time.

PHOTOVOLTAIC GLAZING

Building integrated photovoltaic (BIPV) glazing can help buildings generate their own electricity, by turning the whole building envelope into a solar panel. Companies such as Polysolar provide transparent photovoltaic glass as a structural building material, forming windows, fasades and roofs. Polysolar's technology is efficient at producing energy even on north-facing, vertical walls and its high performance at raised temperatures means it can be double glazed or insulated directly. Apart from saving on energy bills and earning feed-in tariff revenues, its cost is only marginal over

traditional glass, since construction and framework costs remain, while cladding and shading system costs are replaced.

Photovoltaic Glazing

Tree Transplanting Machine

HABITO DRYWALL

A high performance dry wall is a new generation wallboard product that includes the benefits of both old-fashioned plaster and modern drywall. Habito drywall stands on its own, thus eliminating the need for any anchors. This material has high density and gives great sound resistance and impact resistance, thus giving its applications in media rooms and high traffic areas. It is also known for its flexibility and performance as well as its durability for the building.

TREE TRANSPLANTATION

Modern transplanting machines and methods have more than 80% successful rate and include functions like digging pit, uprooting tree keeping root stock and earth ball intact, transporting the uprooted tree, transplanting at new place, filling the pit with dugout soil.

CONCLUSION

Innovative new technologies and materials are indispensable for rapidly changing construction industry. Strength, speed, eco friendliness and reduction in C & D waste are the pre requisites of innovative technology and materials. EPS modular panels meet the challenges of speed, quality, disaster and sustainability making it most suitable material and technology for future. The beauty of this material / technology lies in using one material for walls, roof- flat or curved, chhajjas, domes, curved facades and any other architectural feature. Innovative materials like self healing concrete, smart roads, vertical green cities, titanium dioxide coating, photovoltaic glazing, solar tiles and modern tree transplanting machines are solutions to the problems of maintenance, air pollution, energy and sustainability.

INFLUENCES OF TECHNOLOGY ON ARCHITECTURE AND DESIGN

Dr. Oscar Concessao* and Dr. Ponni Concessao*

Abstract

Cutting edge architecture and design are often great measuring sticks for the state of technology. Architectural technology, or building technology, is the application of technology to the design of buildings. It is a component of architecture and building engineering and is sometimes viewed as a distinct discipline. Architecture and technology have always intersected at a precarious crossroads. In a very real sense, architecture and design are applied sciences that utilize research and development in technology to propel their work to new heights, presenting buildings and products that are not only more interesting, but more responsible and useful as well.

Architectural technology can be summarized as the technical design and expertise used in the application and integration of construction technologies in the building design process, or as the ability to analyze, synthesize and evaluate building design factors in order to produce efficient and effective technical design solutions which satisfy performance, production and procurement criteria.

New technologies have always driven innovation in construction and building design, meaning the present day is an exciting time to be an architect and engineer; the technological advances of the digital age provide the industry with a plethora of new tools to take building design to the next step. Now, digital technologies are gradually entering the construction industry, changing how infrastructure, real estate and other built assets are designed, constructed, operated and maintained.

Drones, Virtual Reality, Artificial Intelligence, 3D-printing, Building Information modeling (BIM), digital prefabrication, Robotics, Parametric, wireless sensors, Big Data and the Internet of Things; such are the new additions to the architects and engineers technology toolbox that will change the way we build.

INTRODUCTION

Cutting edge architecture and design are often great measuring sticks for the state of technology. We will explore some of the latest advancements in technology, and how they apply to the ever-changing world of design. Architecture and technology have always intersected at a precarious crossroads. In a very real sense, architecture and design are applied sciences that utilize research and development in technology to propel their work to new heights, presenting buildings and products that are not only more interesting, but more responsible and useful as well. Everything from digital drawing and rendering, to construction documents and building are becoming easier to do with better results.

We are, however, well on our way to removing the mundanity from life allowing humans to focus their time on the things that matter most. The following products, designs, buildings and ideas are what the people around the world are coming up with using technology as their inspiration. Both

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technique and art, architecture is also a constructed expression of society. As technique bordering on engineering, it has experienced the impact of new materials and innovation in the areas of construction, structures, or installations, facing the historic challenge of sustainability. Computers are becoming faster, stronger, and more globally ubiquitous. Today, around 40% of people on the planet have access to a computer and the internet. That number represents over 3 billion people and is growing every day. With that many people having access to emerging technology, we are learning how to better use them on a massive scale. This article hopes to outline some of that technology, and show how it is being used by architects, designers and artists to build a better, more efficient, more visually stunning digital world.

MATERIALS CHANGING THE FUTURE OF ARCHITECTURE

Materials are a crucial element for architecture; they not only help the designer bring their aesthetic visions to life but they allow them to remain functional. Architecture has evolved alongside building materials–as materials become more sophisticated, so does architecture. Breakthroughs such as reinforced concrete and metallic structures, for instance, changed the way humans inhabit cities forever, allowing for new structures such as skyscrapers and large, durable bridges. With rapid advancement in the quality of materials, what's next for architecture? New technologies—sometimes developed for other fields—have the potential for crossing over and creating impact in the building industry. These new materials could change the way we interact with our buildings, their lifespan, and their appearance.

SELF-CLEANING FINISHES

As high-rise buildings become more common, self-cleaning claddings and finishes can help improve their notoriously challenging upkeep, protecting from dirt and smog. With the help of such materials, cleaning glassed facades can become an obsolete task. Self-cleaning technology is not only useful for the upkeep of large structures, small buildings or residential dwellings can also benefit. By eliminating the necessity of cleaning, the design earns sustainability points when it comes to water saving and the elimination of cleaning substances that can negatively harm the environment. Self-cleaning finishes can be applied to a variety of claddings, such as aluminum, glass, and paint. This technology is possible thanks to nano materials; the claddings are coated in a mixture of nano particles that allow the material to repel water, oil and dirt.

SELF-HEALING MATERIALS

All materials suffer damages over the span of time, whether caused by weather, prolonged use, or unanticipated events. Sometimes, to repair a small crack on a structure an invasive solution is needed as patching it up could cause unwanted structural weaknesses. With self-healing materials, this problem no longer exists. Self-healing metal, concrete, and facades could change a building's life expectancy, drastically cutting costs in maintenance in the long run.

HARDWOOD CROSS-LAMINATED TIMBER

Cross-Laminated timber, a material made of layers of solid lumber, is a valuable alternative for those looking to build sustainably and durability. The material has a strength comparable to reinforced concrete and structural steel, which is attained by layering pieces of solid wood, alternating their strand orientation. Thanks to its strength and durability, the material could gradually start to replace structures usually built in steel.

HOMEOSTATIC FACADES

This facade system adjusts to exterior conditions—such as light and heat—to help the building maintain desired interior conditions, in what is known as "biomimicry". This system is composed by a ribbon made of a dielectric material (a polymer that reacts to electric impulses) encased in a double glass facade. Both sides of the material are coated with silver, which reflects light and distributes the electricity across the surface of the material, allowing it to morph according to the building's necessities.

BIOPLASTIC

Plastic is one of the most contaminant elements in the world, mostly thanks to its slow biodegradation. Bioplastic, or biopolymers, is made of algae, marine chitins, cellulose and a wide variety of renewable biomass resources. Its organic nature makes it easier to degrade after discarding, making it a green alternative to plastic made with fossil fuels. Bioplastic could be used in cladding, structural elements, and other architectural aiding structures.

HIGH TECHNOLOGY IS REVOLUTIONIZING ARCHITECTURAL DESIGN

The shift is altering both the process and end result of a new breed of innovative architecture that is disrupting the industry and heading in unexpected and exciting directions. Technology in architecture from computational design to apps has architects and engineers are doing more than designing and supervising the construction of buildings. They are pursuing new horizons in design, chasing algorithms, experimenting with adaptability, robotics, 3D printing and reality. Today's architects and engineers have access to data and analytics that allow them to focus more on innovation versus production while optimizing performance. In other words—the job of the architect is also evolving. Many, however, are clinging to tradition and resisting the latest technological innovations, all but securing their own demise. Technology will not be ignored, and tech savvy architects are more likely to prosper than those burying their heads in the sand (Fig. 1).

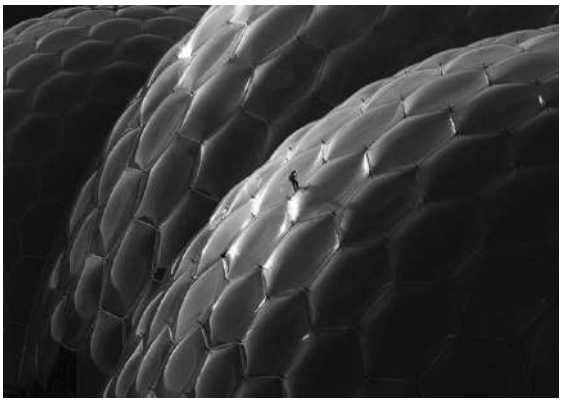

Fig. 1: The Eden Project, design by Nicholas Grimshaw

Following are some of the thrilling technologies that are shaping the face of architecture.

VIRTUAL REALITY AND IMMERSIVE ARCHITECTURE

Imagine an artificial world that you can observe, walk through, reach out to touch objects and see everything around you respond in real time. This is immersive virtual reality and these spaces are created using a combination of computer graphics, wireless tracking technology, headsets, HD projectors, polarized glass and more, all working together to create interactive and real-life experiences. The world of 3D virtual design and engineering is a fast growing field and there's some seriously forward thinking in these fields. Virtual reality offers architects an exciting, dynamic way to collaborate with each other and present ideas to clients. Use of virtual reality technology in architecture is expected to grow as firms, virtual reality companies and BIM software developers work together to create more seamless virtual reality workflows. Some firms are using virtual reality to allow clients to "walk" through projects before these are built, engaging them in the design process.

Augmented reality is taking off thanks to advancements in products that facilitate a greater connection between the physical and digital realms of architectural design. Augmented reality applications allow users to overlay building plans, marketing materials and other 2D collateral on a 3D BIM model.

"VR is a huge leap forward for projects in the conceptual stage. Clients can actually see the proposed designs as they are intended. It's powerful".

BIG DATA AND SMART CITIES

Although Big Data has a lot of buzz around it, I believe that in many ways it is still a relatively new and unexplored concept. However, its potential for human analysis is already obvious. This makes it a perfect and integral part of the planning and creation of smart cities. As population grow and resources become scarcer, the efficient usage of these limited goods becomes more important. Smart cities are a key factor in the consumption

of materials and resources. Built on and integrating with big data, the cities of the future are becoming a realization today.

BIM RISE

The BIM is already an old idea but it has started to build massive momentum in the architectural community. The BIM (Building Information Model) is based on several principles that can be implemented with relative independence:

- We design a project using an unique 3d model which is modified throughout the project's life
- This 3d is not only volumetric surfaces, but has metadata attached like the material of the element and parametric modifiers like the height of a wall
- The 3d model can be stored in a multi-client database and stored in the cloud to be accessible at the same time by several people
- Multi-user permissions on the model can be defined precisely to reflect team member responsibility on the project
- All construction elements are classified using standard categories, namely the IFC
- Libraries of construction products can be inserted in the model and even get actualization if the product version changes …

PARAMETRIC ARCHITECTURE

Parametric architecture is a new way to design a shape, which eventually ends up a building. Parametric design is a generative design system, where adjusting the parameters will compute to create different types of outputs, and create forms and structures that would not have otherwise been possible. Parametric architecture uses internally a geometric programming language that can be used directly by coding. Or you can design parametrically using a software extension of Rhino called Grasshopper 3 and make the same operation visually with a User Interface. Grasshopper shows you the shape of the building, and gives you a way to define handles to control it.

It allows you to do some once impossible tasks when using traditional 3D modeling software. But moreover it changes the relationship we have with the finished building. We actually don't build a building, but a shape that is controlled by a series of parameters or constraints. The computer and human imagination play together to design architecture. The second important point is that it moves architecture closer to programming language.

ARCHITECTURE ROBOTS AND 3D PRINTERS

The way we make things has changed—but will change more drastically still. Robotics is coming to the construction industry. It won't be long before we are assisting in designing to a construction process that involves assembly robots. Assisted robotics, in which a human and robot work together to direct the construction process, is also on the horizon. We've seen 3D printing of consumer items, but new algorithms can actually value engineer a structure, while solving the equation for structural resilience and material use. In architecture, we have seen parametric design tools assist in creating amazing structures. Now the use of large-scale 3D printers will help push the materiality of those structures. 3D-printed construction will greatly expand the limits of construction technologies.

Building construction could change drastically through the use of prefabrication and automation. Again this is not a new technology, as robots have been used for years in construction plants. But whereas the products have been industrialized a long time, the assembly of those products, and a lot of construction techniques, remain manual: concrete, bricks, glass need workers to be put in place on the construction site. The robots used in plants can be huge, are not very flexible, and generally do a specific task they are fine-tuned to accomplish perfectly. While using industrial components for a long time, construction has remained a very manual process, and usually takes years to complete. With the new robotisation era we are about to enter, the building itself can be an industrial product and its construction site a plant.

3D RENDERING AND ARCHITECTURAL VISUALIZATION

Advancements in 3D modeling and 3D rendering technology is having a massive effect on the products we use and the buildings we inhabit. Rendering artists are getting so good at their craft, they are able to produce clearer-than-real-life images pulled straight from the digital fortress and into your eye holes. Modeling software and 3D rendering software such as Rhino, SketchUp, and Maya are revolutionizing the digital world, providing vital design information to architects, city planners and interior designers. Furthermore, applications like Google Earth are becoming so detailed and comprehensive, users are able to pan and orbit around the globe in full 3D. These things do not just happen with magic, hope and prayer either. They are complex networks of 3D models made for the general public by 3D artists and engineers who dedicate their lives to visualization

ARCHITECTURAL APPS AND CLOUD SERVICES

Technology in architecture may take many forms. One such form is the Smartphone—forever getting smarter and more indispensable. As architecture software developers deploy apps for use during every project stage—from conception to completion—architects are learning to rely on them to better serve their clients. Touch screen technology allows architects to sketch directly into software that can be translated into 3D modeling apps. Building Information Modeling (BIM) saves time, increases transparency, enhances details, records changes and encourages collaboration. Using visual scripting tools such as Grasshopper and Revit, architects can streamline their processes, quickly iterate, explore and deliver solutions. Meanwhile, increased use of BIM technology is driving the need for cloud-based design products and services that make it possible for everyone working in a project to access project information at all times.

DRONES

Drones get a bad rap. Between unmanned aircraft indiscriminately removing entire villages from the planet and annoying pre-pubescent teens spying on sunbathing neighbors, drones have become technology public enemy number one. It is not unusual for advancements in technology to stir up such vitriol from the general public. It was not too long ago people were outraged at the irresponsible, often damaging ways people were using the internet. But in such ways that technology is used for evil, it can also be used for good. Amazon recently unveiled a plan to use drones for near-instant delivery on demand. Put in an order for certain items in certain cities and a drone will show up at your doorstep and drop off your order in less than half an hour. Several architects and designers have been collaborating to develop a system of erecting entire buildings with the use of drones. One proposal has drones dropping housing modules into place like Lego blocks, going from foundation to skyscraper in a matter of days.

Additionally, drones have begun to be used by realtors, architects and designers to get people into real interior space before a building has been constructed. The crew will take a drone to a job site, whether it be urban or rural, and can fly the drone around to capture to most precious and important views via an on-board camera. The architect can then take this image data and superimpose it into their renderings for the project, giving prospective clients and buyers an accurate picture of what the living room will look like when viewing the cityscape beyond. It has become a valuable tool for 3d renderers who are looking to produce the most accurate design drawings this side of real life.

CONCLUSION

Architecture and engineering is a very old practice. Architects and Engineers can mix in the same projects highly technical systems and traditional know-how. Architects often play in their project with technical changes, sometimes emphasizing the modernity, sometimes hiding it.

Building a project need years, so changes takes more time than in more immaterial domain. Also architecture involves a network of competencies: architects, engineers, construction firms… The fact that not all team members have switched to

new technologies could be a brake to technology adoption. Nevertheless, technology adoption does impact architecture right now, and here are some of the most notable changes that we estimate could have the most impact on how we design architecture in the next years.

To survive and thrive in this brave new digital world, architecture and engineering firms will need to harness emerging technologies and use them to their advantage.

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APPLICATIONS OF BIO-CONCRETE IN THE BUILT ENVIRONMENT: PROBLEMS AND PROSPECTS

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Abstract

Though concrete is a strong material but when subjected to tensile stresses, it initially leads to the formation of cracks and then ultimately it fails. There has always been a fight to develop a concrete which can heal itself with time. Now the scientists have been able to develop a self-healing concrete which can fill up the cracks formed and increase the durability of concrete. Though bio concrete will obviously be helpful but this technology is bit costly, hence there is a need to develop an economic and efficient bio concrete.

This paper analysis the disadvantages applications and obstacles in using self-healing concrete (bio concrete) in the built environment.

INTRODUCTION

Concrete is a construction material used in making a variety of structures or in other words it is the material responsible for the formation of built environment that we see in our surroundings. Application of concrete like material can be seen in the past in as old as 6500 BC. It is not an ordinary material but is rather a revolutionary milestone in civil and structural engineering.

Concrete is primarily made with cement, water and aggregates though some additives can also be used. One of the drawbacks is that the cracks in concrete are almost unavoidable and leads to the reduction of durability and can lead to the penetration of carbon dioxide which can cause the corrosion of reinforcement used. The repair or maintenance of cracks can be uneconomical therefore researchers have developed a technique to overcome this by making a self healing concrete.

Though concrete itself has some ability to heal small cracks by hydration of unhydrated particles but this ability is not effective for bigger cracks. Due to the vastness of this topic, it is not possible to provide full details about the processes in self-healing concrete, hence this paper is limited to describing the challenges to bring an efficient biological self-healing product to the concrete market and its applications along with giving some alternative methods.

BIO CONCRETE

Bio Concrete: As an Inspiration from Nature

Self-healing concrete works on the same principle as in the healing of bone fracture in vertebrates or when a plant has a small cut on its surface. The cut in animals or plants is healed by biological repair mechanisms which are already inside them like the healing of bone fracture occurs by a phenomenon called mineralization.

Working and Mechanism of Biological Healing

A healing agent has been developed that works when bacteria (embedded in concrete) converts nutrients into limestone to fill up the cracks. Selective type of Bacillus bacteria is added along with calcium lactate, nitrogen and phosphorous and then mixed with concrete. When the concrete cracks in significant amount and water starts to seep in and it comes in contact with the bacteria, spores are germinated which gets activated and

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consumes oxygen and calcium lactate is converted into limestone which fills up the cracks.

METHODS OF SELF HEALING

- **Hydration of Unhydrated Particles of Cement-**

  Concrete has an inbuilt capacity to hydrate the unhydrated particles up to an extent i.e. this is applicable only for small cracks i.e. up to 2mm.

- **By Adding Small Fibers-**

  By adding small (micro) fibers in the mixture, it will lead to the formation of many micro-cracks rather than bigger ones, which are then healed by the internal capacity of concrete to heal small cracks.

- **Sedimentation of Cement Particles and Aggregates-**

  As bleeding occurs, water moves towards the surface of concrete and the small-sized cement particles moves downwards due to the effect of gravity which is then responsible for filling up the internal cracks.

- **Swelling of Surrounding Cement Matrix-**

  This swelling is achieved by using certain hydrogels or superabsorbent polymers (SAP), which when exposed to the environment on crack formation swells up to fill up the cracks to provide fluid to surroundings for further hydration and curing.

- **By Embedding Bacteria in Cement Matrix-**

Certain type of bacteria converts nutrients into limestone to fill up the cracks, this happens when spores germinated gets activated and consume oxygen to form calcium lactate which is converted into limestone to fill up the cracks.

- **Using Plant Fibers-**

  Since plant fibers act as reservoirs to store water, so in dry regions they are used because there is deficiency of water and the water collected reacts with self healing agents to fill up the cracks.

Chemical Equations

As the spores germinate in concrete mixture and get activated, biological activities start which leads to the release of urea ($CO(NH_2)_2$). Then the hydrolysis of urea generates ammonia and carbamate (NH_2COOH) which ultimately will lead to the formation of calcium carbonate on degraded limestone.

This can be seen in the following equations-

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3$$

$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3$$

$$2NH_3 + 2H_2O \rightarrow 2NH^+_4 + 2OH^-$$

$$2OH^- + H_2CO_3 \rightarrow CO_3^{2-} + 2H_2O$$

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{2-}$$

$$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$$

Calcium ions are thus required, which will react with carbonate ions to result in the deposition of calcium carbonate.

OBSTACLES AND DISADVANTAGES

The first obstacle is that the self-healing concrete can be used in structures where high compressive strength is needed-

As for holding the self-healing agent in concrete, clay is used and the clay used normally comprises of 20% of the volume of concrete used. As the clay used has comparatively less strength than that of surrounding aggregates in the concrete matrix, it will reduce the strength of the structure by 25%, which is acceptable only for small structures and not in structures where high compressive strength is needed such as high-rise buildings.

The second obstacle is that self-healing concrete is viable only for structures where high safety is required-

Presently the cost of concrete is 80 Euros (Rs 6250 approx.) per cubic meter and of self-healing concrete is almost double i.e. around 160 Euros (Rs 12550 approx.) per cubic meter (Ingenia issue 46 March2011-www.ingenia.org.uk/getattachment/Ingenia/Issue-46/SelfHealing-Concrete/Arnold.pdf''). So, this technique is viable only where the cost of concrete is much higher on account of

being of much higher quality such as in case of structures where safety is of major concern e.g. marine structures and tunnel linings.

ALTERNATIVES TO MAKE SELF-HEALING CONCRETE EFFECTIVE

One of the ways to make bio concrete effective is by reducing its cost or making it economical. So, for this few engineers have come up with an idea to cover only the surface of concrete structure, rather than infusing bacteria inside the whole concrete. This technique will be more ideal for places with moderate weather changes or sheltered areas.

Since calcium lactate is expensive so it is the major reason for bio concrete to be expensive and the process of embedding bacteria and nutrients into clay pellets is also costly. Therefore a sugar-based nutrient can be used which will decrease the cost of self-healing concrete to half the current price that is approximately 85-90 Euros (Rs 6500-7000 approx.) per cubic meter.

The above-mentioned food nutrient will not remain intact inside clay as calcium lactate remains so the food nutrient will ultimately lead to the increase of settling time of concrete, which is not desirable. So, a new healing agent is being developed which will occupy only 3-5% of the total volume of concrete, due to which the concrete will become much stronger.

Since in dry regions, there is a deficiency of water so the bacteria will not get activated and hence no filling up of cracks will occur. To solve this problem, plant fibers can be used which can act as reservoirs of water and then water will react with self-healing agent to fill up the cracks formed.

APPLICATIONS OF SELF-HEALING CONCRETE

Application in highway construction. Due to the formation of cracks on pavement, the water starts to seep inside and gets accumulated beneath the pavement which in turn weakens the soil beneath. The stresses due to vehicular movement increases the pace of this and it finally leads to the formation of potholes. These potholes cause serious damage to the vehicles by reducing their structural integrity. This damage can thus be reduced by reducing the number of cracks formed, which can be achieved by using bio concrete.

Application in structures which require high safety considerations such as marine structure and tunnel linings.

Application in structures where frequent maintenance and repair cannot be done such as complex structures in which frequent or easy visit of humans cannot be done.

Application in making bricks using bacteria. As the production of bricks in brick kilns can be harmful to the humans and plants since the burning of coal leads to the formation of gaseous pollutants such as carbon monoxide, nitrogen dioxide, sulphur dioxide, nitrogen dioxide which can also lead to pollution and then ultimately global warming. So, bacteria can be used in the formation of bricks, which will prevent all sorts of problems caused by the production of bricks in brick kilns.

CONCLUSION

While there are both pros and cons of the technology but with continuous research, some problems can be solved and there is a need to make self-healing concrete much more economical and efficient.

Since the cost of self-healing concrete is high, this technology is preferred in big structures, because in small and normal structures it will become uneconomical. So there is a need to build a self-healing agent capable to be used in a normal built environment.

There is a need to look for other alternatives to this technology.

Self-healing agent should be capable enough to be used in unfavourable conditions too.

Since the process involved in self-healing is totally biological, so it is pollution free and natural. Therefore this bacteriological approach has excellent potential to contribute to the self-healing capacity of concrete.

It has been observed by scientists that addition of a high amount of bacteria did not decrease the

concrete strength, which was observed since clay used to keep the nutrients intact is weak and can decrease the strength.

This technology has a further scope and by continued research it can serve many purposes and can have a variety of applications in diverse fields.

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INNOVATIVE CONSTRUCTION TECHNOLOGIES AND MATERIALS

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Abstract

Smart building design and innovative construction technologies and appropriate use of building materials are tools for sharing the knowledge of how various building construction technologies and materials can significantly increase production and profit using advanced communication, collaboration and management techniques. The paper provides an overview of the types of technologies and materials available giving a new insight into innovative methods and construction techniques that will be available, and open new doors for advancement and improvement in the construction industry. The new construction technologies and materials discussed in this paper present a small fraction of the options that are available for use by the industry. These advancements have paved the way for the new design and construction methods that make buildings stronger, safer, more durable, more efficient, time and cost effective. Many options are currently available to building owners and decision makers while investigating new technologies that can improve their buildings and the environment.

INTRODUCTION

When humans first walked on the moon in 1969 nobody could have ever imagined that a few decades later most of us would own handheld devices with processing capabilities far beyond that will be found in the computer technology used to transport the Apollo 11 crew to our nearest astronomical planet.And also, in a little over two decades, the internet has absolutely changed the whole scenario on how we live and manage our everyday lives from the way we work, communicate, spend time by watching TV and movies, listen to music, shop and/or do everything else besides our routine daily chores. Similarly the examples show incredible pace at which global technological advancements are moving in construction industry. In construction industry however, new technologies and innovative processes were far slower than most other global industries in the past. The industry is one of the oldest and largest in the world and is now standing on the brink of a technological sea change not seen since the industrial revolution over a hundred years ago. This happened because of technological advancement, innovations and the progress made in every field of construction industry and materials. It is vital to understand the opportunities, benefits and challenges associated with technological advancement and innovations in the building industry.

Technological advancements continued to offer the opportunity for further improvements in building construction performance. Today, the market has increased emphasis on constructing sustainable and energy efficient buildings.

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New technologies and innovations enabled us to construct buildings that consume relatively less amount of energy. Manufacturing improvements, new innovative materials, improved construction methods, techniques and best practices, understanding building science and renewable energy technology are some areas that provide the ability to construct high-performance, smart and efficient buildings. Many different building components have seen significant growth with regard to technological advancements that offer great benefits to the building industry. Insulation used to consist of straw and mud being stuffed between the spaces of the walls of structures. Over time, new materials, such as fiberglass, cellulose, and foam insulation type concrete, laminated plastic or wooden building materials have been developed; all of these materials have continued to improve the thermal performance of our buildings. In the 18th century, a fireplace was the main source of heating for a building. Today we have extremely efficient whole-house heating systems that incorporate air-conditioning and ventilation that provide improved comfort at the touch of a button. The following paras discuss some of the innovations.

Technologies – Physical

Equipment, machinery and materials in the construction industry are constantly evolving to improve total project. This has brought the benefits of certain efficiencies and savings from both time and cost perspectives.The development of new technologies such as 3D printing offer the promise of enormous benefits in terms of process efficiency and flexibility, waste reduction and cost savings. In addition, process automation through robotics has advanced to a point where it can offer enormous benefits to construction projects through increased productivity, quality, accuracy and safety whilst reducing the construction time and the costs.

Technologies – Digital

Perhaps the greatest developments in construction industry will come through the application of digital technology. Building Information Modelling ("BIM") is still relatively a novel idea but is finding a foothold in many new projects. Through the production and development of digital models representing the various elements of a project, designers, contractors and owners are afforded to greater flexibility and control over all phases of the project from design and construction through to operation. If implemented correctly BIM will bring with it the benefits of improved efficiencies and reduced costs. BIM will play its part in a wider "internet of things" in construction projects which will see the generation and exchange of data amongst the users and electronic devices.

Other Innovations

Whilst technological advances represent the most significant potential innovations in the construction industry, there are other areas where innovation can be applied. The traditional "build only" and "design and build" contracting models are tried and trusted but have not always been the most efficient or cost effective. Contracting models which saw the contractor involved at an early stage in the process allowing greater integration of the design development and construction processes can at the same time influence cost certainty by allowing either target pricing or guaranteed maximum pricing.

Challenges and Barriers

The ever increasing array of new technologies coming to the market should constitute once in a lifetime opportunity. However, in reality, this is not the case as a number of obstacles stand in the way of their uptake. Compared to other global industries, construction has traditionally been slower to evolve and embrace innovation and new technologies. The industry is rooted in a conservative corporate culture and most construction projects are traditionally linear in nature. The alliance of these factors creates an environment where radical change is difficult to implement.Further, on the client/employer side of projects, the overriding objective is to see the contracted work delivered on time and within budget. Clients quite rightly desire tried and trusted methods, materials and a contractor in whom they have confidence to deliver their project.

Whilst advances in technology bring with them enormous potential benefits, they also pose fresh challenges. In order to apply a greater level of digitisation to projects employers, designers and contractors will need to acquire the required skills to use such technology. The construction industry has not attracted young digital talent which in itself is a barrier to advancing new software based technologies. A higher level of digitisation also brings with it issues of data ownership and possible data protection issues. Projects may also face cyber security issues if they become more software driven and the measures required to reduce these threats will come with an associated costs.

Changes and Incentives

It is beyond question that climate change must be the single most powerful driver behind innovation and technological advancements in construction. The World Economic Forum's 2016 report on Shaping the Future of Construction noted that the construction industry is the largest global consumer of raw materials and constructed objects account for 25 – 45% of the world's total carbon emissions. The report further highlighted that 30% of global greenhouse gas emissions are attributable to buildings – this, coupled with the fact that the population of the world's urban areas is increasing by 200,000 persons per day, underlines the importance of ensuring the construction process as energy efficient and as lean as possible so as to make built environment more sustainable.

The desire to bring this change must come from all elements of the construction sector, that is, clients/end users, designers, contractors, manufacturers and suppliers. The fragmented nature of the industry does not however lend itself naturally to a cohesive approach in this respect. Government (both at a national and wider at state level) must therefore, play a greater role in incentivising industry players to embraced advance technology and bring construction into the 21st century. This can be done through incentives (e.g. tax breaks, grant funding etc.) or via penal means through increased building and environmental regulations through NGT etc.

Building Materials of the Future: Greener Materials

Future building materials will take their cue from current scientific technologies. Self-healing concrete may be available within the next few years which could eliminate concrete cracks and expensive concrete maintenance.Alongside and influencing these technologies is a greater awareness and need to build greener, with sustainable materials used at the construction phase by manufacturing foam material from plant materials like hemp, kelp, and bamboo that will be used in insulation, and furniture. The foam can provide high moisture and high resistance to heat, and when used can also give protection against moulds and pets.

Re-Defining Future Design

While it may be easier to stick to familiar construction methods, the industry is changing and the new, innovative greener techniques, while challenging to develop to the point that they become standard, can be highly beneficial to the quality of the urban environment. The design of a skyscraper is shaped like a budding flower which may harness wind energy; the said skyscraper will slightly open its peak to allow wind funnel to converting it into energy source. The design team, as part of its green architectural design plan, also needs to take steps to minimise the solar heat, adding solar panels to the fa3ade of the skyscraper to take advantage of the natural daylight coming from the sun, thus decreasing carbon dioxide emissions.

Considering the future of construction development can give us a wider perspective and fresh ideas when it comes to designing the living spaces such as condos, skyscrapers, skylines and office spaces being built in major cities. Architects and designers have given exciting ideas that will define the way we live, and the kind of living that next generation will experience. More importantly, as these buildings are constructed, experts should ensure that every material and every action taken in the construction processes will minimise environmental damage, ensuring the world outside these future buildings as pleasant as it is inside.

Construction Techniques - Aluminium Shuttering

Aluminium shuttering was introduced in India more than a decade ago. Though sparingly used in the past, the technology has now gained wide acceptance and is present in most of the high-rise construction. Aluminium shuttering increases the overall cost on construction but reduces the construction time which will allow developers to start sales earlier than planned. Where timely delivery of the project is one of the prime concerns owing to regulatory reforms and escalating construction costs, aluminium shuttering has become a saviour. In conventional building techniques, transportation of building material such as bricks, wastage of materials during carriage and handlings, makes construction more expensive than aluminium shuttering.

Benefits

- Repetition – the durability of the material yields to repetition in typical high-rise construction
- Saves time and speed to market project
- Block work / Brick work can be eliminated in case used for walls
- Impeccable smooth finish achieved with concrete, with no need of plastering as in case of brick wall construction
- Due to less thickness of walls in comparison to brick walls, greater carpet area can be achieved
- Concrete structure requires less maintenance

Prefabricated Construction

Another construction technology gaining ground is prefabricated or offsite construction. It is the practice of assembling a variety of components of a structure at a manufacturing site and transporting them to the construction jobsite to be assembled. It is considered as a low-end and mass-produced mode of construction, but in reality, it is quite the opposite as it requires meticulous planning and detailing as well as a greater eye for quality and precision. Prefabricated construction is essentially of two types:

- Pre-engineered Buildings: Pre-engineered Buildings (PEB) use steel columns, beams and other structures. These structures are fabricated, brought to site and assembled to the final form. Traditionally, steel structural members are combined with composite metal panels and other wall and roof systems. PEB systems are widely used in industrial construction and warehouses.
- Pre-cast Construction: Here, structural members are cast in concrete offsite, brought to site and assembled. The wall, slab, and roof members may be in situ concrete, dry wall systems or metal cladding. Long used for infrastructure and pavement construction, the technique is more affordable and is now gaining acceptance in the building industry.

Benefits

- Faster: The elements can be mass produced in a factory the cycle time from design to completion can be shortened.
- Environment-friendly: Construction debris and waste can be reduced to a great extent along with noise, soil and air pollution at worksites, making sites cleaner and safer. Workers and engineers on sites are exposed to less health risks.
- Quality: Since factory-produced elements are precise, the overall attention to detailing, integration of various components in the building and quality of construction gets enhanced.

Drywall Systems

While the above two systems greatly enhance construction of the building shell, interior walls are also undergoing a change with use of drywall systems and concrete and other precast panels.

These systems have been around for a while and have been used in certain types of buildings/ interiors but are now fast gaining ground in mass buildings as well. The construction of walls can be faster, easier and cleaner on site. Requirement for a large labour force is reduced and quality of the finished product is enhanced.

Construction has seen a huge boom in the last decade and continues to grow by leaps and bounds with Housing for All by 2022 vision of the Government of India and the growing Indian economy. Also, acceptance of some of the newer construction technologies is increasing as the industry keeps pace with the growth. 2017 was a year for technology innovation in the construction industry, and that pace is unlikely to slow down in the years to come. Construction technology innovations need to be considered as discussed below:

- Virtual Reality - through a fully interactive experience prior to finalizing plans and produce the plans that fully meet the expectations. It also allowed to work around unique conditions including the schedule needs. 4D system allows construction companies to plan every aspect of the construction project, improving everything from safety to efficiency, and delivering a more consistent and quality final product.

- Augmented Reality - virtual reality allows users to "walk" through 3D and 4D model environment without actually moving on their feet, augmented reality allows the users to walk through real 3D environments, with their feet, while gathering and/or viewing additional real-time information about that environment, Measure dimensions and the level and place objects to get information from the 3D models laid against the image that is framed in the device.

- Wearable Technology - The construction site has never been safer than it is today, and we think it's only going to get safer with the introduction and mainstreaming of wearable technology track where workers are on the job site, alert them in real time of potential hazards, and identify when someone has tripped, slipped, or fallen, so help can be sent right away immediately.

- Machine Learning – Smart video, for instance, aggregates visual data from the job/project site and intelligently analyses it for a variety of purposes including safety, quality, progress tracking, and marketingas well as tagging items by room and associating them with the plan data.

This allows folks in the job trailer or the office to quickly find visual information about the site

without having to sort through the masses of data. Additionally, it also makes it easy to identify visual data to use for marketing purposes.

- Prefabrication - The construction industry has been using prefabrication in various applications for decades. However, new technologies are making the benefits of prefabrication easier to access, and changing the way the construction industry integrates prefab into the process and also will gain competitive advantages. It also enhances the speed of construction.
- Predictive Analytics–any successful construction company and the struggling construction company's ability lies into managing the risk. Project IQ analyses data from subcontractors, materials suppliers, design plans, and the site itself to analyse risk factors based on historical data. It provides a dashboard where GCs can identify which elements of their project are at highest risk and need attention, and allows them to drill down to see the reasons for the risk assessment. Project IQ learns both from past data and from how the GC interacts with the information it provides, in order to continuously provide better and more accurate risk assessments.
- Connected with Job Sites - Communication delays between the job sites, trailer, design office, and engineering can be costly and aggravating. In short, a disconnected job site can quickly burn up your profits.Everyone holds the ability to file RFIs and issues in the palms of their hands. Likewise, everyone in the trailer and design and engineering has immediate access to everything that is happening on the job sites.

Innovation is a wide concept that includes improvements in processes, products or services. It involves incorporating new ideas which generate changes that help solve the needs of a company and so increase its competitiveness. The application of innovation to the construction industry is not straightforward, despite the importance of this sector in the development and growth of the wider economy. Every construction project is different, which means that construction companies have to adapt their processes and resources to suit each project. Every site is a singular prototype whose configuration changes over time. Construction works are located in different places, and involve the constant movement of personnel and machinery. In addition, the weather and other factors can prevent consultants from applying previous experience effectively.

Innovation needs to change from being just the application of good ideas to a process that can be managed, measured and controlled systematically. Consequently, the standardisation of innovation is very important. The key lies in considering innovation as a management process. Each part of the organisation can control and improve different aspects of innovation and integrate them into the rest of the company's processes.. Discussed below are some of the innovations in the construction materials like use of hollow bricks, foam concrete, light generating cement, green mix concrete, use of Nano technology in construction materials, use of translucent wood material and laminated timber, solar tiles.

CONCLUSION

The remarkable technological advancements discussed above have largely been brought about through the innovative and progressive thinking of engineers and other building professionals yet they must make up the bulk of construction industry to embrace these advanced technologies. The opportunities to improve the industry in terms of process efficiencies, flexibility, safety, climate and the environment and ultimately in terms of cost are concepts to be adopted whole heartedly.

The construction industry is changing rapidly, and new materials and technologies are being introduced on a regular basis. Execution of construction projects and their timely delivery should become a prime concern for developers in view of the buyer's agitation on delay in construction. Especially after RERA, which emphasises the need for timely completion of projects, adoption of modern technologies has become the need of the hour. The construction industry is also keeping track with the latest technologies to improve the quality of buildings, geared towards

the future of man's day-to-day living through sustainable construction practices. When it comes to construction technologies, the possibilities are endless, and the current rapid innovation and technology of construction will shape the future of new buildings. In terms of building construction, the construction workers of the future could be robots. Rising industrial, residential and commercial growth is driving demand for faster construction and world-class quality. It has become imperative to use newer products and technologies to meet this increasing demand. The construction industry in India is at the cusp of suitable changes with new materials, building technology, software, digitization and artificial intelligence changing the way we conceptualize and build our buildings.

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COUNTERING CONSTRUCTION CHALLENGES

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Abstract

Revolutionary changes in the making and use of materials used for building construction is seen throughout the globe, both at urban and rural levels. The paper puts forth various infrastructural issues, site constraints due to location and topography, environmental concerns, availability of advanced material, technology and skilled labour, which have led to incorporation of innovative techniques in building construction.

The paper discusses case studies showing how the challenges in construction have been countered to generate changes to benefit society at large. The case studies of different building typologies are compiled to represent diverse construction challenges which have been responded with innovative management and construction techniques using modern materials in inventive ways to address current global issues with examples of management and use of zero energy materials, passive architectural design, reuse of containers to be used as hotel rooms, crиches, public toilet blocks and recycling of contemporary waste substances as construction materials

INTRODUCTION

Construction challenges arise due to infrastructural issues mainly from constraints on site. Revolutionary changes are seen in construction technology all over the world as a meaningful responses to the various construction concerns. Challenges for building construction faced due to site locations, access to site and construction resources, availability of skilled labour force are addressed in the case studies which represent different ordeals in construction. The following case studies attempt to discuss innovative solutions to achieve timely results relevant to the context. The different building typologies on diverse site conditions help to reveal the tremendous scope of dissimilar solutions for potential transition of construction approaches to counter site challenges.

Case Study 1: Krushi Vigyan Kendra, Sagroli, Maharashtra

Krushi Vigyan Kendra, Farm science centre at Sagroli in Maharashtra is located on sprawling 300 acres site surrounded by agricultural fields. The site location gave rise to design and construction challenges arising from climate, material and labour availability. Alternative materials and construction technology was adapted as a response to counter the challenges. Zero energy materials such as stabilized earth blocks from soil of old local dilapidated structure and sand from local river bed was used for the construction. The cost incurred was only for local transportation, local labour of making the blocks on site and cement to stabilize the blocks. Cavity walls of hollow stabilized earth blocks, use of ferrocement for casting vaults at terrace levels which act as a stack, locally available tandoor stone for jali pattern for inlet of evaporative cooling shaft help in countering both climate, material and labour availability issues on site. The construction technology adapted for roof is of dry brick laying in a particular pattern to create cavity between the RCC slab and brick layer to insulate the horizontal surface. Due to the alternative construction technology there is no external heat gain and due to the integrated cooling system the

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building experiences a difference of 10 degrees Celsius from the outside to inside. The water ponds inside the building collect the rain water which is stored in the overhead water tank to be used for evaporative cooling. Use of exposed concrete and grit plaster of grit of local kadappa stone provides for a permanent finish which in turn reduces the lifecycle cost of the building. Sloping side towards the leeward direction guides the hot air to escape through the vaulted stack (Fig.1).

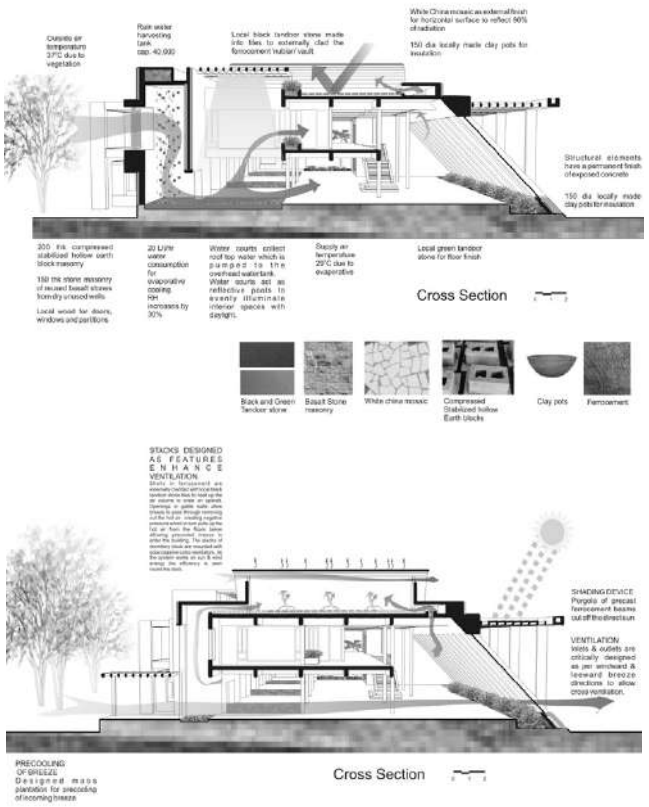

Fig. 1: Cross Sections of Building

Case Study 2: Koan residence, Pune, Maharashtra

The house sits on a tight plot admeasuring 269 sq m., in an urban context, it appears to be spacious due to the carefully placed levels. One space seamlessly flows into the next in the house planned on the open plan concept.

The road edge acts as a first layer of the fasade of the house and the entrance is an abstract of gateway observed in traditional architecture. The gradual progression of levels takes one to the elevated ground floor, through the entrance verandah. The entrance door comes in view as a surprise only after entering the verandah creating a visual pause. Indian cultural footprints are literally depicted by the scroll of engraved footprints of Goddess Laxmi in to concrete walls, on the way to the entrance verandah. Engraved flying birds on the concrete wall visually connect the edifice to the sky. The central court experiences dynamics of light throughout the day as the sun travels through the water ceiling into the space below. The glass bottom of the swimming pool at terrace level allows light at different times and seasons to creates different patterns on the wall throughout the day. The pergola spanning over the swimming pool gives a humane scale to the space on the terrace. Outdoor space attached to the elevated ground floor gives a feeling of garden attached to the interior space.

The structural system is designed to allow and create interesting fenestrations to capture unobstructed views. The house resembles a haveli with detailing of internal facades of glass and wood screens. Partition between the bathroom and bedroom is also designed on the same concept, making the internal mass light. Visual connectivity is the spirit of the house emphasized by the open spine wall staircase holding all the levels. The mid landing of the staircase is extended to form an alcove housing a library which forms an extension of the living room at mid level. The staircase railing in wood, in an interesting pattern is a structural element to hold the treads. The house looks spacious because of use of courtyard and neutral pastel colour scheme with highlights of orange acting as a backdrop to all common spaces such as living, dining, and the staircase. The orange backdrop gives a visual pause within the flowing spatial connects.

The colour patterns are reflected in the furniture, to be a cohesive part of the house. The concrete beds, headboards and the wash hand basin cantilevered counters, appear to draw up from the structure keeping with the monolith concept. Large full size murals in grey tones made in Siporex creates an interesting interactive backdrop and acts as a screen for the bed. The house has green features incorporated in the design in all aspects.

Spaces are oriented to achieve daylight from North and South. East and West is protected to cut off glare. Buffers of the service shaft and bathrooms on east and concrete and glass with screen wall on the west protect the internal spaces from the heat gain. Power is generated through photovoltaic panels for the entire lighting load. Flat plate collectors for water heating system are a part of the design towards sustainability. Permanent finishes reduce the maintenance cost of the structure (Fig.2 &3).

Fig.2: Building Plan

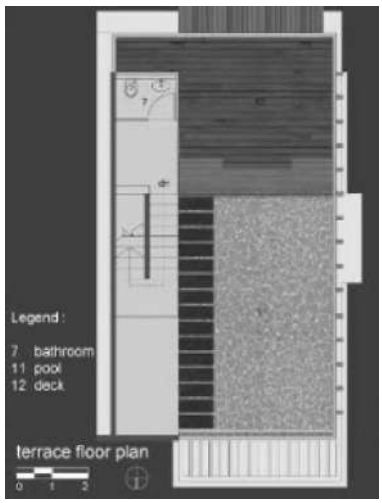

Fig 3. Koan residence, Pune – Different Views

Case Study 3: Zostel, Panchgani, Maharashtra

Located on a hilly terrain and a tight site, the hostel building intended for backpackers provides

an innovative solution to the site constraints, tight budget, availability of labour and tight timelines.

Fig. 4: Innovative use of old Recycled Bins

Old recycled containers have been put to use innovatively and aptly to counter the construction challenges faced on the hilly tight site. The containers were modified away from the site under critical supervision and measurement details and later driven to site to be positioned at various angles to take in the spectacular natural views from the sloping site. The recycled containers provided appropriate solutions for time and material management (Figs. 4 & 5).

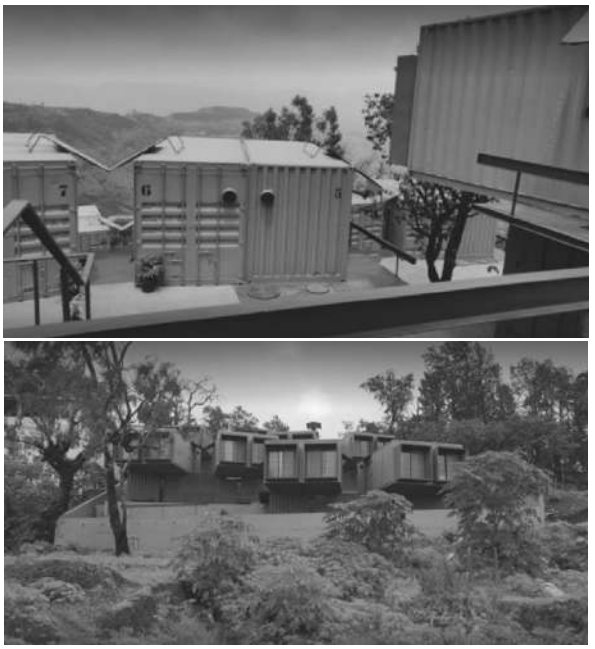

Fig.5: Innovative use of Recycled Bins

CONCLUSION

Advanced technology provides the notion of branding and image building. High technology in construction illustrates the culture of consumption. The construction intervention should be a responsive process rather than a reactive route. The construction techniques should most importantly be able to address the challenges faced on site rather than be a cause of the construction issues. The construction techniques should respond to the site constraints to provide a potential base for innovative solutions as a choice for practitioners towards long lasting sustainability.

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MODERN CONSTRUCTION TECHNOLOGY, MATERIALS AND MANAGEMENT TECHNIQUE FOR COST EEFECTIVE HOUSING

DR. J. BHATTACHARJEE*

Abstract

Housing inadequacy is largely felt in India at the level of low and middle income group. This is more so with continuous rise in cost of construction at all levels. This necessitates the use of appropriate and cost effective new technologies, new materials including latest construction Management Techniques in housing construction. The use of conventional construction materials and Techniques in the housing sector poses primarily two major problems, firstly they are comparatively time consuming and costly and secondly they cause pollution and disturb the environmental balance. To overcome this, there is a need for developing cost effective, durable housing using new technologies, new materials and modern management techniques.

In this paper deliberation has been made to identify and discuss about various types of technological development, new materials and management Technique for cost effective solutions. The present state of Housing and special needs of Urban India is also discussed. The various emerging technologies like adoption of panel Building System using steel mesh, polystyrene core and chipping concrete; Technologies using expanded steel mesh panel, polystyrene beads and alleviated concrete; Pre-stressed precast prefab technology using plastic form work; Monolithic concrete construction using aluminum form work; Pre-cast concrete panel; Industrialized –S system and GFRG/ Rapid building system technology etc. have been discussed in the paper. Further, New generation materials are coming up in construction industry and that may very well change the way we build now. The futuristic construction technologies like Self-healing concrete; Transparent aluminum; Aerogel insulation; Robotic swarm construction; 3D printed houses; Smart roads; Bamboo cities; Smart bricks; Vertical cities; and Pollution fighting buildings is also discussed in details.

INTRODUCTION

India is facing a huge housing shortage which is currently estimated to be more than twenty five million homes in the country, out of which, EWS (economically weaker sections) and LIG (lower income groups) account for 95%. In 2015, the Indian government launched the Housing for All mission with an aim to provide affordable housing to urban poor. It was proposed to build twenty million houses for the urban poor by the year 2022. To achieve this goal, the government and private real estate developers have launched large scale affordable housing projects all over the country.

However, the construction industry is facing issues with skilled manpower shortage and rising cost of construction materials. The cost of labor has gone up significantly and availability of construction workers particularly skilled one has become problematic. Furthermore, the pressure on developers has increased as customers are

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demanding on-time delivery of their homes with good quality construction work. Conventional construction methods is not able to exploit the advantages of mass housing and in the current scenario; it is evident that new construction technologies should be utilized to deliver homes fast with minimum labor and zero wastage of materials. Especially in Europe, after the Second World War, the housing shortage was solved by implementing new technologies like precast concrete construction. Precast concrete construction is a building method where building components are prefabricated off site on an assembly line using advanced tools and equipment and thereafter transported to the building site, where they are erected using building cranes. Precast concrete construction has evolved over the past five decades towards a flexible building technology, which is used in many infrastructure projects and building projects throughout the world. In India precast Concrete technology is introduced in recent past. Some projects of affordable group housing project with medium-rise apartment towers were constructed in Ghaziabad, Uttar Pradesh. The second project of an affordable group housing project with medium-rise apartment towers located in Bangalore, Karnataka, was constructed. The third project consisting of low-rise villas located in Greater Noida, Uttar Pradesh has come up. Many more is now coming up.

OBJECTIVES

Our main objective of affordable housing should be to tackle the needs of migrated people from rural to urban areas, essentially in search of job, which is the trend of day all over India. Due to rapid growth in the urban population, owning a house, which is a basic necessity, still remains a dream for many, in spite of several initiatives taken by the Govt. of India. While a number of programmes are being supported through Central and State Governments, Banking Sector, Housing Finance companies, Cooperative Initiatives, the houses remain in shortage and requirement particularly in urban areas continues to grow at a rapid pace, indicating the need for innovative and rapid measures to address the ever increasing demand. Constructing affordable houses with innovative technology within the reach of a common and middle income group at fast speed is one solution for providing roof to all in this era of diminishing resources and economy resulting into alarming hike in construction cost. Resolving housing shortages is a challenging job for country since at present conventional and traditional housing technologies are mostly used in actual construction and same is being taught in the engineering institutions. 'Housing for All' is the key issue of the day before the nation and, therefore, to implement this theme, the number of Seminars/Conferences is being arranged, where discussions are normally planned on sub-themes, like Comprehensive Planning Technique, Safety and Quality of Efficient and Affordable Housing; Prefabrication Plant and Equipment's; Role of CAD/STAAD and Other Computer Applications in Innovative Concept and New Technology; Mass Scale Housing Technologies; New Affordable Housing Techniques and Technologies; Innovative Building Materials for affordable housing.

AFFORDABLE HOUSING AND THE PRECAST TECHNOLOGY

The word affordable house itself meant for the people to buy houses at a reasonable price within their strength of income resources, it means the cost of construction and land must come down drastically compared to the current scenario. As far land is concerned Governments are providing lands for the Economically Weaker Section people, and also it is insisting developers to provide 10% of the building to EWS. But the million dollar question is the construction cost, as it can't come down drastically as it involves men, materials and machineries and the contractor has to allocate sufficient funds for all these activities. However, there is a way to reduce the cost of construction using Precast Technology and by which it can make the EWS people to afford to have their own houses.

One can see in all major cities of India, lakhs and lakhs of houses are unsold as the demand is so low and supply is plenty. This is mainly due to developers targeted the elite and higher middle-class sector people. Whereas, as per the Pradhan Mantri Awas Yojana (PMAY) scheme, there is demand for about 20 million housing units in rural and urban poor whose salaries range below 3.4 Lakhs p.a. If one keenly see the Indian income pyramid there

are 56% of people, who have been classified as EWS and about 30% of people have been classified as LIG.

Affordable house starts with the design phase itself, an integrated design approach by the client is very much essential during the early phase of the project, in which the client, architect, structural engineer and the Pre-caster need to sit together to design the houses in a modular concept. This kind of modular design of the houses helps the client to reduce the cost of the project to greater extent. The optimum sizes of the rooms and standardization of the precast elements will be decided during this phase. The perfect modular design will have more sharing of structural members and walls between each tenement with consideration of good ventilation, MEP services and all architectural requirements. A good modular design concept will definitely save 10 to 15% of the project cost. The productivity will be much higher in modular design, thus the tenements can be delivered on time. There are some indirect savings when the construction time is reduced, as we know that TIME = MONEY. It is observed based on various studies that Precast Technology can bring the cost down. In general construction cost depends upon the 3M – Men, Materials and Machineries which plays a big role which is decided by the 4th M that is the top Management.

Men: In Precast Technology the man power used is almost 1/10th in comparison with the conventional method of construction, as most of the works are done by machineries. When one can reduce the manpower, there is direct cost savings in labor component and there is some other cost savings such as lesser requirement of labor hutments, labor license fee, insurances, water, power, sanitary facilities, ESI, EPF charges etc. More than the above cost saving, the contractors will be relieved to have lesser supervisory staffs and avoid managing the huge labor's strength which itself a big challenge for them. Government can identify affordable house construction at rural areas for their current 100-day work scheme under NAREGA for rural people, which will create job generation for them and at the same time their services shall be used for good cause.

Materials: On the material saving, there are few items which most of the contractors ignore but it really has huge impact on the project cost. In precast technology, the shutters used are steel moulds, which can be used for more than 500 repetitions, whereas the conventional method of shutter made of plywood which are used to 6 to 8 repetitions and later it is scrapped for almost zero value or used as fire wood by the workers; whereas in steel moulds even after 500 repetitions, it can be scraped for 50% of the material cost. In precast technology, the steel consumption cannot be optimized, as the bar bending schedule for the entire project is done at the beginning stage of the project itself. In case the pre-caster chooses to go for two tier or three tier columns the column lap length happens only on the second or third floors. On the precast members such as walls, columns, beams, slabs, and staircase, the plastering shall be completely avoided as the surface itself is good enough to receive putty and paint.

Machineries: On the machinery part, precast technology requires suitable cranes for erection works, upon selecting the correct cranes for the project the contractor may be spending little more comparatively with the conventional method of constructions, As these cranes rental charges are expensive, it is advisable to make capital investment in order to reduce their impact on the rates or by deploying additional crane operator and operate the machine for 24 hours so that machinery rental charges is been halved and there will be a good increase in the productivity. When there is saving in material this little increase in cost will not have an impact in overall cost of the project. On site precast yard can be established for construction volume of over 5 lakhs square feet. On site precast yard can't be compared with the state of art precast plants as the efficiency will definitely differ. There are number of advantages of having onsite precast yard.

EMERGING TECHNOLOGIES

The various emerging technologies are brought out below:

1) Panel Building System using steel mesh, polystyrene core and chipping concrete

Materials used are meshes manufactured using high resistance steel bar of dia 2.5 – 5 mm, self-extinguishing polystyrene core and chipping concrete. This building system is a load bearing wall construction which is seismic resistant and thermally insulated. Buildings of any typology and architectural/structural ranging from most simple to most complicated ones could be constructed. The base element of this system is a modular panel composed of two electro – welded galvanized steel meshes having dia 2.5 – 5 mm joined by connectors, in the middle of which is suitably shaped foam polystyrene plate. This polystyrene is self-extinguishing foam polystyrene which is used as disposable foam and as an insulating layer. EPS is made of carbon hydrogen and 98% air.Once the panels are installed, they are anchored and finished with the application of light concrete on both the sides.

Salient features are good heat and sound insulation; Versatility in constructions; Lightweight but strong; Earthquake resistance; Resistance to Hurricane / tornado forces including blast explosion of 50 psi; Fire resistance; Cost effective; Rapid installation; Energy efficient; Environmental friendly - non-toxic and CFC free.

2) Technology using expanded steel mesh panels, polystyrene beads and alleviated concrete Materials used are expanded steel type of galvanized steel mesh panels, cast and expanded in continuous process from 1.6mm thick and 30 cm wide galvanized sheet coil and Alleviated concrete made up of cement, fiber, sand and expanded polystyrene beads (1-4mm). This system is entirely an on-site construction process. The concrete base and the foundations of the structure are prepared in a conventional manner by regular, poured, heavy concrete or alleviated concrete. In order to get good thermal insulation and good comfort from ground, it is advised to use at least one layer of alleviated concrete. The galvanized steel mesh panels are tied to the soldered wire mesh and to the iron rods in the base and in the foundations and assembled in accordance with the design of the house. The complete skeleton of the construction along with the roof is formed by fitting galvanized steel wire studs horizontally and vertically into each other. Once this procedure is completed, alleviated or light concrete is injected with a special concrete pump. The injected walls are then finished, leveled and smoothen from both the sides.

   Salient features are earthquake/hurricane/ tornado resistant; Fire and termite resistant; Cost effective; Minimal man power; Energy efficient and Environment friendly.

3) Pre-stressed precast prefab technology using hollow core slab, beams, columns, solid walls, stairs, etc Materials used are cement concrete steel strands and reinforcing steel. As the name says, these slabs, columns, beams, stairs, etc. are designed and manufactured in the factory shipped and erected at site. The structural frame is commonly composed of rectangular columns of one or more storeys height. The beams are normally rectangular, L-shaped or inverted T-beams. They are single span or cantilever beams, simply supported and pin-connected to the columns. The joint between the floors elements are executed in such a way that concentrated loads are distributed over the whole floor. This system is widely used for multi storeys buildings. Salient features are Cost saving; Savings on exterior painting and finishing; Increased in carpet area and Energy savings.

4) Monolithic Concrete Technology using Plastic Form Work Material used are M20 grade concrete wall, slabs and HYSD reinforcement of Fe415/Fe500 grade. In this technology walls and slabs are cast in one operation in specially designed light weight form/moulds. Concrete is poured in forms and once after the setting of concrete takes place the forms are removed which gives box like cubical structure of the required architectural design. This pre-designed formwork acts as some sort of assembly line production and enables rapid construction of multiple units of repetitive type. This technology reduces the cost of maintenance and repair

as compared to conventional system Salient features are Cost effective; Fire resistant and durable against earthquake.

5) Precast Concrete Panel: Material used are cement, aggregate, sand with additives, welded mesh and plates, polystyrene core. These load bearing panels are made of reinforced concrete with a polystyrene insulated core that varies in size from 40mm to 200mm depending upon the insulation requirements. These panels are moulded in a specially designed steel moulds under controlled factory conditions. Then the panels are removed from the moulds and stacked vertically for curing. Power and water conduits are installed in the panels during production. Due to cohesive structural design, this system requires only strip foundation for most of the buildings. The concrete panels can be designed with the strength of 5000 psi to have a stronger thinner and light weight panels as compared to concrete blocks or most poured concrete walls.This system takes two hours to prepare foundation and three hours for the panels to set. Salient features are reduction in labour cost; Tornado/Hurricane damage resistance; Fire resistant; Earthquake resistant and Energy saving.

6) Industrialized 3-S system: Material used are concrete, cellular light weight concrete slabs, and precast columns. This industrialized construction technology is based on factory mass manufactured structural prefab components conforming to norms of IS standards and BIS certification mark. In this system, dense concrete hollow column shells are used in combination with pre-cast dense concrete beams. The hollow columns are grouted with appropriate grade of in-situ concrete along with secured embedded reinforcement of appropriate size, length and configuration to ensure monolithic continuous resilient behavior.

7) GFRG/Rapidwall Building System Technology: Material used are gypsum plaster reinforced with glass fibers. This is a panel product suitable for rapid mass-scale buildings construction, originally developed and used since 1990 in Australia. These panels are presently manufactured to a thickness of 124mm.The main application is in the construction of walls, it can also be used in floor and roof slabs in combination with reinforced concrete. It is mandatory to provide embedded RCC horizontal tie beam over all the walls below the floor slab/roof slab. The panels may be unfilled, partially filled or fully filled with reinforced concrete as per requirement. These panels possess substantial strength not only as load bearing elements but also capable to resist earthquake and wind. Buildings up to ten storeys in low seismic zones can be designed with these systems. GFRG building systems can be constructed only with technical support or supervision by qualified engineers and constructors. Salient features are Water resistant; Fire resistant; Eco-friendly; Earthquake resistant and Reduction in construction cost.

8) Building Information Modeling: Building Information Modeling (BIM) is an emerging technology in the construction industry.

The concept of BIM is to build the project virtually, so that all facets of the project can be planned out before site construction begins. This level of pre-planning includes spatial coordination of all the materials, labor, and sequencing for the construction of the project, and then allows for the virtual planning of how the building will be used and reused by the proposed owner after construction. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder. BIM is very heavily based technology, especially software, to manage all the data and the process. It is extremely important to have good interoperability; the ability to manage and communicate electronic product and project data among collaborating software, individuals, design teams, and firms. If all members of the collaborating team can freely exchange data across different platforms and applications, every member of the team can better manage the BIM and project delivery process.

In addition, following futuristic construction technology can also be adopted for cost effective housing by using:

- Self-healing concrete
- Transparent aluminum
- Aerogel insulation
- Robotic swarm construction
- 3D printed houses
- Smart roads
- Bamboo cities
- Smart bricks
- Vertical cities
- Pollution fighting buildings

CONCLUSION

One of the dire needs in India is that of housing, especially for the lower end of the spectrum. The objective of achieving affordable low cost housing for masses needs to be realized in a holistic manner, through multi-pronged strategies. Mass affordable housing targets can be achieved by replacing the conventional methods of planning and executing building operation based on special and individual needs and accepting common denominator based on surveys, population needs and rational use of materials and resources, keeping green building concept in mind for sustainable development. Adaptation of new technology/methodology as discussed in the paper and use of new materials and re-use of materials in a cost effective manner is the key, as construction in our country is still primitive as compared to developed world. Lot of R & D project/work is required to meet the demand of mass population in an affordable manner. As brought out in the paper, it has become imperative to produce innovative building technology for various elements of construction and take recourse to alternative technology, considering the short supply, increasing cost and energy and considering environment consideration for traditional and conventional materials.

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MODERN TECHNOLOGIES AND CONSTRUCTION MANAGEMENT TOOLS IN CONSTRUCTION OF TALL BUILDINGS OF THE WORLD

DR. MUTYALA R. PRAKASH*, DR. ANARA SULTANALIEVA AND GURINDER KAUR*****

Abstract

One of the significant developments in construction industry on the onset of 21st Century is creation of World's tallest buildings and Towers by different countries. The attempt to construct tall buildings is supposed to serve the boosting of images of technocrats and their engineering talents besides commercialization. These buildings are expensive which might range at a value of US Dollars 1.4 to 2.0 billions per unit. Some of the countries tend to show their financial might by owning such buildings and declaring them as tallest in the World. The paper starts with citation of historical buildings which were constructed with multiple objectives, amongst which the height of the buildings and their Crown Structures played important role.

The Modern Technologies in buildings and invention of new construction management tools invigorated the builders and financiers to venture in creation of the new tall buildings. The competition to construct the new tallest buildings are supposed to be kept alive in centuries to come. The paper brings out narration of tallest buildings of those created in the recent past in countries like, Canada, U.S.A, Dubai, Saudi Arabia, and China. Some countries which have meager funds to invest, found their way to erect tallest statues of different kind. However the paper restricts the arguments only to the buildings which are either being used as museums, hotels or any other public place.

Further the authors attempted to list out the tools those are being used in construction of tall buildings and equipment. Towards the technical skills are concerned, the paper brings out the need for institutions which might train the people, as the ordinary skills in construction sector are not adequate and relevant.

INTRODUCTION

The Skyscrapers, Tall buildings, Tall High Towers, have similarities one way or other. "A Skyscraper" is a continuously habitable high-rise building that has over 400 floors and is taller than approximately 150 m (492 ft). Historically, the term first referred to buildings with 10 to 20 floors in the 1880's. The definition shifted with advancing construction technology during the 20th Century. Skyscrapers may host commercial offices or residential space, or both.

For buildings above a height of 300 m (984 ft), the term "supertall" can be used, while skyscrapers reaching beyond 600 m (1,969 ft) are classified as "megatall". The World celebrates, 3rd September as the global commemorative day for Skyscrapers, called "Skyscraper Day". Along with the growth and increasing popularity of Skyscrapers, new technologies have emerged in construction sector. What is the chief characteristic of the tall office building? It is lofty. It must be tall. The force and power of altitude must be in it, the glory and pride of exaltation must be in it. It must be every inch a

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proud and soaring thing, raising in sheer exaltation that from bottom to top it is a unit without a single dissenting line.

Based on the historical evidence, there were less number of failures than the successful completion and commissioning of Skyscrapers. It is important to know the reasons for cancellation of Skyscrapers worldwide, before we embark on the success stories of the same, it is said that, as every failure is a stepping stone to success. The paper limits its discussion to the reasons for cancellation but avoids the reasons for the Destruction, Attacks and Demolition of Skyscrapers though they are small in number, are not relevant to the focus of this paper.

A Skyscraper is not easy to build as the same has to fulfill certain basic conditions. The basic requirements in brief are 1. Economic; 2. Engineering and 3. Management. Though the intention and approval to build Skyscrapers are enabled by certain countries, Global Financial Crisis in different stages of World's economy hampered the construction of Skyscrapers, and led them to cancellations and delays.

Before discussing the complexity in construction of Skyscrapers, the paper attempts to highlight, World's renowned Skyscrapers at Table 1, having 150 meters or more as criterion. In the same Table 1 "Italic Fonts" show the details of Skyscrapers "Under Construction or Incomplete". In the Columns 1 & 5 indicate ranking of Skyscrapers constructed/under construction respectively. In the same Table.1 the top five Skyscrapers are mentioned as Sub-Table.

The Table 1 undisputedly drives the point home that the Skyscrapers are high potential segment for the future construction activity, and they tow up to the increasing pace of modern technologies in the business World. The Skyscrapers are growing in their physical numbers and innovations, which might dominate, different kind of economic activities. Those countries encountered with limited spatial areas for human habitat, landlocked, and desire to optimize construction cost over the revenues have no other better choice except opting for Skyscrapers.

Table 1: Status of Important Skyscrapers Constructed in the World Taller than 150 m (492 ft) and Skyscrapers Under Construction Shown in ITALIC (Columns 5 to 8)

Rank	City	Country	No of Scrapers	Rank	City	Country	No of Scrapers
1	2	3	4	5	6	7	8
01	Hong Kong	China	353	01	Shenzhen	China	49
02	New York	US	273	02	Mumbai	India	47
03	Dubai	Emirates	190	03	Dubai	UEA	43
04	Shanghai	China	157	04	New York	US	34
05	Tokyo	Japan	149	05	Shenyang	China	32
06	Shenzhen	China	148	06	Wuhan	China	30
07	Chicago	US	123	07	Toronto	Canada	27
08	Chongqing	China	118	08	Guangzhou	China	25
09	Guangzhou	China	108	09	Kuala Lumpur	Malaysia	23
10	Jakarta	Indonesia	85	10	Chongqing	China	22
11	Singapore	Singapore	85	11=	Melbourne	Australia	20
12	Shenyang	China	82	11=	Nanning	China	20
13	Bangkok	Thailand	81	13=	Guiyang	China	18

14	Chengdu	China	81	13=	Shanghai	China	18
15	Seoul	South Korea	80	15	B.Comboriu	Brazil	15
16	Toronto	Canada	60	16	Busan	South Korea	14
17	Kuala Lumpur	Malaysia	59	17=	Jakarta	Indonesia	13
18	Busan	South Korea	57	17=	London	UK	13
19	Nanjing	China	55	17=	Ningbo	China	13
20	Wuhan	China	44	17=	Xi'an	China	13
21	Panama city	Panama	52	21=	Bangkok	Thailand	12
22	Nanning	China	51	21=	Hangzhou	China	12
23=	Miami	US	50	23=	Hefei	China	11
23=	Tianjin	China	50	23=	Moscow	Russia	11
25	Istanbul	Turkey	45	25	Urumqi	China	10
26	Mumbai	India	44	26=	Makati	Philippines	9
27	Melbourne	Australia	43	26=	Riyadh	Saudi Arabia	9
28=	Beijing	China	41	28=	Chengdu	China	8
28=	Makati	Philippines	41	28=	Kunming	China	8
28=	Osaka	Japan	41	28=	Los Angeles	US	8
31=	Dalian	China	40	28=	Miami	US	8
31=	Mosco	Russia	40	28=	Nanjing	China	8
33	Houston	US	38	28=	Tianjin	China	8
34	Abu Dhabi	UAE	37	28=	Xiamen	China	8
35	Hangzhou	China	36	35=	Changchun	China	7
36	Doha	Qatar	35	35=	Gurgaon	India	7
37	Sydney	Australia	34	35=	Mexico City	Mexico	7
38	Incheon	South Korea	32	35=	Sydney	Australia	7
39	Changsha	China	29	39=	Beijing	China	6
40	Nanchang	China	28	39=	Changsha	China	6
41=	Suzhou	China	26	39=	Chicago	US	6
41=	Xiamen	China	26	39=	Gwangmyeong	South Korea	6
43=	Los Angeles	US	24	39=	Jinan	China	6
43=	San Francisco	US	24	39=	Suzhou	China	6
43=	Zhuhai	China	24	39=	Zhanjiang	China	6
46=	Jinan	China	22	39=	Zhuhai	China	6
46=	Qingda0	China	22	47=	Ankara	Turkey	5
48	Hefei	China	21	47=	Baku	Azerbaijan	5

49=	Dallas	US	20	47=	Colombo	Sri Lanka	5
49=	Liuzhou	China	20	47=	Dalian	China	5
49=	Macau	China	20	47=	Harbin	China	5
49=	Mexico city	Mexico	20	47=	Jeddah	Saudi Arabia	5
49=	Ningbo	China	20				
49=	Wuxi	China	20	TOP	WORLD'S FIVE	SKYSCRAPERS	EXISTING
55=	Boston	US	19	Rank	Cities	Country	Height
55=	London	UK	19	1	Dubai	UEA	828 m
55=	Seattle	US	19	2	Taipei	China	509 m
58=	Atlanta	US	17	3	Kuala Lumpur	Malaysia	452 m
58=	Calgary	Canada	17	4	Chicago	US	527 m
58=	Riyadh	Saudi Arabia	17	5	New York	US	443 m
61=	Fuzhou	China	16				
61=	Ho Chi Min	Vietnam	16				
61=	Kunming	China	16				
61=	Kuwait City	Kuwait	16				
65	Mandaluyong	Philippines	15				
66=	Frankfurt	Germany	14				
66=	Goyang	South Korea	14				
66=	Las Vegas	US	14				
66=	Pyongyang	North Korea	14				
66=	Taipei	Taiwan	14				
66=	Taiyuan	China	14				
72=	Brisbane	Australia	13				
72=	Manama	Bahrain	13				
72=	Philadelphia	US	13				
72=	Sao Paulo	Brazil	13				
72=	Taichung	Taiwan	13				
72=	Tel Aviv	Israel	13				
72=	Xi'an	China	12				
79=	Paris	France	12				
79=	Pattaya	Thailand	12				
79=	Sharjah	Emirates	11				
82=	Bogota	Columbia	11				
82=	B. Aires	Argentina	11				
82=	Jersey City	US	11				

82=	Nagoya	Japan	11				
82=	Zhengzhou	China	10				
87=	Daejeon	South Korea	10				
87=	Dongguan	China	10				
87=	Kuwasaki	Japan	10				

Table 2: Cancellation of Skyscrapers Construction

Year	Name	Country	Height	Reasons for Cancellation
2008	Russia Tower	Russia	610 m	Global Financial Crisis
1937	Palace of Soviets	Russia	-	1941 War
1989	The Miglin-BeitlerSkyneedle	US	-	Persian Gulf War
1990	Chicago World Trade Centre	US	700 m	Unknown
-	Nakheel Tower	Dubai	1000 m	Financial Problem
-	Grant USA Tower, Newark	US	550 m	Bankruptcy
-	Project 2000 Tower, Chicago	US	610 m	Unknown
-	1 New York Place	US	320 m	Unknown
2008	Vision Brisbane	Australia	-	Global Financial Crisis
-	International Commerce Centre	Hong Kong	574	Height Restriction
2010	India Tower, Mumbai	India	718 m	Disputes

CONCEPT OF CITIES IN THE SKY

In the past decade or two, several malls, high rise buildings were constructed. Some of them provide the spaces for offices, shops, restaurants, services, entertainment and banquet halls, but rarely residential spaces. The Skyscrapers tend to provide the residential units which complied with the requirement to be qualified as a "City". Skyscrapers have several floors vertically built towards sky as an advantage to gain the physical space unless the a Government restricts the height similar to a skyscraper. "Chicago World Trade Centre" by the United States. After the year 2020, most likely, the kilometer high skyscrapers might appear (Kingdom Tower Jeddah), in the world perfectly to be called as city in the sky as shown in Fig. 1.

A day is not far off, if some skyscrapers might facilitate growing food crops, and fruits in their terraces. Though it is fictional, it is not very far off to declare each of the skyscraper as the "city within the city" or "skyscraper local self government" within the Government with elected councilors to govern the skyscraper cities similarly to "cantonments" and "notified area administration" in India.

Fig. 1: Kingdom Tower – Jeddah. Cost $1.23 Billions. Height: 3,281 feet. Expected Year of Completion: 2020. Usage: Offices, Hotels, Residential, Observation and Retail Business.

DEPT OF HIVE SKYSCRAPERS

Sky scrapers have one biggest disadvantage known as 'access limitation' in to the building. The physical access to the different floors of skyscraper is limited to the ground floor. The people and physical items have to be vertically transported by single or double decker elevators as one can not climb the stairs, after 10 to 15 steps. The elevators have limitations in performing their trips and time taken per trip. Very recently, some business houses have proposed the concept of hive skyscrapers. The hive skyscrapers are built on hexagonal shear wall basement which symbolizes 'storage space advantage' of honey comb. The building will have several outlets and inlets as shown in Fig.2 in several floors of the building, so as to facilitate "drone flying machines". These machines are capable of flying with a load of 15 lb to 40 lb. Special infrastructure is provided for loading and unloading the products in building design for drone service.

Fig. 2 : Hive Skyscraper showing the Inlet and Outlet Windows for Drone Flying Machines in different Floors of Skyscraper.

The large business houses such as amazon and others have indicated their intent to set up their mega online stores or any other businesses in these hive-skyscrapers and it is believed that they got their patents for the "hive skyscrapers" construction. By any measure of the yardstick the skyscrapers which were once existed as the exhibition models and wonders to watch, are fast becoming activity centres and multi facet - human habitats. The companies involved in the courier services such as DHL, BlueDart and any other can reap good advantage to conduct their businesses in hive-skyscrapers.

Economic Viability

A skyscraper of 150 m tall having the mix of residential, commercial, and recreational components, might costs a builder, anything between $ 1 billion to 1.4 billions. In order to recover the funds invested in project, the building must have occupancy ratio of minimum 50 % round the year. Unless a skyscraper is located in highly urbanized and business area, it is very difficult to achieve the occupancy ratio which would plough back the yearly cash flows needed to recover the investment in these buildings. Several skyscrapers were cancelled during the global financial crisis which has direct link to the prospects of skyscrapers. It is observed from the Table 2 that those countries who had constructed several number of skyscrapers progressed economically better such as United States, China, Emirates and Japan. These countries foreign trade was much better as compared to others, thereby one may perceive the well conceived skyscraper is an asset for a country and not just decorative piece nor liability. On economic viability front, a skyscraper is generally evaluated based on the following simple economic system as stated in relation (1) and (2)

Price of Floor Area (Rupees /Sqm) = (Total Value of land area ÷ total floor area/Sqm) … (1)

Price of Floor Area ‹ Price of Land area. … (2)

Developments in Skyscraper Construction

Basic Structural Changes

The shear walls played an important role in buildings constructed by bricks, and cinderblock to bear the vertical and horizontal loads of the tall structure until early 1950's. In the case of tall buildings, the shear walls increase along with the height of the building thereby adding to weight of the building and occupied space which otherwise would have been available to the users.

The steel frame replaced the shear walls, constructed by bricks and cinder blocks. The drawback of steel frame construction said to be

apart from adding weight to building, they became inefficient if the skyscraper is more than 40 stories.

The new structural system using framed tubes came into skyscraper construction in the early 1960. Fazlur Khan and J. Rankine who was known as fathers of tubular frame structure, defined it as, "a three dimensional space structure composed of three, four or possibly more frames, braced frames, or shear walls, joined at or near their edges to form a vertical tube-like structural system capable of resisting lateral forces in any direction by cantilevering from the foundation". This technology was used by the builders of "Burj Khalifa" the first tallest building in the world today.

HEXAGONAL SKYSCRAPER

The hexagonal skyscrapers are preferred by builders, over other structural forms, in the design as they enable the substructure of the building to raise from bedrock having natural stability.It is easier to construct hexagonal shaped elevators which could accommodate more people and goods to transport. Geometrically, the hexagonal shapes are preferred if someone wanted to gain the space as compared to any other shapes in skyscrapers construction.

3D Printing in Construction in Skyscrapers

The 3D Printing in construction sector opened up new tools of construction management as shown in Fig. 3. The technology started in a small way in constructing one or two floors of buildings. The process involves the 3D printing equipment/ software and material inputs recommended by a laboratory. Incase of small buildings, only two persons are on the job. A 100 sqft house can be built in 24 hours having all the components except loose furniture. It is helpful system to replicate huge number of uniform shaped houses in shortest time. The first home was built in United States in the year 2017 and in India it is expected in the year 2020. The technical and cost details are not within the scope of this paper.

CRANE PRINTING TECHNOLOGY

The 3D Printing technologies enabled the newly innovated cranes which are capable of tow with the 3 D Printing Technology. The skyscraper builders, of 'Kingdom Tower', Jeddah claim that they are the first in the World to use 'Crane Printing' in constructing Kingdom Tower in Jeddah. The Cranes capable of 3D printing might revolutionize the construction technology especially those skyscrapers under construction. One may imagine the 3D printing technology will replace the most tedious and time consuming activities in skyscraper buildings such as construction of shear walls, plastering, fixing the windows, and flooring. Even it might be useful to maintain buildings to color & refurbish certain items cleaning and polishing walls.

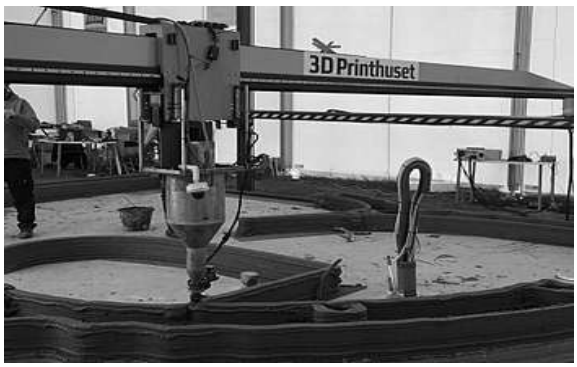

Fig.3: The 3D Printing Equipment

REVOLVING SKYSCRAPERS & AXIS MUNDI

Some skyscrapers under construction are adding a new feature in skyscrapers known as 'Axis Mundi' a pillar that connects earth to heaven and the four compass directions to one another. The resident can chose the orientation of their homes as per their choice by moving their homes independently. In simple terms it is revolving hotel where the entire floor can be rotated 360 degrees and may be fixed as per the choice of visitors on the floor.

GREEN SKYSCRAPERS AND SELF GENERATION OF ENERGY

Some of the skyscrapers tend to adopt decorative elements and extravagant finish under the guise of marketing gimmicks by the builders to attract customers. Such a move have severe environment damage potentials. The next generation of skyscrapers will focus on the environment including performance of structures, types of materials, construction practices, absolute minimal use of materials/natural resources, embodied energy

within the structure, and more importantly, a holistically integrated building system approach[5]. As many of the skyscrapers will accommodate habitats to live, the regulations of green buildings are applicable and certification in this regard might be voluntary or mandatory depending on the regulations of a country.

SKYSCRAPERS PARKING CONUNDRUM

It is important to note that the parking spaces for skyscrapers have become major issue and a conundrum. While the parking spaces for all, within the skyscraper is almost impossible, the builders have to look for parking spaces which might require larger area than the land area under the 'Skyscraper' having some what ridiculous situation, as one can not expect another mini skyscraper needed to be constructed for vehicular parking. Even drone and helicopters are no way to solve this tricky problem. In case skyscrapers develop self sufficient habitat within the structure, the dependency on parking might be partially solved if not fully.

CONCLUSION

The skyscrapers are attractive and hygienic to live. In reality the urban lands are expensive and more buildings to construct laterally may not be possible in cities having land lock problem. These cities have to construct the skyscrapers. The modern technologies, new construction management tools and global trade will enable more skyscrapers add in to the list.

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MODERN METHODS OF CONSTRUCTION TECHNIQUES

T.R. DAKSHAYANI* AND NISHA**

Abstract

Construction sector is one of the fastest growing sectors in the world. It is expected that construction industry have a projected growth rate of 4.5% for next several years making construction staffing the leading sector in wages and employment growth.

In today's world, construction field includes buildings such as underground structures to skyscraper; culverts to flyover bridges and many more. The cost of materials used for construction is growing very high because of scarcity of natural resources. Hence in this paper an attempt is been made to focus on various modern and fast growing construction techniques and its possible implementation with respect to economy and feasibility.

INTRODUCTION

The concrete industry embraces innovation and modern methods of construction (MMC) by offering concrete solutions which can be used to reduce construction time and promote sustainable development, as well as offering cost savings. A wide variety of modern methods of construction techniques and products have been developed that have completely changed the behavior of construction industry from what it was before. This change is amazing and is in the way to bring more and more developments in this sector. Modern construction methods are methods that are developed in construction industry with proper planning and design so that each project reduces the construction time, cost and maintain overall sustainability. There are many methods followed and constructed in the present scenario widespread. In this paper an attempt has been made to bring about the most famous and highly applied methods of modern construction as listed and explained below.

TYPES OF MODERN METHODS OF CONSTRUCTION

The different MMC used in construction field includes:

- Precast Flat Panel System
- 3D Volumetric Modules
- Flat Slab Construction
- Precast Concrete Foundation
- Concrete Wall and Floors
- Twin Wall Technology
- Concrete Formwork Insulation
- Precast Cladding Panels

Precast Flat Panel System

This method of construction involves the procedure of making floor and wall units off site. Once the panel units are made as per the design specification and requirements, they are brought to the site and placed as shown in Fig.1. This method is best suited for repetitive construction project activities.

The panels manufactured have the services of windows, doors and the finishes. This method also brings building envelope panels which are provided with insulation and decorative cladding that is fitted by the factory which can also be used as load – bearing elements. Also, floor and wall units are produced off-site in a factory and erected on-site to form robust structures, ideal for all repetitive cellular projects. This offers factory quality and accuracy, together with speed of erection on-site. This

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type of construction is normally called cross wall construction.

Fig.1: Precast Flat Panel System

3D VOLUMETRIC CONSTRUCTION

3D Volumetric construction (also known as modular construction) involves the production of three-dimensional units in controlled factory conditions prior to transportation to site. Modules can be brought to site in a variety of forms, ranging from a basic structure to one with all internal and external finishes and services installed, all ready for assembly and installed at site as shown in Fig. 2.

Fig. 2: 3D Volumetric Construction

The casting of modules uses the benefits of factory conditions to create service-intensive units where a high degree of repetition and a need for rapid assembly on-site make its use highly desirable. The transportation of the modules can be carried out in various forms or methods. This can involve the transportation of the basic structure or a completed unit with all the internal and external finishes, services installed within it, that the only part remaining is the assembly. The factory construction brings different unit of same product maintaining their quality throughout. Hence this method is best suited for repetitive projects so that rapid assembly of the products is possible. This modern method of construction offers the inherent benefits of concrete, such as thermal mass, sound and fire resistance, as well as offering factory quality and accuracy, together with speed of erection on-site.

FLAT SLABS

Wherever it is necessary to seal the partitions to the slab soffit as a reason of acoustic and fire concerns, the flat slabs are a desirable solution. When compared with other forms of construction, the flat slabs are faster and more economic in nature. The construction of flat slabs can be completed with good surface finish for the soffit, this enables to utilize the exposed soffits. The flat slab construction is also a means of increasing the energy efficiency as this allows the exploitation of building thermal mass in the design of ventilation, heating and the cooling requirements. Flat slabs are built quickly due to modern formwork being simplified and minimized. Rapid turnaround is achieved using a combination of early striking and panelized formwork systems. Use of prefabricated services can be maximized because of the uninterrupted service zones beneath the floor slab; so flat slab construction offers rapid overall construction, as it simplifies the installation of services. The flat slabs are structural elements that are highly versatile in nature. This is this versatility that it is used widely in construction. The flat slab provides minimum depth and faster construction. The system also provides column grids that are flexible. In addition to saving on construction time, flat slab construction also places no restrictions on the positioning of horizontal services and partitions.

Fig.3: Flat Slab Construction

This offers considerable flexibility to the occupier, who can easily alter internal layouts to

accommodate changes in the use of the structure. Post-tensioning of flat slabs enables longer and thinner slabs, with less reinforcement, and hence offers significant programme and labour advantages. Flat slab construction is shown in Fig.3.

PRECAST CONCRETE FOUNDATIONS

For the rapid construction of foundation, the precast concrete system can be employed. Here, the elements required for the construction of foundation are constructed separately in the factory (off site) and brought to the site and assembled. The manufactured product must have the assured quality as specified by the designer.

Fig. 4: Precast Concrete Foundations

The foundation assembled is mainly supported by concrete piles. During assembling, both the systems are connected together. These foundation systems helps in increasing the productivity, increase quality, decrease the soil excavation quantity. This is best suited for extreme and adverse weather conditions. These systems improve productivity, especially in adverse weather conditions, and reduce the amount of excavation required - particularly advantageous when dealing with contaminated ground. Fig. 4 depicts the Precast Concrete Foundations.

CONCRETE WALLS AND FLOORS

Concrete walls are mainly applied for seat walls, retaining wall, decorative exterior, and interior finishes. As per the latest technology, the concrete floors can be provided with good finish to provide smooth and attractive flooring. When compared with any other material, the concrete floors provide a wide variety of material for applications like acid-stained painted, radiant floors, overlays, and micro toppings. The concrete flooring can also be called as cement flooring. When compared with other flooring types, concrete flooring is affordable and maintenance is easy. Proper sealing of concrete flooring can be cleaned by a dust mop.

TWIN WALL TECHNOLOGY

The twin wall technology is a hybrid solution of wall system that combines the qualities of erection speed and precast concrete with the structural integrity of in-situ concrete. This type of wall system guarantees structural integrity and waterproof reliability for the structure.

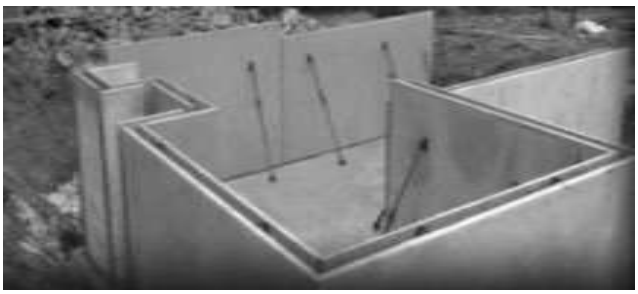

Fig. 6: Twin Wall Technology

The twin wall system has two walls slabs that are separated as shown in the Fig. 6. The two slabs are separated by a cast in lattice girders. The wall units are placed in the site. The twin units are propped temporarily. The wall units are later joined by means of reinforcing. The gap between the wall units are filled by means of concrete. This system of construction is faster than normal construction methods and economical. The twin wall system is mainly employed in association with the construction of precast floors.

INSULATING CONCRETE FORMWORK

The system of insulating concrete formwork (ICF) has twin walled panels that are either polystyrene panels or blocks are employed. These are built quickly to create the formwork as the wall of the buildings.

Fig.7: Insulating Concrete Formwork

The formwork that is made is filled with concrete. This concrete is factory produced that has quality assurance as of a ready – mixed concrete. Mostly the mix is ready mix concrete. Higher level of thermal insulation is provided by expanded polystyrene blocks. The concrete core will provide good robustness and better sound insulation.

Insulating Concrete Formwork (ICF) systems consist of twin-walled, expanded polystyrene panels or blocks that are quickly built up to create formwork for the walls of a building as shown in Fig. 7. This formwork is then filled with factory produced, quality assured, and ready-mixed concrete to create a robust structure. The expanded polystyrene blocks remain to provide high levels of thermal insulation and the concrete core provides robustness and good levels of sound insulation.

PRECAST CLADDING PANELS

The cladding system is the installation of a material over another that finally acts as a skin or a layer. This system of layer is not only intended for aesthetics, but it can help in controlling the infiltration of the weather elements.

Fig. 8 : Precast Cladding Panels

No kind of waterproof condition is provided by the cladding. Instead, the cladding is a control measure against water penetration. This safely helps in directing the water or the wind so that there is control of the runoff. This helps to prevent the infiltration into the building structure. Fig. 8 depicts the Precast Cladding Panels.

CONCLUSION

To be adopted by the industry on a widespread basis, volumetric construction needs to be seen to be providing benefits for house builders. At present other MMC approaches, such as panelized systems and sub-assemblies, are seen to be enhancing the build process by increasing the speed of construction and improving quality; given the concerns about full volumetric construction, these alternatives are providing solutions sufficient for many house builders' and housing associations' needs at present.

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CRACK MANAGEMENT IN BUILDINGS AND THEIR REMEDIES

AJAYA KUMAR HARIT*

Abstract

The construction industry in India has advanced leaps and bounds during the last 6 decades. Many marvels have been created all over the country but we have utterly failed in hiding the dampness caused in the ceiling of the roof slab, toilet and bathroom walls and the dampness in walls above floors at ground floors. These have in fact become challenges haunting both the Engineers and the Architects apart from the users of such buildings.

The paper deals with new technologies to address such issues encountered in buildings.

INTRODUCTION

The building industry is facing Two major challenges which are:

- Almost all failing waterproofing systems have become a major challenge for the construction industry. The falling concrete cover of roof slabs RCC is visible anywhere and everywhere even in new construction. This causes cracks in waterproofing layers above RCC slabs.
- Damp walls due to rising dampness above ground floor, trapped water in sunken slabs, toilet and Kitchen Walls.

Both the Challenges are discussed as under:

ROOF/TERRACES:

The Issue:

The prolonged entrapped moisture between the Roof RCC Slab and top finishing tiles/PCC on roof and terraces sets in a condition where the alternate dry-wet cycles lead to the oxidation process of steel, thereby increasing its volume. This increase in volume creates a stress on concrete cover over steel leading to de-bonding which ultimately leads to spalling.

This has led to a very grim and scary situation where we feel limited to:

- All round distress of RCC. structures eventually in 10-15 years of construction.
- Ironically the nodal agencies have lowered the age of RCC. from at least 200 years to less than 50years to rationalize the limitation.
- Health hazard due to dampness
- No long term SOLUTION in sight

The Study:

The author's study led to an answer to the repeated cracks development in the roof tiles,

This is the basic reason for failure of almost all waterproofing products till date. The significance of failure is all round distress of RCC ceiling of almost all buildings which is visible in the falling concrete cover.

It has been found that the grading course of almost all roofs i.e. between the RCC slab and top finishing tiles/PCC etc is wet. The moisture/water from this substrate is evaporated in warm weather. This creates a air pressure-an up thrust causing the weakest section of top layer, to develop crack/s to facilitate the release the hot compressed air. The crack so formed is created by lifting of the lower end (towards the slope). The lower section being lesser in thickness lifts creating a type of funnel for rainwater to get absorbed into the substrate

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thus rewetting it, acting, as a catchment. This phenomenon has been named as "The Hariton Effect".

Now that we had discovered the basic reason of non-structural cracks development, we now needed the crack management tool which is discussed as under:

Crack Management Tool:

The biggest challenge was the roof cracks development. The study of the phenomenon was done at Dehradun, Uttrakhand. Dehradun is a typical area which receives rainfall at least once in a week. The biggest crack development is observed with a sudden cloud formation in a hot afternoon and a sudden downpour (called 4 o'clock rain)-this causes a type of thermal shock-complimented by "Hariton Effect".

To counter the cracks, initially we created a chimney sort of arrangement at highest locations in the roof. This was a cumbersome process and backfired at some locations on account of maintenance issues. A product aquavent [R] for roofs conceived in 1996-97 and aquavent [W/M] for walls in 1998 and finally submitted for © and patent in 2016. The roof model was initially made of UPVC pipes, later in MS and finally in Aluminum, because of its good conductivity, paintbility and durability.

Finally the Standard Operating Procedure of this Tool is:

- Installation of AQUAVENT (Moisture release system) 1 per 40 Sqm.
- Injection grouting of cracks @ 1 -2 kg/Sq.cm pressure using grouts with bonding aids.
- Gravity Grouting in substrate with anti corrosive grouts to inhibit corrosion process.

WALLS

The basic issue with respect to the walls is capillary action. This is activated by :

DPC Failure:

The basic reason for this is neglecting/lack of understanding of the DPC layer/Plinth Beam i.e. Plastering across the Plinth Beam/foundation up to the brick wall neglecting the basics of DPC. (Damp proofing course). This connects the wet soil to the brick wall. The logical capillary action is activated leading to wet walls.

Many unsuccessful attempts have been made like coatings, masking reinforcements, tiles, PVC paneling etc. The dampness is seen to cross over even up to Roof ceiling across the tiles etc. (Provided to cover the damp areas).

Wet Sunken Slabs:

Here the foam concrete/filling of sunken slab once saturated by leakages from sewerage or water pipes and fittings transmits capillary action as in DPC leading to wet patches outside bathrooms, urinals etc. Waterproofing /coating is provided over the tiles etc periodically. This again cracks up, as explained above, leading to failure of waterproofing system.

This has been termed as 'Hariwon' effect discovered in 1998 while solving the matrix of DPC failure and rising dampness. The basic issue with respect to the walls is capillary action. This is activated by DPC failure. The basic reason for this is neglecting the DPC layer/Plinth Beam i.e. Plastering across the Plinth Beam/foundation upto the brick wall.

This connects the wet soil to the brick wall. The logical capillary action is activated. The wet walls resulted into peeling of painting, effervescence, saltpeter and even wearing up of plaster. The above has to be painted with waterproofing products, reinforcements, tiles, wooden, plastic paneling and re-plastering etc. All these products and practice have also failed to deliver, as, the dampness travels beyond the tiled area and even rises to the roof.

The phenomenon is transmission of moisture by capillary action from a highly saturated area to a lesser saturated area. This is termed "Hariwon Effect"

Management Tool

A systematic procedure has been developed to Counter the 'Hariwon Effect' in wall and sunken slabs as explained below. The wall model was initially developed in an earthen model with various

versions in 1998, UPVC in1999 and finally in Aluminum in 2016.

The Standard Operating Procedure is:

DPC failure:

- Installation of Aquavent (Moisture release system) 1 per Rmt along skirting.
- Injection grouting for creating a chemical DPC @ 1-2 kg/Sq.cm pressure using grouts and Soil stablizers at ground level.

Sunken Slabs:

- Installation of Aquavent (Moisture release system) 1 per Rmt along skirting/outerface.
- Injection grouting for creating a chemical DPC @ 1 -2 kg/Sqcm pressure using grouts
- Pressure Grouting of traps, chowkhats / doorframes, corners and hollow with anti corrosive waterproofing grouts to inhibit corrosion process.

AQUAVENT has been successfully used in india at :

- 1996: VSNL [Ahmed Satellite Station, Lachiwala, Dehradun, Uttrakhand]
- 1998:1KN Marg, NDC Tees January Marg, Base Hospital,New Delhi,.
- 2016: GPO. [A heritage building] Fort Mumbai.
- 2018-19:
- Birla House, New Delhi
- Birla House Jaipur
- Munjal Farms, Delhi
- Rainbow Mess, Triveni Mess
- 510-AD missile Unit [CE -DZ, Delhi Cantt.],
- Itrana Cantt- Alwar (2018-19),
- KV-OLF, Raipur Dehradun, Uttrakhand.
- Gurudwara Sahib: New Rajendra Nagar.

The advantages of using AQUAVENT®-roof model are:

AQUAVENT® will revolutionize the retrofitting and waterproofing world wide. The game changer is:

- Cost: Saves approximately 50-70% cost.
- Time: Saves upto 90% time as compared to the conventional way of removing everything upto RCC. slab and redoing.
- Guarantee: Upto 20 years already in India. [spotless]
- GREEN aspect:
  - No pollution
  - Saving trees, as, less mining for raw materials. Natural resources on account of sand, cement, stone grit, manpower. You save natural resources needed for re-grading etc.
  - No debris
  - Ease of working during the rains, as, dismantling not done.
  - The increase of Actual usable life of structures on account of being free of leakage/seepage.
  - A boon for restoration of heritage structures, as, no dismantling needed.

CONCLUSION

The study of the author on crack management and dampness check tools has led to introduction of AQUAVENT® - roof model and AQUAVENT-wall model which have been found to be quite effective in the projects implemented as shown in forgoing paras.

TECHNICAL SESSION II:
CONSTRUCTION MATERIALS

USE OF CONSTRUCTION AND DEMOLITION WASTE IN INFRASTRUCTURE PROJECTS

K.K. KAPILA* AND DR. MAHESH KUMAR**

Abstract

Use of Construction and Demolition Waste (CDW) aggregates is a widely accepted practice in many countries like, Denmark, USA, UK, France, Japan, etc. Delhi city produces about 3000 tonnes of construction and demolition waste every day. Re-utilization or recycling is an important strategy for management of such waste. Recycling of aggregate material from construction and demolition waste can help to reduce the demand-supply gap for aggregates, conserve depleting sources of good quality stone aggregates and decrease environmental degradation due to quarrying activities.

The paper gives details of two case studies – one in Ambala District and the other of Dumping Yard at Delhi and thereafter has arrived at some very useful conclusions.

INTRODUCTION

The Indian construction industry is highly labour oriented and accounts for approximately 50per cent of the country's capital outlay in successive Five Year Plans projected investment which continues to show a growing trend. Out of 48 million tonnes of solid waste generated in India, Construction and Demolition Waste (CDW) makes up 25 per cent annually. The percentage of India's population living in urban areas increased from 14per cent at the time of independence to more than 30per cent at present. Rapid economic growth leading to urbanization and industrialization is generating waste, which is adversely effecting the environment. Ban on mining by judicial courts have compelled for use of CDW.

Use of Construction and Demolition Waste (CDW) aggregates is a widely accepted practice in many countries like, Denmark, USA, UK, France, Japan, etc. Delhi city produces about 3000 tonnes of construction and demolition waste every day. Re-utilization or recycling is an important strategy for management of such waste. Recycling of aggregate material from construction and demolition waste can help to reduce the demand-supply gap for aggregates, conserve depleting sources of good quality stone aggregates and decrease environmental degradation due to quarrying activities.

Projections for construction material requirement by the infrastructure sector indicate a shortage of aggregates to the extent of about 55,000 million m^3. An additional 750 million m^3 of aggregates would be required to achieve the targets of the highway sector.Estimated waste generation during construction is 40 kg per m^2 to 60 kg per m^2. Similarly, waste generation during renovation and repair work is estimated to be 40 kg per m^2 to 50 kg per m^2. The highest contribution to waste generation comes from the demolition of buildings, bridges and culverts.

The pilot project for use of CDW envisages an appropriate collection mechanism for CDW generated in the city, its transportation to the designated processing site, proceeding of the waste and reclaiming of the land by filling up, levelling up, levelling and compaction.

The recycling process at the central processing unit shall consist of the following steps:-

- The CDW material after being received at the plant is first segregated for being processed.

**CMD, ICT Pvt. Ltd. & Chairman, International Road Federation **President, ICT Pvt. Ltd. New Delhi*

- The segregated CDW is then screened to remove loose soil and muck.
- The screened material is collected in the hand sorting section where bricks and concrete is separated.
- Bigger size concrete boulders are broken by help of a rock breaker.
- Further size reduction is done by the help of processing machines.

HIERARCHY OF TECHNIQUES FOR CDW TREATMENT

Hierarchy of techniques of CDW treatment is discussed as under:

Reduce

CDW generated shall be reduced to minimum of suitable approved strengthening techniques as available for distressed structures. These distressed structures shall be regularly monitored to check the default and timely repair or remedial measure may reduce the CDW.

Reuse

The next step shall be how best these CDW are reused using their potential in them. These CDW are generally categorized into different groups.

Recycle

When it is not possible to reduce and reuse the damaged concrete components, these shall be crushed/ broken into small pieces and processed, staggered and graded into different sizes so that their best potential could be used.

Dispose

When CDW do not find any use in above three categories, these shall be disposed to suitable place after getting due approval of the concerned agencies taking care of environment i.e. air, earth or ground water etc. so as not to pollute them. For example, material passing 75 micron containing clay or other organic matter may be disposed of until these are found of some suitable use.

Multiple case studies have been done so as to arrive at definite conclusions and formulations for future use:-

CASE STUDIES

Case Study of Ambala District

No special equipment for production of Recycled Concrete Aggregate (RCA) was used and study was done based on CDW available at Ambala. The entire process basically involved three steps:

- Breaking the bigger concrete blocks / slabs into the size of 6 inch to 8 inch so that the same can be fed to the stone crushers.

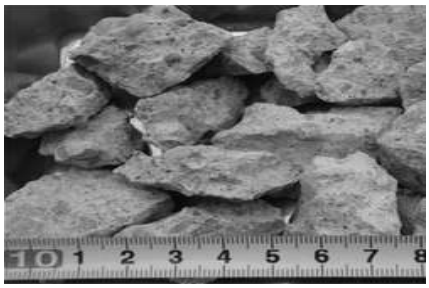

Fig. 1: Breaking of Bigger Concrete into Small Pieces

- The second step will involve crushing of broken blocks into RCA of required grade.

Fig. 2: Crushing Broken Blocks

- The third step is to produce high quality aggregate which will be achieved by mechanical grinding, heating, rubbing and eccentric rubbing method.

Fig. 3: Production of High Quality Aggregate

The RCA was produced manually by breaking of concrete in two steps:

- Breaking into smaller pieces 150mm to 200mm with the help of heavy hammer
- Breaking into required sizes of 20mm and below with the help of routine manual process as in the case of WBM material

LABORATORY INVESTIGATIONS

Around 400 kg of material of 20mm, 10mm and fine aggregate was produced for laboratory investigations.

- Water absorption test
- Impact value test
- Specific gravity test
- Flakiness andElongation index
- Sieve analysis
- Then, the Comparison of the properties of RCA with Fresh Aggregates was done.

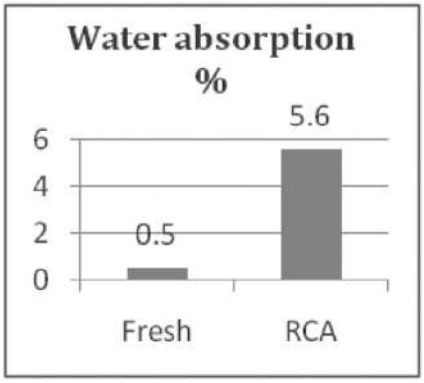

Fig. 4 : Water absorption%

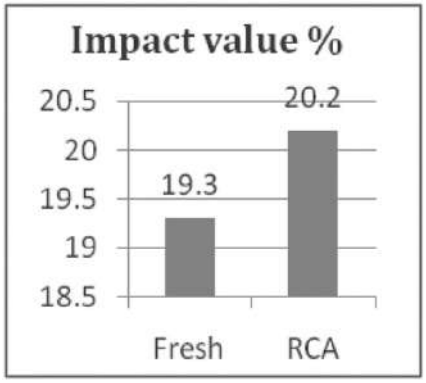

Fig. 5: Impact Value%

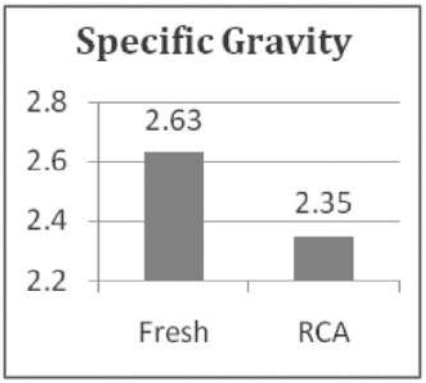

Fig. 6 : Specific Gravity

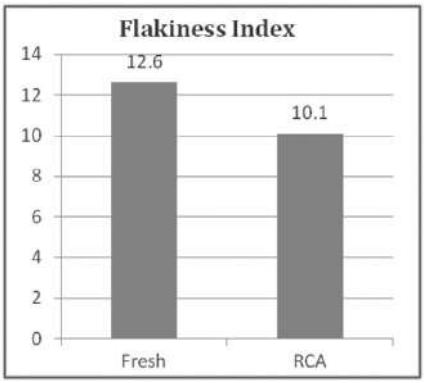

Fig.7 : Flakiness Index

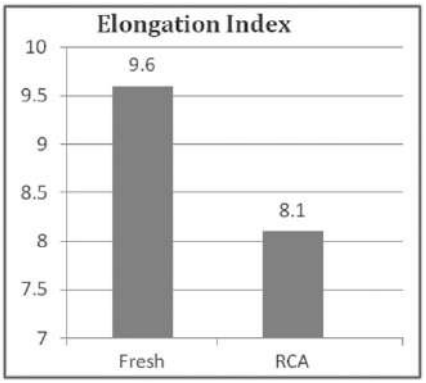

Fig. 8 : Elongation Index

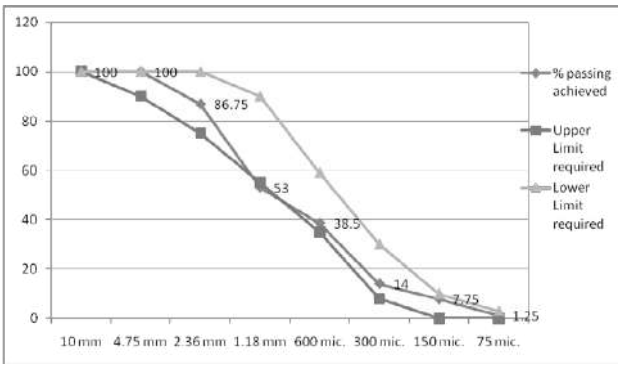

Fig.9 : Fresh Fine Aggregate (Coarse Sand) – Particle size sieve Analysis

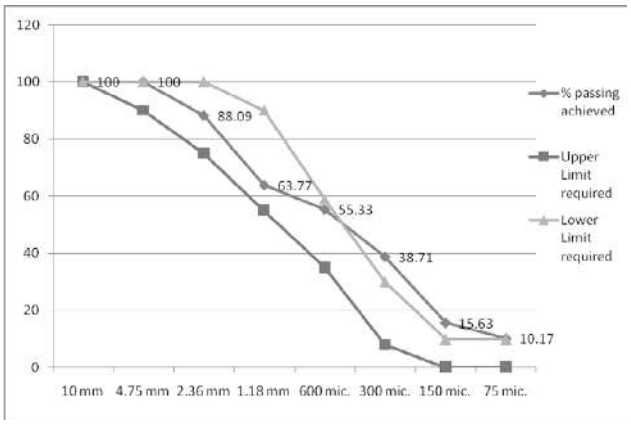

Fig.10 : Fine Aggregate (RCA) (Coarse Sand) – Particle size sieve Analysis

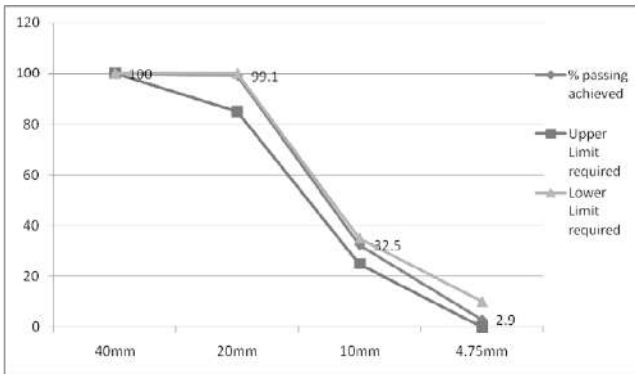

Fig.11 : Fresh Coarse Aggregate – 20mm nominal size – Particle Size Sieve Analysis

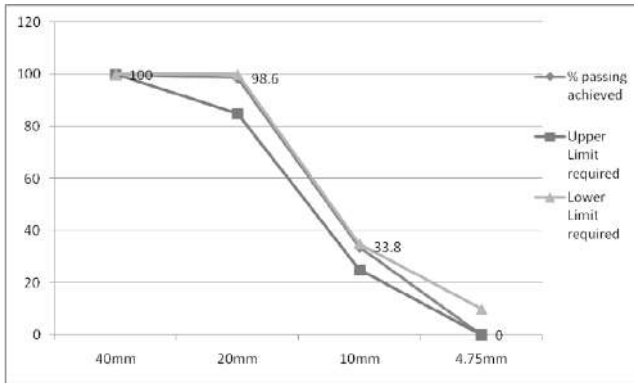

Fig. 12 : Coarse Aggregate (RCA)-20mm nominal size – Particle Size Sieve Analysis

PRODUCTION OF CONCRETE USING RCA

The following trial mixes of M40 Pavement Quality Concrete (PQC) were carried out using different percentages of RCA i.e. 0 per cent (All fresh aggregate), 30 per cent, 40 per cent, 50 per cent and 100 per cent (All RCA).

The Production Methodology in concrete using RCA is as below:

- The job mix design for M40 PQC was used for all the above trial mixes and same quantity of admixture was used to produce trial mixes having different percentages of RCA.
- By preparing various mixes of concrete with different percentage of RCA, no recycled fine aggregate has been used keeping in view the fact that Recycled Fine Aggregate has large percentage of fines i.e. 38.71per cent, 15.63per cent and 10.17per cent on 300 micron, 150 micron and 75 micron respectively, whereas the fresh aggregates have a percentage of 14per cent, 7.75per cent and 1.25per cent respectively as per tests based on sieve analysis.
- The fine aggregate produced by recycling of old concrete has lot of fine particles passing 300 micron sieve, which is a high quality inert material having high silica and can be a substitute of filler material and for fine aggregates. The recycled fine aggregates can also be used for preparing cement mortars but with greater control because of high percentage of fine material and it is recommended that not more than 30per cent of fine RCA should be used in preparation of cement mortars.
- The trial mixes of M40 pavement quality concrete (PQC) were carried out using different percentages of RCA.
- Results of six test cubes of each trial mixes were prepared and 7 days / 28 days compressive strength were tested and their results have been shown in Fig. 13.

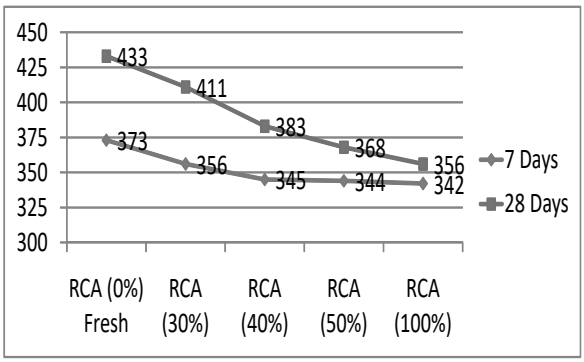

Fig. 13: Comparison of compressive strength of Cement Concrete M-40 (PQC)

Besides above comparison, the other significant comparison between other properties of concrete using RCA and fresh or natural aggregate depending upon the percentage of RCA used is as given below:

- Reduction in flexural strength is between 0 to 15 per cent.
- Reduction in tensile strength is between 0 to 17 per cent.
- Reduction in bond strength with steel is between 0 to 15 per cent.
- Reduction in shear strength is between 0 to 18 per cent.
- There are certain limiting factors in the entire production and evaluation process:
  - The RCA has been produced manually. Resulting that good to medium quality of RCA has been produced
  - The manual production of RCA is similar to the process of producing aggregate by crushing with cone crusher
  - The quality of RCA when produced with jaw crusher which are most commonly used for producing aggregate may not be as good as produced manually or by cone crusher

COMPENSATION OF STRENGTH

From the Fig.13, it can be seen that reduction in strength, if 100 per cent RCA is used is about 18 per cent in M-40 concrete. This reduction in strength varies with the grade of concrete. Higher the grade of concrete, higher is the reduction in strength. This reduction in strength can be compensated by adding additional cement says; an addition of around 25 and 50kg of cement and reducing a minor quantity of water cement ratio to the tune of 0.02 to 0.03.

CASE STUDY OF DUMPING YARDS AT DELHI

CDW dumped at dumping yards in Delhi mainly consisted of demolished building rubble having particles of different sizes – Big sized chunks as well as finely crushed material were found to have been mixed. So it was decided to crush and sieve the sample to make it suitable for laboratory investigations. One truckload of CDW (about 6 tons) was collected from CDW dumping yard and the material was got crushed from an aggregate crushing plant in Delhi-Haryana border. The crushed CDW was sieved using mechanical sieving screens available at the aggregate crushing plant and separated into three fractions as given below:

- CDW coarse aggregate particles – passing 20mm sieve and retained on 6.3 mm sieve (Comprising about 42 per cent of the material crushed).
- CDW aggregate – Jeera size particles (6.3 mm nominal size – About 30 per cent of crushed material).
- PowderedCDW (About 28 per cent of crushed material)

CHARACTERIZATION OF CDW

Examination of CDW aggregate sample after crushing (passing 20 mm and retained on 6.3mm) showed that typically, it consisted of about 22 per cent (by weight) of cement mortar/tile pieces, 14 per cent (by weight) were brick pieces and the rest, i.e. 64 per cent consisted of stone aggregates (Delhi quartzite). The chemical composition of CDW showed that silica (about 82 per cent) and alumina (about 6 per cent) are the main components and pH value was about 9.78. CDW aggregate samples were then subjected to various tests as per relevant IS codes of practice.

PHYSICAL PROPERTIES OF CONSTRUCTION AND DEMOLITION AGGREGATES

The specific gravity of CDW aggregates was found to be 2.30, which is lesser than specific gravity of conventional hard stone aggregates used in road construction. Generally specific gravity of aggregates used in road works varies from 2.60 to 2.85. Lower value of specific gravity of CDW aggregates indicate lower strength of CDW aggregates and it may probably be attributed to presence of brickbats, which are porous. When CDW aggregates are further crushed to either Jeera

size (less than 6.3 mm) or powder form, the specific gravity of such a material increases to about 2.67.

Water absorption of CDW aggregates was found to be about 4.50 per cent, higher than 2 per cent limiting value. Further it was noted that water absorption of Jeera size CDW particles as well as powdered CDW was quite high, at about 13 to 14.8 per cent. This may be because while crushing, all most all brick particles tend to get powdered when compared to stone aggregates. This higher quantity of brick particles in Jeera size aggregates and CDW powder would contribute to increase in water absorption.

Particle size distribution curves of different CDW fractions are shown in Fig 14. The sieve analysis test showed that powdered CDW comprises of sand size particles with very low fines content (low percentage of particles finer than 75 micron sieve). Cu and Cc value of powdered CDW were found to be 6.4 and 1.0 respectively. Thus this material can be classified as 'SW' as per Unified soil classification (IS Classification).

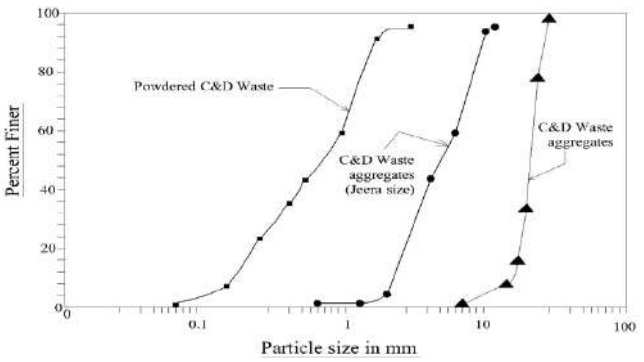

Fig 14: Particle Size Distribution of CDW

ENGINEERING PROPERTIES OF CDW AGGREGATES

The test results relating to engineering properties of CDW aggregates are given in Table 1. From Table 1, it may be seen that unit weight of aggregates in loose and compacted state were found to be 1280 and 1650 kg/m^3. This value is considerably lower than unit weight of conventional hard stone aggregates. The aggregate crushing value of CDW aggregates was found to be 37 per cent. Ten per cent fines value of CDW aggregates was determined separately for stone chips, brickbats, mortar pieces as well as representative CDW sample (comprising of all these fractions). As expected, ten per cent fines value of brickbats and mortar pieces are very much on the lower side (Table 1).

Table 1: Engineering Properties of CDW Aggregates (20mm to 6.3mm)

Property	Test Result	Permissible limits
Unit weight (CDW aggregates) – Loose state (kg/m^3) Compacted state (kg/m^3)	1280 1650	-
Aggregate crushing value (%)	37	-
Aggregate impact value (%)	33	30% (Max)
Ten per cent fines value (CDW aggregate representative sample)	45 kN	50kN(Max)
Ten per cent fines value (CDW comprising of stone chips only)	98 kN	-
Ten per cent fines value (CDW comprising of mortar pieces only)	24 kN	-
Ten per cent fines value (CDW aggregate comprising of brick bats only)	25 kN	-
Soundness (%)	1.6	12% (Max)

Aggregate impact value (AIV) of CDW aggregate sample was found to be 33 per cent. Generally for aggregates to be used in road construction, AIV should be less than 30 per cent. Hence CDW aggregates can be considered as a marginal material. The higher value of AIV may be attributed to presence of brickbats and mortar pieces in CDW aggregates. To further study the AIV characteristics of these materials, CDW was segregated into stone chips, brickbats and mortar pieces and AIV test was carried out separately on these individual samples. AIV tests on soft aggregates can be carried out as per IS 5640. The test procedure as per this code, stipulates that sample passing 12.5 mm sieve and retained on 10 mm sieve should be immersed in water for 3 days before subjecting it to impact test. Accordingly all the three samples were immersed in

water for three days and tested. To further study the effect of soaking on AIV results, CDW aggregates soaked in water for 24 hours as well as oven dry aggregates were tested. The results of these AIV tests are given in Table 2.

Table 2: Aggregate Impact Value of CDW Constituents

Constituents	Testing Condition	Impact Value (%)	Permissible limits as per MORTH
Stone Chips in CDW Aggregate	3 days of soaking	29.3	
	1 day soaking	28.6	
	Dry	26.0	30 per cent (Max)
Brick bats in CDW Aggregate	3 days of soaking	46.4	
	1 day soaking	45.0	
	Dry	42.2	
Mortar pieces in CDW Aggregates	3 days of soaking	46.5	
	1 day soaking	45.2	
	Dry	51.3	

From these results it can be seen that brickbats and mortar pieces have a high aggregate impact value in dry state itself. Soaking in water further degrades such aggregates and marginally increases the AIV. The stone chips in CDW mainly comprise of Delhi Quartzite and hence they have aggregate impact value of about 26 per cent in dry state, which increases to 29.3 per cent after 3 days of soaking.

Soundness test was conducted to determine the resistance to disintegration of aggregates by using saturated solution of sodium sulphate. This test furnishes information helpful for judging the soundness of aggregates subjected to weathering action. The test indicated a weight loss of 1.6 per cent after 5 cycles of alternate immersion in the Na_2SO_4 solution and drying. As per the IS: 383, weight loss after 5 cycles should not exceed 12 per cent. Thus, it can be inferred that the CDW aggregates satisfy the soundness test requirement.

ENGINEERING PROPERTIES OF POWDERED CDW

The density of compacted layer is one of the important factors, which controls strength properties. From the results tabulated in Table 3, it may be noted that standard proctor compaction test conducted on CDW powder yielded MDD value as 1.75 gm/cc and OMC as 12.5 per cent. Modified proctor compaction test conducted on the same material showed MDD to be 1.93 gm/cc and OMC to be 10.5 per cent. The density and water content relationship curves obtained were found to be relatively flat. The MDD values obtained are comparable to MDD values of soil particles of similar gradation.

Table 3: Engineering Properties of Powdered CDW

Property	Value
Modified Proctor Compaction Test	
Maximum Dry Density (MDD) (gm/cc)	1.93
Optimum Moisture Content (OMC) (%)	10.5
Standard Proctor Compaction Test	
Maximum Dry Density (MDD) (gm/cc)	1.75
Optimum Moisture Content (OMC) (%)	12.5
California Bearing Ratio (Soaked), (%)	74
Direct Shear Test – Angle of internal friction (Ø)	50^0
Cohesion (c)	6 kN/m^2
Liquid limit (%)	31.0
Plasticity index	Non Plastic
Permeability (cm/sec)	1.86×10^{-4}

Powdered CDW was found to be non-plastic in nature and hence could not be rolled into threads to determine its plastic limit. The coefficient of permeability of powdered CDW was found to be 1.86×10^{-4} cm/sec (Table 3). This value of permeability indicates that it is a free draining material and has potential for its utilization in sub-base layer of infrastructure projects. Powdered CDW was found to be having a high angle of internal friction equal to 50^0. California Bearing Ratio (CBR) of powdered CDW compacted to MDD and tested after four days of soaking, was found to be as high as 74 per cent.

ANOTHER CASE STUDY

Coarse aggregates from the 15 years old concrete from concrete road was taken and coarse aggregates were manufactured by crushing with Jaw Crusher. The proportion of 20 mm : 10 mm was 60per cent : 40per cent. Cement used was PPC and was taken having 3 dayscompressive strength = 171 kg/cm^2 and 7 dayscompressive strength = 221 kg/cm^2. Concrete mixes were designed at Water Cement ratio 0.38 for M 35 Grade concrete as per IRC: 44-2008 (Guidelines for Cement Concrete Mix Design for Pavements). The test results of both coarse aggregates after recycling and natural coarse aggregates are given in Table 4.

Table 4 :Test results of Recycled and Natural Aggregates

Property	Recycled Aggregate	Natural Aggregate	Variation
Impact Value (%)	29.9	24.7	+ 21%
Crushing Value (%)	35.7	26.5	+ 35%
Loss Angles abrasion value (%)	50.2	32.3	+ 55%
Specific gravity	2.45	2.63	- 7%
Bulk density Kg/M^3	1530	1600	- 4%
Water absorption 24 hours %	4.7	0.4	-11 times
Flakiness Index (%)	15.6	36	- 57%
Elongation Index (%)	17.5	24	-27%
Fineness Modules	--	2.35	

Test results carried out with Coarse Recycled aggregates and Natural Aggregates in both the cases aregiven in Table 5 to Table 7.

Table 5: Test Results of Concrete Mix Design

Property	Recycled Aggregate	Natural Aggregate
Slump	15 mm	12 mm
Flexural Strength	35 kg/cm^2	35 kg/ cm^2
Compressive Strength	M 35	M 35
Water Absorption	3.5% in 1 hr.	0.4% in 24 hr
Cement	500 kg	500 kg
20 mm + 10mm	1003 kg	1049 kg
Sand	635 kg	635 kg
Water	190 + 39	190 +8
Specific Gravity of sand	2.45	2.63
Specific Gravity of Cement	2.62	2.62
Specific Gravity of Concrete	3.0	3.0
Density of concrete	2220 Kg/m^3	2400 Kg/m^3

Table 6: Comparative Test Results of the concrete made with Recycled aggregates and Natural Aggregates

Property	Conventional Concrete	Concrete with Recycled Aggregate	Variation
Compressive Strength, Kg/cm^2	160 at 3d	132 at 3d	- 17
	269 at 28d	245 at 28d	- 9
	385 at 90 d	371 at 90d	- 4
Flexural Strength, Kg/cm^2	34	29.5	- 13
Tensile Strength, Kg/cm^2	26.6	22	- 17
Bond Strength with steel, kg/cm^2	40	36	- 10
E value in compression, kg/ cm^2	280000	200000	- 43
E value in Tension, Kg/cm^2	320000	270000	- 16
Shear Strength, Kg/cm^2	19.5	23	+ 18
Drying shrinkage percentage	0.04	0.067	+ 67
Loss on abrasion, percentage	0.13	0.16	+ 23

Table 7: Durability Test Results of Convention and Recycled Concrete after 90 Cycles

Durability Test	Conventional concrete in per cent	Concrete with recycled aggregate in %	%
Compressive Strength continuously immersed for 90 days	100	100	0
Compressive Strength, Heating –Cooling, for 90 days	95.8	96.6	+1
Compressive Strength, Freezing and Thawing for 90 days	103	124.1	+ 20
Compressive Strength Immersion in sulphate solution and heating in 90 days	43.1	58.6	+ 36

CONCLUSION

CDW is a material having some of its strength properties slightly lesser than the specified limits as per various specifications. However at the same time, it is non-plastic, permeable and its strength can be improved . Hence CDW can be adopted for various infrastructure projects in different forms. The major conclusions are given below:

- We may use mobile crushing plant and sieves to get required quality of graded crushed aggregates.
- Construction and Demolition aggregates can be used for partial replacement of conventional hard stone aggregates used. Laboratory tests showed a decrease of about 12+ to 28 per cent of compressive strength of concrete mix depending on use of equipment for crushing. Hence, while designing concrete pavement using CDW aggregates, proper mix design using the available CDW aggregates and conventional hard stone aggregates is to be carried out and replacement of conventional aggregates by CDW aggregates can be restricted to about 35 per cent of conventional aggregates.
- Some of the general observation regarding use of RCA (100 per cent), compared to concrete with natural aggregate, compressive strength is decreased up to 25 per cent, flexural and split tensile strength up to 10 per cent is decreased, there is increase in drying shrinkage and creep up to 50 per cent, increase in water absorption up to 50 per cent. It is generally accepted that when natural sand is used, up to 30 per cent of natural crushed coarse aggregate can be replaced with coarse recycled aggregate without significantly affecting any of the mechanical properties of the concrete for grade upto M40.
- It has also been observed that if natural coarse aggregate is replaced 100 per cent by RCA, using 100 per cent natural sand and increasing 1 bag of cement (of 50kg each) per cubic meter of concrete, strength reduction as compared to conventional concrete with natural aggregates could be avoided.
- Flexural strength and modulus of elasticity of RCA concrete are proportional to compressive strength of recycled concrete aggregate.
- Drying shrinkage and creep of RCA concrete may be higher than in natural aggregate concrete. However, the values seldom fall outside the limit permitted in structural codes, and up to 20 replacements can give comparable results as in natural aggregate concrete.
- RCA concrete tends to be less resistant to those deleterious reactions which are dependent on fluid transport into concrete, mainly as a result of increased permeability. Chloride ingress is more rapid. Abrasion resistance is lower. RCA concrete has, however, better resistance to carbonation than natural aggregate concrete.
- Crushed CDW can be utilized as a fill material for construction of embankment. The side slopes of such embankments should be protected against surface erosion. Efforts should be made for adequate compaction of the layers. CDW after crushing can be used for sub-grade construction.
- Stabilized CDW mix (mixture of CDW aggregates and CDW powder) admixed with about 5 per cent of cement or similar material as accredited can be used for sub base course construction in infrastructure projects.

Construction and Demolition Waste (CDW) material should be analyzed for an appropriate testing and results studied before being put to use on a large scale. An appropriate methodology has to be evolved for its use.

WOOD – HONEYCOMB SANDWICH CONSTRUCTION

SHIVANGI AJMERA* AND DR. ALOK RANJAN**

Abstract

The trend towards modern technologies in the built environment is especially important in the construction industry, where it has been embraced by the architects and civil engineers. Nowadays, there are constant innovations in the building industry, resulting enormous products of building materials available in the market. These new materials introduce different distinctive practical application for designers. Wood is considered as one of the most versatile raw materials especially in the construction/ building sectors, despite of having several substitutes like plastic, steel, aluminium etc. The consumption of industrial wood has risen over the last decade in every region of the world. It has been estimated that the present demand for industrial wood in India is 54 million cubic meters, while the availability is estimated as 30 million cubic metres.

To meet the growing need of demand and supply, R&D support is very much needed to provide the acceleration to assure the growth and prosperity of wood in future. The study aims to understand how advancement in framework structure of the wood can help make it lightweight and hence reduce its consumption.

INTRODUCTION

Since ancient times, being second to stone, wood has been used as a building material for thousands of years. In spite of inherited complex chemical properties, human beings have successfully harnessed the unique characteristics of wood to build a seemingly unlimited variety of structures. India has made an impressive economic growth, which is quite evident from the increase in income of people, resulting into increase in consumption of wood and wood products such as furniture, construction timber etc.there are large gaps between the demand and supply of forest products due to reduced supplies and increasing demand. This has resulted in increase in imports of timber and timber related products.

The information on production of wood and timber in India is scattered. As per the estimates of Forest Survey of India (2011), while the annual production from the natural forests is quite low, the production from the 'Trees Outside Forest (TOF)' is much higher. The Forest Development Corporations (FDCs) have been producing the major part of the total timber produce from the government forests approximately 65-66% of their requirement according to the estimation from the available figures. Most of the industrial wood in India is produced from outside government forests and agro forestry/farm forestry in the country. Interestingly, a large section of total production of Industrial wood in India is sourced from unknown or unregistered sources (more than 35%). Such sources may include illegally harvested wood and reclaimed wood. Imports contribute about 8% among roundwood sources.[1]

Table 1: Production of Timber in India (Million Cubic Meters per year)

Sources of Wood in India	Volume (million cum)
Total Estimated Production of Wood from Natural Forests	3.175
Annual Production of Wood from Trees outside Forests (TOF)	44.34
Total	47.51

Sources: State of Forest Report, Forest Survey of India, 2011, "Forest Sector Report India, ICFRE, 2010

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Despite having 21.34 per cent of the country's total geographic area under natural forests, it has a limited role in meeting this growing demand. It contributes just 6.4 per cent—about 3.17 million cubic metres (cum) of the demand, according to the State of Forest Report 2011 (this is the latest estimate available) published by the Forest Survey of India. Trees outside Forests (TOF), including the agro-forestry, is meeting timber demand much more than natural forests. Currently, 44.34 million cum of timber is harvested from this source annually as shown in Table 1. The growing stock (GS) of trees under agro-forestry is approximately 70 per cent of the total GS of the TOF.

As far as the consumption of wood is concerned, fuel wood alone amounts to be approximately 90% of the total wood production in India. According to FSI (2011), there are 3 major industrial sectors for wood consumption – House construction, Furniture and Agricultural implements[1] as shown in Table 2 and Fig. 1&2.

Table 2: Consumption of Wood in India

Consumption Category	Units	Value
Construction, Furniture and Agricultural Implements (RWE)*	Million Cubic Metres	48
Plywood and Panel**	Million Cubic Metres	8.3
Paper, paperboard and newsprint	Million Cubic Metres	8.7

Source: *SFR 2011 Forest Survey of India
**Association of Furniture Manufacturers and Traders (AFMT)
***CPPRI, 2016

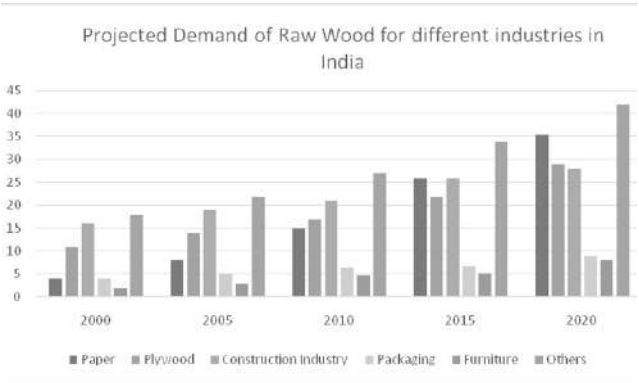

Fig.1

Source: www.indiastat.com

Plywood and Panel industry is the major wood based sector which are majorly dependent on wood extracted from plantations grown under farm forestry and agro forestry. This industry accounts for 8.3 million cubic metres of consumption of wood.

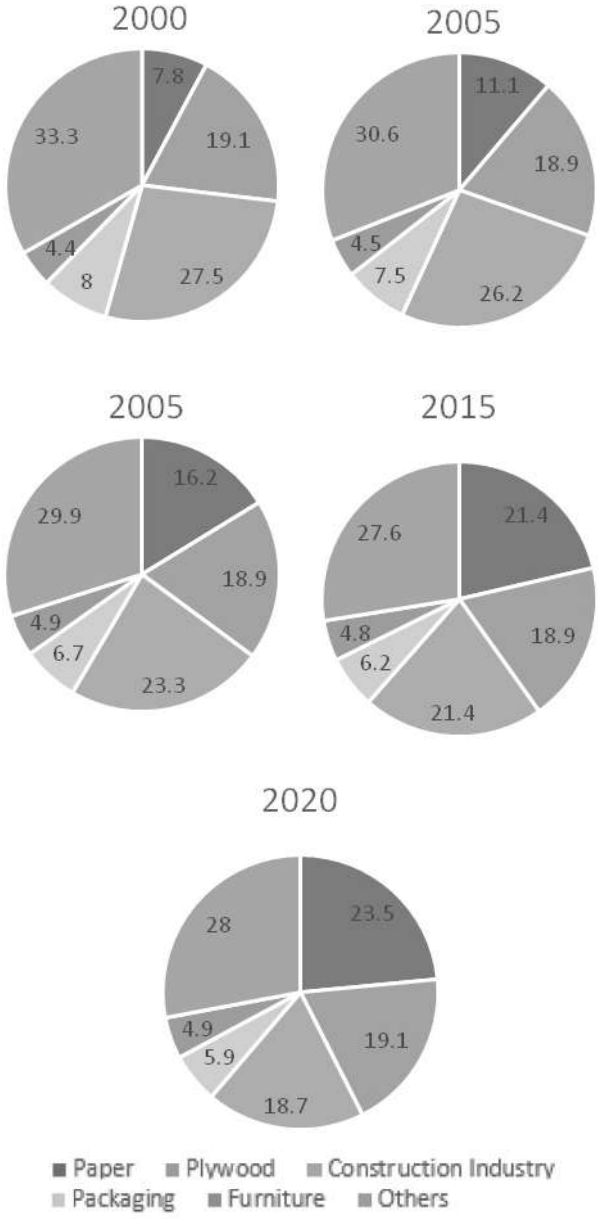

Fig.2

The gap between consumption and production of wood in India is rapidly increasing and it is difficult to quantify this gap due to the lack of authentic data on consumption of wood and wood products since it is a highly unorganized market. Hence the Indian wood market faces the following issues:

- The amount of wood consumed is far more than what is produced in India and this gap is rapidly increasing.
- The unaccounted and unorganized wood market in India.
- It is difficult to calculate the consumption figures within the Indian wood based products as it is highly unregulated.

There is a need to explore alternative products to wood or some new construction technology that involves reduction in consumption of wood, since the growing population and the growing economy always be dependent on wood and wood based products. There are lots of creative alternatives available in the market like hemp, bamboo, plastic wood, wood composites, etc., which can be used to replace the dependency on traditional wood. Even with the coming alternatives there will be dependency on the traditional wood and its use will increase with increase in time. Hence, as designers we need to inquire into methods that reduce the consumption of material without compromising with the alternatives of the wood. One such technology which has been in practise is the sandwich technology which has evolved over the period of time. This paper discusses the sandwich construction technology based on the study from secondary sources only.

SANDWICH CONSTRUCTION TECHNOLOGY

The challenge in evolving the construction technology had always been that how the designers can reduce the mass of the material. This required looking deeply into the structure of the material. The reduction in the mass of the product will eventually reduce the consumption of material as well as the price of the product. Today, the exploitation of the economical advantages of weight reduction has become an important area of exploration.

Sandwich structures are arranged in the manner that it consists of a pair of thin stiff, strong face sheet, a thick, lightweight core to divide the skins and carry loads from one skin to the other, and an adhesive attachment as shown in Fig.3. The shear and axial loads are transmitted to and from the core with the help of adhesive. An efficient structure is produced with the separation of the face sheet by the core, increasing the moment of inertia of the panel with little increase in weight, for resisting bending and buckling loads.

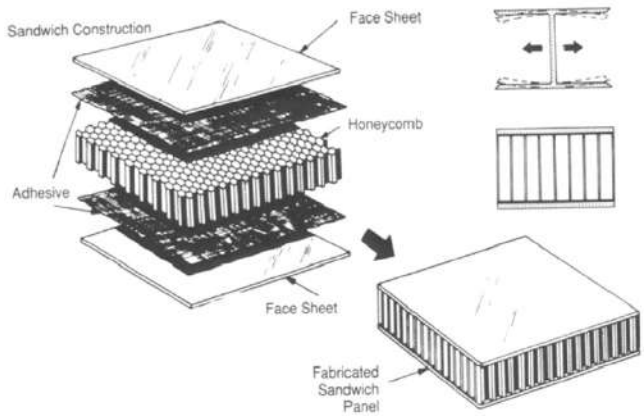

Fig.3: Sandwich Panel Components and Construction

High stiffness and high strength for lightweight panels and parts can be achieved by task distribution in sandwich construction. Sandwich construction can not only be more lightweight but also more cost effective, by using low cost materials, especially because the advancement and automation of production processes results in a reduction of the production cost for lightweight sandwich panels.

In case of thickness increase, when using a monolithic material, there will be an increase in both weight as well as the cost of the panel. This is where the combination of materials can be used to utilize their suitable properties, which is the based concept behind composite construction technology. Sandwich constructions use the fact that the core of a panel that is loaded in bending does not carry much in-plane stresses and does not represent the surface of the panel. The core can thus be made from a different, more lightweight and/or less expensive material.

The different demands on the central layer (core) and surface layers (skins) are taken into account in sandwich construction. According to the selection and optimisation of the different material layers, the weight and/or cost specific properties of the constructionare improved. The potential economic advantage of low cost core materials is as big as the potential weight saving due to low density core

materials.[2]The main task of every sandwich core material is to support the skins (to prevent relative displacements of the skins out-of-plane and in-plane).

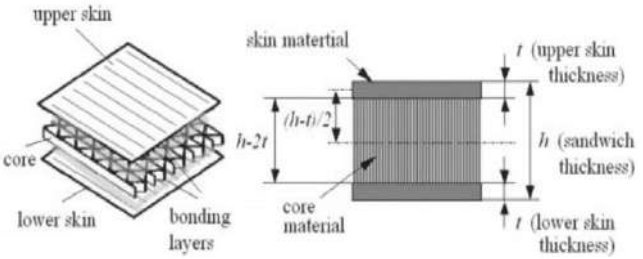

Fig. 4: Task-Distribution

The task of the core is usually relatively thick in lightweight sandwich construction having much lower density compared to the skins. The foremost mechanical demand for the core layer is to stop the movement of the skins relative to each other (in-plane and out-of-plane). Sufficient out-of-plane compression properties of the sandwich core are required to support the skins to maintain their distance from the neutral axis, to prevent them from buckling and to restrict their deformations due to local out-of-plane loads.[2] Furthermore, sufficient out-of-plane shear properties of the core are demanded to restrict in-plane displacement of the skins relative to each other due to bending moments and transverse loads.[2] The core layer usually have additional functions e.g. thermal and acoustic isolation or energy absorption during impact as shown in Fig.4.

The task of the skins in sandwich constructions, the skin layers carry the in-plane tensile/ compression stresses and in-plane shear stresses. They have a high stiffness and strength and are relatively thin. They have high mechanical in-plane properties per weight and are required to fulfil other demands like low costs, high surface quality and good impact performance.

The Table 3 shows the effect of the sandwich concept on bending stiffness, panel weight and panel material cost. For this simple differentiation the density of the core is assumed to be 20 times lower than theskin material density, which is commonly achieved in honeycomb sandwich construction. the positive effect of the sandwich height on the bending stiffness can be seen in two examples. Only 1.2 times the height allows to reach the bending stiffness a monolithic panel with only 30% of the amount of skin material compared to a monolithic panel.[2] The last column of the table 3 shows the "optimized" sandwich example in which only 6% of skin material is sufficient to achieve similar bending stiffness. The lower amount of skin material paves way for substantial cost reductions if a low cost core material is used, along with weight reduction.

Table 3: The Economic Advantage of Low Cost Core Materials

Sandwich effect on bending stiffness weight and material cost	monolithic $h_1 = 2\ t_1$	sandwich $h = 1.2\ h_1$ $t = 0.3\ t_1$	optimised $h = 2.4\ h_1$ $t = 0.06\ t_1$
Relative thickness	1	1.2	2.4
thickness ratio $2t/h$	1	0.25	0.025
Relative bending stiffness D	1	1	1
Relative homogenized bending modulus ($E = 12\ D / h^3$)	1	0.575	0.07
Relative weight / m² (core density 20 times lower compared to the skin density)	1	0.345 - 65%	0.177 - 82%
Relative cost / m² with expensive core (equal to skin cost per vol.)	1	1.2	2.4
Relative cost / m² with low cost core (20 times lower cost per vol.)	1	0.345 - 65%	0.177 - 82%

The two lowest rows of the table present a comparison of the relative cost per m² based on material cost with an expensive core and a low cost core. For the expensive core material costs per weight are assumed to be 20 times higher than the cost per weight of the skin material. Since our exemplary core material has a 20 times lower density this results in equal cost per volume for core and skin material. For the low cost core, the material costs per weight are assumed to be equal to the cost per weight of the skin material. The relative cost per m², based only on cost per m² of the core and skin materials, compared to the monolithic panel show the large effect of the core material cost as shown in Table 3. The cost savings due to low cost core materials can be as big as the weight savings due to low density core materials.[2]

HONEYCOMB SANDWICH CONSTRUCTION

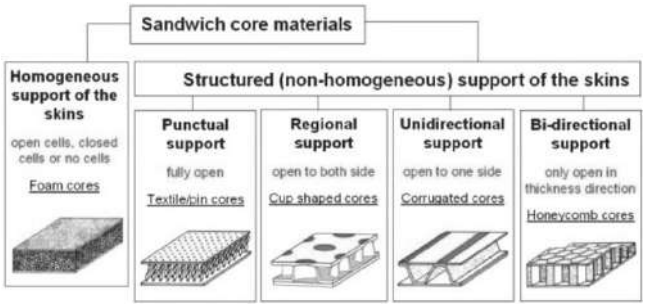

Fig. 5: Classification of Sandwich Core Materials

Foam Cores: Homogeneous core materials, e.g. polyurethane (PU) foams, are widely used in low cost applications (e.g. in building and automotive industry). The out-of-plane compression and shear performance is for equal density however lower compared to honeycomb cores. Recently, polypropylene foams (EPP) have become a better recyclable alternative to PU foams. However, they are more expensive and have even lower mechanical properties than PU foams.[2]

Textile and Truss Cores: Production cost reductions had been one driving force for the development of truss of textile type of structured cores which provide a punctual support for the skins. In combination with a foam filling these textile cores can provide good mechanical properties. However, this leads again to higher cost.[2]

Corrugated Cores and Cup-Shaped Cores: The corrugated core in cardboard is well known for its low cost packaging applications, but due to its low cost it has also been used in automotive headliners and, made from metal sheets, in building applications. The efficient in-line production technology of corrugation leads to very low costs. However, the corrugated core has rather low mechanical properties especially transvers to the corrugations.[2]

Honeycomb Cores: Honeycomb core materials can offer weight and cost savings thanks to their excellent performance per weight. Unlike corrugated core types, where cell opens in the in-plane direction, honeycomb core types have vertical cell walls and only openings in the out-of-plane direction and provide a bi-directional support for the skins. The desire for lightweight design to enable savings in raw material and energy resources will continue to increase and spread to many traditionally less weight sensitive industrial sectors.[2]

Honeycombs are used in aerospace industries since many decades as the preferred core material for very light and strong sandwich panels and structures. From all sandwich core materials as shown in Fig. 5 honeycombs enable the best mechanical performance per weight, thus they offer the largest potential for material cost savings.[2]

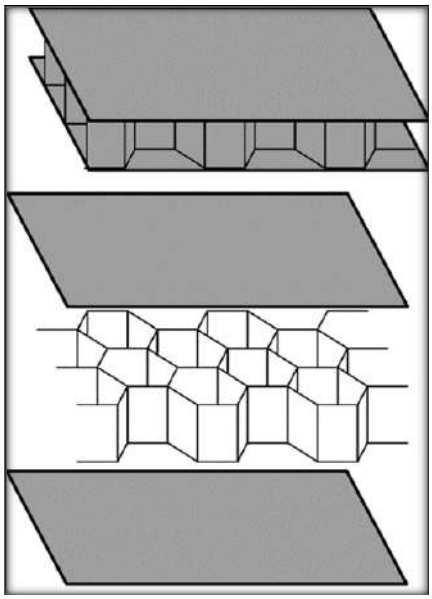

Fig. 6: Honeycomb Sandwich Structure

Honeycomb cores as shown in Fig. 6 are one of the most structurally efficient core constructions, especially in stiffness-critical applications. The basic idea of honeycomb panel was to use the honeycomb as a shear web between two skins.

- It provides minimal density and high out-of-plane compression and shear properties.
- It has high strength to weight ratio and good impact resistance.[2]
- Structural properties of honeycomb structure depend on lower and upper face sheet thickness, the core material thickness, cell diameter, cell angle and foil thickness.[2]
- Debonding is one of the major failure modes of honeycomb sandwich panels.[2]
- Material used for the honeycomb construction also has very important in its structural performance.[2]

CONCLUSION

Sandwich construction technology is the best method to achieve the required strength by optimising the weight and the quantity of material. There is a further scope of research in understanding the various permutations and combinations of materials that can be put in use to achieve the desirable characteristics and also reduce the cost and dependency on traditional monolithic use of materials. Honeycomb sandwich construction is considered the best way to attain the mechanical performance in least weight, thus offering the largest potential to save material and cost of the product.

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APPLICABILITY OF DUCTILE IRON PIPES IN GRAVITY SEWER NETWORK

SABARNA ROY* AND RAJAT CHOWDHURY**

Abstract

Ductile Iron of K7 class is suitable for gravity sewer application with internal and external lining done as per standard specification. Use of Ductile Iron pipes in Gravity Sewer Network may be advantageous in areas of high water table, coastal area and in environment corrosive to cement concrete. Ductile Iron pipes can offer 100% leak tight joints thereby erasing the chances of infiltration of sub-soil water inside the sewer and exfiltration of the sewage into the sub-soil water. The construction time can be reduced due to easier installation, handling and availability of longer DI pipe length than RCC pipe.

The paper puts forth the viable techno economical pipe matrix comprising Ductile Iron Pipes with internal lining and external coating as per standard specification for underground sewer network. It also shows a comparative analysis of different pipes with the help of Life Cycle Cost Analysis

INTRODUCTION

In Cast Iron, graphite is present in plate like flakes which are a source of inherent weakness. Under heavy shock loads, cracks spread along the flakes making CI brittle. In Ductile Iron, shape of graphite structure becomes a spheroidal nodule. This nodular shape increases tensile strength and gives elongation property by preventing spreading of cracks.

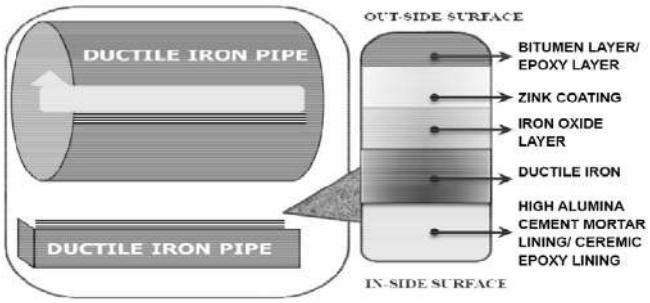

Fig1: Cross sectional view of Ductile Iron Pipe

APPLICATIONS

- Raw and Clear water transmission (pumping and gravity main)
- Irrigation Systems
- Distribution network of potable water
- Water supply for industrial / process plant application
- Ash-Slurry Handling & Disposal system
- Fire-fighting systems – on-shore and off-shore
- Desalination Plants
- Sewerage and waste water force main
- Gravity sewerage collection and disposal system
- Storm water drainage piping
- Effluent disposal system for domestic and industrial application
- Recycling system
- Piping work inside water and sewage treatment plants
- Vertical connection to utilities and reservoirs
- Piling for ground stabilization
- Protective piping under major carriage-ways

**Senior Vice President **Sr. Executive; Electrosteel Castings Limited, Kolkata*

PROPERTIES OF DUCTILE IRON PIPES

Sl.	Properties	Ductile Iron Pipe
1	Tensile Strength	Min. 420 MPa
2	0.2% Proof Stress	300 MPa
3	Elongation (min.) at Break	10% (percent)
4	Modulus of Elasticity	1.7 X 1010 kg/ m^2
5	Hardness	Max. 230 BHN
6	Density	7050 kg/m^3
7	Bending / Beam Strength	Over 200 MPa
8	Crushing Strength	500 MPa
9	Bursting Strength (min.)	Factor of Safety against Bursting is 8 to 10

HOW CORROSION OCCURS IN CONVENTIONAL SEWER PIPES?

Underground sewer pipes are required to resist and operate safely under various external loads, as well as severe environmental conditions. The degradation of sewer pipes over time in combination with the effects of overlaying soil and surface traffic loads can sometimes cause catastrophic failures in sewer pipes.

For cementitious sewer pipes, corrosion is the main cause of deterioration. Corrosion can cause reduction in structural strength of the pipeline, leading to pipe collapse. Bacteria in the slime under flowing sewage convert Sulphates in the sewage into Sulphides. Sulphides in the liquid make their way to the surface of the sewage and released into the sewer atmosphere as Hydrogen Sulphide gas.

Hydrogen Sulphide gas in atmosphere makes contact with slime in the crown of the sewer, which contains more bacteria. Bacterial action converts Hydrogen Sulphide gas to Sulphuric Acid which causes corrosion in the crown of the pipe and this corrosion is also called Crown Corrosion. For RCC Sewer Pipes, which is of corrodible nature, sulphuric Acid attacks the pipe material causing ultimate failure (Fig.2-6).

The sulfate ion (SO_4^{2-}) naturally occurs in water supplies and in sewage as well. Sulfates are reduced to sulfide and to hydrogen sulfide (H_2S) by bacteria under anaerobic condition of sewer pipe. The H_2S is then biologically oxidized to sulfuric acid (H_2SO_4).

$$SO_4^{2-} + [\text{Organic matter}] \rightarrow H_2S$$

$$H_2S + 2O_2 \rightarrow H_2SO_4$$

PROCESS OF SEWER FAILURE DUE TO HYDROGEN SULFIDE CORROSION

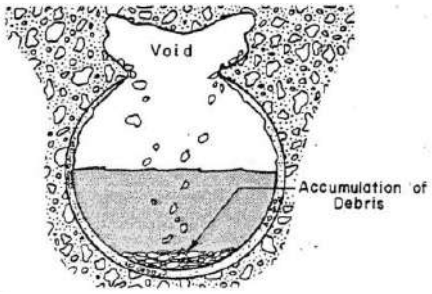

Fig. 2: Corrosion reduces Structural Integrity of Pipe Crown.

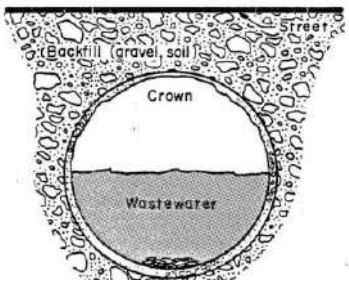

Fig. 3: Crown collapses and voids forms from backfill washing into sewer.

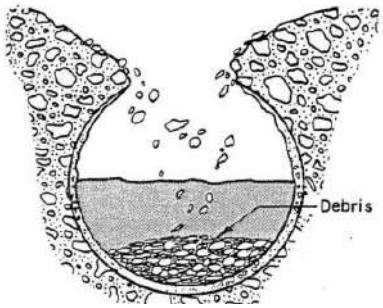

Fig. 4: Backfill continues to wash into Sewer Blockage and/or Street collapse

Fig. 5 (a)

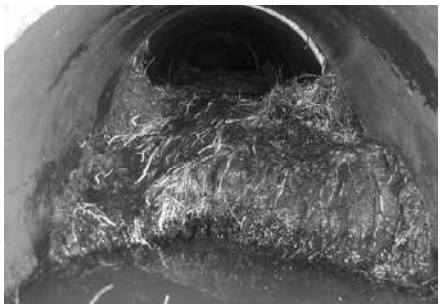

Fig. 5 (b)

Fig. 5 (c)

Fig. 5 (d)

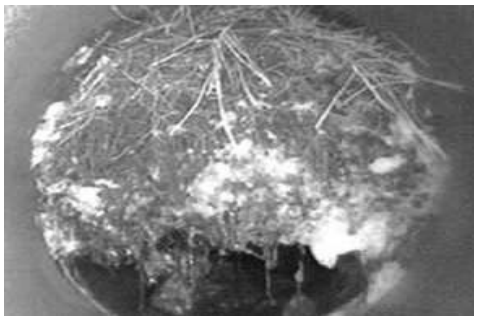

Fig. 5 (e)

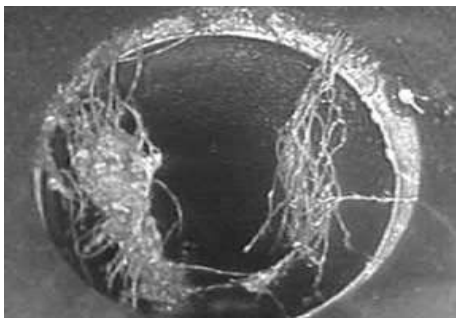

Fig. 5 (f)

Fig. 5: Damage of RCC Sewer Pipes due to Root Penetration

Fig. 6 (a)

Fig. 6 (b)

Fig. 6 (c)

Fig. 6 (d)

Fig. 6: Photographs of RCC Sewer Pipe Line failure due to Hydrogen Sulfide Corrosion

TECHNICAL SPECIFICATIONS FOR USE OF DUCTILE IRON PIPES IN GRAVITY SEWER NETWORK

- **Pipe Material:** Ductile Iron pipes of thickness Class K-7 conforming to IS: 8329-2000.
- **Inside Lining** (To be able to cater to abrasion and corrosion properties of Sewerage to be transported): High alumina cement mortar lining of suitable thickness applied at factory satisfying the "Type Tests for Chemical Resistance and Abrasion Resistance" conforming to Clause Nos. 5.3, 5.4, 7.6 and 7.7 of ISO:7186 (International Standard for Ductile Iron products for Sewerage Applications) or Ceramic Epoxy lining of suitable thickness applied at factory satisfying the "Type Tests for Chemical Resistance and Abrasion Resistance" conforming to Clause Nos. 5.8, 5.9, 7.9 and 7.10 of EN:598 (European Standard for Ductile Iron Pipes, fittings, accessories and their joints for Sewerage Applications).
- **External Coating:** Zinc base (130 gms/m^2 minimum) with a finishing layer of red epoxy or brown bitumen coating of 70 microns' average (50 microns' local minimum) applied at factory as per IS: 8329-2000.For soils of higher corrosivity, higher thickness of zinc coating can be used along with or without Polyethylene Sleeving (Fig.1).

PROVISIONS OF EN 598:2007

Clause No. 5.8 of the Standard, titled: Chemical resistance to effluents, states "Except for components intended only for the transport of rainwater, long-term performance of pipes, fittings and joints shall be demonstrated by six-month exposure tests to an acid solution and to an alkaline solution. Their field of use is given in Annexure 'C'."

After six months of testing, the following conditions shall be met:

- Thickness of the cement mortar lining shall be within 0.2 mm of the original thickness;
- There shall be no visible cracking, blistering or disbonding of the epoxy or polyurethane based coatings (fittings, pipe spigots and sockets and pipe linings);
- There shall be no visible cracking on the rubber gasket; its hardness, tensile strength and elongation shall remain in conformity with the specified values.

All other combinations of coatings may be tested according to the same procedure; the values of pH may be modified in order to demonstrate long-term behavior in different environments."

Clause No. 5.9 of the Standard, titled: Abrasion resistance, states "The pipes shall not have an abrasion depth greater than 0.6 mm after 100000 movements (50000 cycles) for every type of cement lining or 0.2 mm for epoxy or polyurethane linings."

PROVISIONS OF IS 8329:2000

In the Annex-B (Clause No. 16.3), titled: Cement Mortar Lining, cement used for lining, pursuant to Clause No. B-1.1 (c), states "High alumina cement (as per IS: 6452) mortar lining is suitable for continuous use of pH between 4 and 12 and no severe damage occur after occasional exposure to pH 3 to 4 and 12 to 13."

In the Table 14, titled: Recommended type of cement used for lining, pursuant to Clause No. B-1.1, it is stated as follows: -

Sl.	Water Characteristics	High Alumina Cement
i)	Minimum value of pH	4
ii)	Maximum content (mg/l) of:	
	Aggressive CO_2	No limit
	Sulphates (SO_4^-)	No limit
	Magnesium (Mg^{++})	No limit
	Ammonium (NH_4^-)	No limit

CERAMIC EPOXY LINING

Electrosteel brand Ductile Iron Pipes and Fittings are internally lined with high build impervious ceramic enhanced system containing a minimum of 20% ceramic quartz pigment dispersed in a phenol derived epoxy resin.

Usages:

- Domestic and municipal wastewater
- Industrial wastewater and effluents
- Water with solid particles leading to inner wall abrasion
- Foul water with high chance of biologically induced corrosion

Advantages:

- Exhibits superior mechanical bonding strength with the metal substrate
- Can resist prolonged exposure to corrosive environment
- Impervious coating resists chemical attack
- Protects effectively against sewer gas corrosion

Experiments and Test Results of Ceramic Epoxy Lining:

Sl.	Tests Conducted	Relevant Standard	Test Method	Performance
1	Abrasion test	ASTM D 4060-07	(CS-17 Wheel, 1,000 cycles, 1,000 gram load)	No more than 76 mg loss, average of three tests
2	Abrasion type test A	BS EN 598: 2007+A1: 2009	Rocking Abrasion of 50000 cycles	No more than 0.01 mm (0.6 mils) thickness of coating loss
3	Abrasion type test B	BS EN 598: 2007+A1: 2009	Rocking Abrasion of 100000 cycles	No more than 0.14 mm (5.5 mils) thickness of coating loss
4	Adhesion test	ASTM D 4541-09	Method E, Type V Tester, Scored	No less than 1,450 psi (10 MPa) pull, average of three tests
5	Cathodic disbondment	ASTM G 8-96 (2003)	Applied at 37 mils average DFT and cured 14 days at 75°F (24°C)	No more than 0.00 inch (0.00 mm) disbonded equivalent circle diameter, average of two tests
6	Chemical immersion	NACE TM 0174-2002	NACE Solution Exposed to White Metal Blast Cleaned and cured 30 days at 75°F (24°C)	No blistering, cracking, checking, erosion or delamination of film after one year continuous immersion at 72°F (22°C)
7	Immersion Test 20% H2SO4	ASTM D714-87	Sample immersed in 20% H_2SO_4 Solution	No effects after 2 years
8	Spark Holiday Test	EN 14901	Using Standard Holiday detection device	Safe test Voltage - 2.5 KV
9	Chemical resistance Type test	BS EN 598: 2007+A1: 2009	Reagents applied to ductile iron pipe and cured 14 days at 75°F (24°C)	No blistering, disbonding, softening, discoloration or loss of gloss after six months immersion, recirculated at 1.0 lit/min and maintained at 64°F (18°C)
10	Coating Hardness	ASTM D 2240-05	Cured 30 days at 75°F (24°C)	No less than a Shore Type D hardness of 78, average of five tests
11	Immersion in water	ASTM D 870-09	Continuous immersion for 4000 hours in 1400F de-ionized water after curing for 14 days at 75°F (24°C)	No rusting, cracking, checking, or delamination of film
12	Salt spray test (Fog)	ASTM B 117-09	Exposer for 5000 hours after curing for 14 days at 75°F (24°C)	No blistering, cracking or delamination of film

13	Water absorption test	ASTM C 413-01 (2006)	Immersion in water after curing for 14 days at 75°F (24°C)	No absorption of water
14	Water vapor transmission	ASTM D 1653-03 (2008)	(Method B Wet Cup, Condition C)	No more than 1.25 g/m^2 per 24h water vapor transmission (WVT), and no more than 0.09 perms (0.06 metric perms) water vapor permeance (WVP), average of three tests
15	Impact Resistance	ASTM 2794	Resistance of Organic Coatings to the effects of Rapid Deformation (Impact); Modified for thick metal substrate.	160 lb-in

THICKNESS OF PIPES WALL, HAC MORTAR LINING & CERAMIC EPOXY LINING

Nominal Diameter (DN)	External Diameter (DE)	Nominal wall thickness of Class K7 Pipes (mm)	Nominal thickness of High Alumina Cement Mortar Lining (mm)	Nominal thickness of Ceramic Epoxy Lining (µ)
80	98	5	4	1000
100	118	5	4	1000
125	144	5	4	1000
150	170	5	4	1000
200	222	5	4	1000
250	274	5.3	4	1000
300	326	5.6	4	1000
350	378	6.0	5	1000
400	429	6.3	5	1000
450	480	6.6	5	1000
500	532	7.0	5	1000
600	635	7.7	5	1000
700	738	9.0	6	1000
750	790	9.7	6	1000
800	842	10.4	6	1000
900	945	11.2	6	1000
1000	1048	12.0	6	1000
1100	1152	14.4	6	1000
1200	1255	15.3	6	1000

SERVICE LIFE OF RCC PIPES AND DUCTILE IRON PIPES AS PER NEERI HAND BOOK

The design useful service life of various kinds of pipe materials published by National Environmental Engineering Research Institute, Nagpur in October 2002 in Volume II (Pipe Selection Hand Book for Water Supply and Sewerage) titled, Design Algorithm & Software mention the following for service life of RCC pipes and Ductile Iron pipes:

Description	RCC Pipes	DI Pipes
Minimum Design Useful Service Life(in Years)	10	70
Maximum Design Useful Service Life(in Years)	30	90

LIFE CYCLE COST ANALYSIS BETWEEN DI PIPES & RCC PIPES (CONSIDERING DESIGN PERIOD 30 YEARS)

Basic Equation of Product Life Cycle Cost Analysis

The Total Effective Cost (Current Rupees) of the limited life pipe is determined from the equation:

$$EC = P\{1+[(1+I)/(1+i)]^{n} + [(1+I)/(1+i)]^{2n} \ldots [(1+I)/(1+i)]^{mn}\}^{1}$$

Where:

EC = Total Effective Cost (Current Rupees)

P = Current estimated Price (Current Rupees)

I = Inflation Rate over the period of the Project Life (percent)

i = Interest Rate over the period of the Project Life (percent)

n = Service Life of the material (years)

m = Number of times the pipe material with the limited life must be replaced to equal the longer service life material

The Interest/Inflation Factor equals $(1+I)/(1+i)^{1}$

(Reference: Taking the Guesswork out of Least-Cost Analysis by W. O. Kerr, Ph.D. and B. A. Ryan, Arthur Young & Company. Updated by W. O. Kerr for NCPI – April 1993.)

As per Pipe Material Selection Handbook for Water Supply and Sewerage published by National Environmental Engineering Research Institute, Nagpur; Maximum Life of DI pipe is 90 years & Minimum life of DI pipe is 70 years. From this, we get Average life of DI pipe is 80 years. Similarly, Maximum Life of RCC pipe is 30 years & Minimum life of RCC pipe is 10 years. From this, we get Average life of RCC pipe is 20 years.

Pages from approved detailed project report for sewerage system of Berhampur town, Odisha Water Supply and Sewerage Board, Bhubaneswar, Volume – I, which has been approved by CPHEEO, MoHUD.

Selection of Sewer Pipe Materials

Every sewer pipe has merits and demerits. It will be useful to keep in mind that sewers pass through a whole length of roads in a habitation and varying soil conditions, bedding conditions, locations, etc., will be encountered at various places. Hence, a particular pipe material may be suitable in a particular location but may require some other material at some other locations. A guide for this is presented in Appendix A.3.10. (Refer Clause No. 3.56.11 of Chapter 3, Part A of Manual on Sewerage and Sewage Treatment System published by CPHEEO in 2013).

Care shall be taken that in high ground water locations and coastal locations, the sewer pipes shall not be stoneware or vitrified clay pipes and instead shall be cast iron / ductile iron pipes or other non-metallic pipes with safeguards against floatation as discussed later in the section on laying of sewers (Refer Clause No. 3.6 of Chapter 3, Part A of Manual on Sewerage and Sewage Treatment System published by CPHEEO in 2013).

Selection Criteria of Pipe Materials as per CPHEEO Manual

As per Clause 3.12.1of the CPHEEO Manual on Sewerage and Sewage Treatment Systems, 2013, the factors influencing the selection of materials for sewers are:

- Flow characteristics,
- Availability in the sizes required including fittings,
- Ease of handling and installation,
- Water tightness and simplicity of assembly,
- Physical strength,
- Resistance to acids, alkalis, gases, solvents, etc.,
- Resistance to scour,
- Durability and
- Cost including handling and installation.

The Manual notes that no single material can meet all the conditions that may be encountered in sewer design. So, selection should be made for the particular application and different materials may be selected for parts of a single project.

As per CPHEEO Manual selection factors for sewer material, comparison between RCC< DWC- HDPE and Ductile Iron pipes characteristics are given in the table below:

Sl.	Required characteristics as per CPHEEO Manual	Characteristics of RCC Pipe as per IS 458:2003	Characteristics of DWC-HDPE Pipe as per IS 16098 Part 2	Characteristics of DI Pipe (Class K-7) as per IS 8329:2000
1	Availability of required size including fitting and specials	RCC pipes are available in the range of 80 mm to 2600 mm. RCC fittings are not available.	DWC PE pipes are produced in sizes DN/ID 75 mm to 1200 mm. DN 350, 450, 700, 750, 900 and 1100 diameters are not available in DWC pipes. (Table 5, IS 16098 Part 2).	DI pipes are available in the range of 80 mm to 1200 mm. Ductile Iron fittings are manufactured conforming to IS: 9523. (Clause no. 3.12.8, Chapter 3 – Design and Construction of sewers, Part A of CPHEEO manual).

2	Limitations	Not suitable for high Sulphate levels in sewage / soil water, unless good lining such as HDPE/GRP/PVC/PE/CM with Sulphate resistant cement lining is provided or pipe manufactured with Sulphate resistant cement or Alumina cement. The quality of the lining shall be ensured by the competent authority. Not in aggressive soils / ground water or tidal zone unless Sulphate resistant cement or high alumina cement is used in manufacture. (RCC-1 and RCC-2 of Appendix A 3-10, Part A of CPHEEO manual).	Not in location subjected to vehicular load and has insufficient cover. Not in areas subjected to third party interference, e.g. excavations within 2m of pipeline by other parties. Not in ground offering low side support strength to the pipe. Not in ground which allows migration of pipe embedment material into it. Not in ground contaminated with deleterious chemicals. Not suitable for above ground installation. Not suitable as reticulation systems except for special applications (SP-1 to SP-7 of Appendix A 3-10, Part A of CPHEEO manual).	DI pipes are not to be used near buried electricity transmission high tension cables. Wherever used above ground supports at each pipe length shall be ensured without any subsidence. Pipes with external synthetic coatings not to be used in marine coastal environments to prevent leaching of constituent chemicals into the environment. (CIDI-1, CIDI-2 and CIDI-3 of Appendix A 3-10, Part A of CPHEEO manual).
3	Physical strength	I. Tensile Strength (Minimum): 2.5 MPa (Clause no. 5.5.2 of IS: 458). II. Poisson's Ratio: 0.20 III. Young's Modulus of Elasticity (E): 29,580 MPa (Table 6.7, Chapter 6 of CPHEEO manual). IV. Impact Resistance: Negligible. V. Minimum Elongation at Break: 0% VI. Structural strength (Crushing strength): 300 Kg/cm² (Approximate) Normal Backfill. VII. Comparison of pipe weight: Heavy (Table 6.2.4 of NEERI Hand book). VIII. Pipe Length: 2.5 m each pipe (Clause no. 8.1 of IS: 458).	Poisson's Ratio: 0.42 for PP & 0.45 for PE Young's Modulus of Elasticity (E): ≥1250 MPa for PP & ≥800 MPa for PE. (The above values are taken from Table A.1, Clause No. A.2, Annex A of EN 13476-1: 2007	I. Tensile Strength (Minimum): 420 MPa (Clause no. 10.1.6 of IS : 8329). II. Poisson's Ratio : 0.28 III. Young's Modulus of Elasticity (E): 170,000 MPa (Table 6.7, Chapter 6 of CPHEEO manual). IV. Impact Resistance: <0.713 V. Minimum Elongation at Break: over 10% (Clause no. 10.1.6 of IS : 8329) VI. Structural strength (Crushing strength): 5000 Kg/cm² (Approximate) Normal Backfill. VII. Comparison of pipe weight: Medium (Table 8 of IS: 8329-1994). VIII. Pipe Length: 5.5 m or 6 m each pipe (Clause no. 13.1 of IS : 8329).

4	Flow characteristics	Manning's coefficient of roughness for collar joint fair condition – 0.013, collar joint good condition – 0.015 and socket & spigot joint – 0.011 (Table 3.11, Chapter 3 – Design and Construction of sewers, Part A of CPHEEO manual).	Manning's coefficient of roughness n is 0.010 for HDPE/uPVC pipes.	Manning's coefficient of roughness n is 0.011. (Table 3.11, Chapter 3 – Design and Construction of sewers, Part A of CPHEEO manual).
5	Ease of handling and installation	Installation is slow as no. of joints are more and pipes are heavy. Laying is slower. As nos. of joints are 2-2.25 times higher than DWC HDPE pipes and DI pipes; more construction time will be required in RCC pipelines.	Installation is faster compared to RCC pipes. However, limitation of crown depth from 0.8 to 6.0 m (Sl. No. II, Table 24 of IS 16098 (Part 2). Moreover, DWC pipes need precaution in water logged area. The uplift during high groundwater conditions above the pipe level is a problem specifically in high ground water and coastal areas. The concrete surrounds or piles shall be used to hold these in place where ground water can rise above the sewer (Clause no. 3.56.8, Chapter 3 – Design and Construction of sewers, Part A of CPHEEO manual).	Installation is fast due to simple Push-on type Jointing system and lesser no. of joints. Saves project cost and public inconvenience due to faster laying. Construction time will be less in DI pipelines. By using DI pipes, construction time may be reduced. Can be laid at any depth and has no limitation for crown depth. DI pipes are comparatively heavier in weight. Hence, there is no floatation risk with DI pipes.
6	Water tightness and simplicity of assembly	Joint is relatively inflexible. Hence, can't adopt to ground movements and cause exfiltration of sewer and infiltration of sub-soil water. Eg., for a 100 m length pipeline; there are 40 joints in RCC pipes. Jointing method is unreliable and susceptible to leakage. Moreover, more joints mean possibility of leakage is more.	Type Tested not for such adverse conditions as Ductile Iron pipes in real application.	Type Tested for very high adverse conditions in real application. Joint is flexible. Hence, can adapt to ground movements easily. Push-on joints offer excellent leak-proof joint. Eg., for a 100 m pipeline; there are 18 joint in DI pipes. Joints are type tested for very adverse conditions. (for high alumina cement mortar lining Chemical Resistance and Abrasion Resistance conforming to Clause Nos. 5.3, 5.4, 7.6 and 7.7 of ISO:7186 and for Ceramic Epoxy lining Chemical Resistance and Abrasion Resistance conforming to Clause Nos. 5.8, 5.9, 7.9 and 7.10 of EN:598).

7	Resistance to acids, alkalies, gases, solvents, etc.	These pipes are subject to crown corrosion by sulphide gas, mid depth water line corrosion by sulphide and outside deterioration by Sulphate from soil water. (Clause No. 3.12.3, Chapter 3 – Design and Construction of sewers, Part A of CPHEEO manual).	Inert to acids, alkallies, gases, solvents etc.	High alumina cement mortar lining is suitable for continuous use of pH between 4 and 12 and no severe damage occur after occasional exposure to pH 3 to 4 and 12 to 13. Maximum content of aggressive CO2, Sulphates (SO4), Magnesium (Mg++) and Ammonium (NH4+) there is no limit for high alumina cement mortar lining. (Clause no. B-1.1 c. and Table 14 of Annexure B, IS: 8329).
8	Resistance to scour	Good.	Good.	Good.
9	Durability	Concrete pipes have to be properly handled, bedded and back filled, if they have to carry safely the full design loads. Even the highest quality of concrete pipes manufactured in accordance with the specifications may be destroyed by improper handling, bedding and backfilling. (Clause no. 0.3, Foreword of IS: 783).	Impact strength is very low. Requires careful handling.	The ductile iron pipes have excellent properties of machinability, impact resistance, high wear and tear resistance, high tensile strength, ductility and corrosion resistance. Impact strength is very high. Hence, pipes will not be damaged during handling. They are strong, both inner and outer surfaces are smooth, free from lumps, cracks, blisters and scars. The ductile iron pipes stand up to hydraulic pressure tests as required by service regulations (Clause no. 3.12.8, Chapter 3 – Design and Construction of sewers, Part A of CPHEEO manual).
10	Design Useful Service Life	Minimum - 10 years Maximum - 30 years (as per Pipe Material Selection Handbook Published by National Environmental Engineering Research Institute (NEERI)	Likely as per HDPE pipes Minimum - 10 years Maximum - 25 years (as per Pipe Material Selection Handbook Published by National Environmental Engineering Research Institute (NEERI)	Minimum - 70 years Maximum - 90 years (as per Pipe Material Selection Handbook Published by National Environmental Engineering Research Institute (NEERI)

FOR Rates of RCC (NP-3) Pipes, DWC-HDPE (SN-8) Pipes and DI (K-7) Pipes:

Sl. No.	Diameter	FOR at Berhampur RCC (NP-3) – Rs./m	FOR at Berhampur DWC HDPE (SN-8) – Rs./m	FOR at Berhampur DI (K-7) – Rs./m
1	200	779.59	434.00	1,500.00
2	250	908.18	676.00	1,977.00
3	300	1,339.99	902.00	2,499.00
4	350	2,540.52	-	3,115.00
5	400	2,828.16	1,631.00	3,731.00
6	450	3,161.30	-	4,394.00
7	500	3,539.44	2,377.00	5,172.00
8	600	4,545.48	4,099.00	6,831.00
9	700	5,378.49	-	9,244.00

10	800	6,808.40	6,796.00	12,168.00
11	900	7,649.21	-	14,776.00
12	1000	9,904.13	11,067.00	17,636.00
13	1100	11,528.59	-	23,107.00
14	1200	13,153.04	-	26,870.00

Capital Cost comparison between RCC (NP-3) Pipes, DWC-HDPE (SN-8) Pipes and DI (K-7) Pipes (considering supply cost, erection cost and bedding cost only excluding earth work cost):

Sl.	Option for Sewer Network	RCC (NP-3) (Rs. In Crores)	DWC HDPE (SN-8) (Rs. In Crores)	DI (K-7) (Rs. In Crores)	Total (Rs. In Crores)
1	Option I (DWC pipe up to diameter 250, DI pipe from 300 mm to 700 mm & RCC pipe above 700 mm diameter)	12.86	47.61	14.34	74.81
2	Option II (DWC pipe up to diameter 250 & RCC pipe above 250 mm diameter)	23.28	47.61	0	70.89

Life Cycle Cost Analysis (LCCA) between RCC (NP-3) Pipes, DWC HDPE (SN-8) Pipes and DI (K-7) Pipes considering supply cost, erection cost and bedding cost of pipes:

Sl.	Option for Sewer Network	Effective Cost of Sewer Network with RCC Pipes including Net present value of 1 replacement after 20 years (Rs. In Crores)	Effective Cost of Sewer Network with DWC Pipes including net present value of 1 replacement after 17.5 years (Rs. In Crores)	Effective Cost of Sewer Network with DI Pipes (Rs. In Crores)	Total (Rs. in Crores)
1	Option I (DWC pipe up to diameter 250, DI from 300 mm to 700 mm & RCC above 700 mm diameter)	24.00	88.00	14.34	126.34
2	Option II (DWC pipe up to diameter 250 & RCC above 250 mm diameter)	43.00	88.00	0	131.00

Calculations of Net present value for RCC pipes and DWC-HDPE pipes both for Option-I and Option-II are enclosed in Annexure A.

As per NEERI Handbook Maximum Life of DI pipe is 90 years & Minimum life of DI pipe is 70 years. From this, we get Average life of DI pipe as 80 years. Similarly, Maximum Life of RCC pipe is 30 years & Minimum life of RCC pipe is 10 years. From this, we get Average life of RCC pipe as 20 years. Similarly, Maximum Life of DWC pipe is 25 years & Minimum life of DWC pipe is 10 years. From this, we get Average life of DWC pipe as 17.5 years. So for a system life of 30 years, DI pipes will not require any replacement whereas RCC pipes and DWC pipes will require one replacement. Hence, Option-I has been selected in the DPR.

CONCLUSION

From the aforesaid comparative analysis of DI, RCC, DWC-HDPE and HDPE pipes, it is seen that Ductile Iron of K7 class is also suitable for gravity sewer application with internal and external lining done as per standard specification. Use of Ductile Iron pipes in Gravity Sewer Network may be advantageous in areas of high water table, coastal area and in environment corrosive to cement concrete. Ductile Iron pipes can offer

100% leak tight joints thereby erasing the chances of infiltration of sub-soil water inside the sewer and exfiltration of the sewage into the sub-soil water. The construction time can be reduced due to easier installation, handling and availability of longer DI pipe length than RCC pipe.

While preparing DPRs of sewerage project, it is recommended to carryout life cycle cost analysis and other comparative analysis as per CPHEEO Manual for DI, RCC, DWC-HDPE and HDPE pipes and accordingly pipe material may be adopted in the upcoming projects.

So, suggested pipe matrix is –

- DWC HDPE SN 8 pipe up to diameter 250 mm.
- DI K7 pipe with HAC lining from 300 mm to 700 mm.
- RCC pipe above 700 mm diameter.

STEEL SLAG AS A SUBSTITUTE FOR AGGREGATES IN CONSTRUCTION INDUSTRY FOR SUSTAINABLE INFRASTRUCTURE DEVELOPMENT

GAURISHANKAR DUBEY*

Abstract

Growing environmental restrictions to the exploitation of sand from river beds and coarse aggregates from hills lead to search for alternatives. This has brought in severe strains on the availability of sand and coarse aggregates forcing the construction industry to look for alternative construction materials without compromising the strength criteria of concrete.

The iron and steel industry generates substantial solid waste. Blast Furnace Slag (BFS) and Steel Making Slag (SMS) are residue obtained in iron and steel making process. Iron and steel making processes thus generate huge amount of slag which is basically a non-metallic product consisting of silicates and ferrites, combined with fused oxides of iron, aluminum, manganese, magnesium, calcium, phosphorous etc.

Iron making slags, known as Blast Furnace Slag (BFS) are predominantly utilized in the cement making, but the Steel Making Slags, both from BOF (also called as LD Converter) as well as EAF/IF have limited usages.

However in India, the importance of steel slag utilization is yet to be fully realized and implemented by adopting already proven technologies worldwide. India has about 55 million tone capacity of steel production through BOF route, where slag generation is about 150-175 kg/t of steel. Steel slag has a great potential as a replacement for natural rock/ aggregates in construction. Steel slag processing has been developed worldwide to enable its use as product acceptable by the construction industry. Steel slag aggregate meets all important physical characteristics of aggregates.

Steel slag can also be used for amending acidic soils for soil neutralization and as source of growing agents. India is having nearly 40% of arable land as acidic and thus steel slag can be the best and cheapest source for such soil to correct the acidity as well as improve the crop productivity.

This paper discusses the opportunities and strategies needed for effective utilization of steel slag in a cost effective manner by making steel slag utilization a sustainable, energy efficient and environment friendly sector zhereby contributing to natural resource saving, CO2 emission reduction and also provide ecological advantage.

INTRODUCTION

Sand is an important mineral for society, in aquatic ecosystems (rivers and lakes), it supports organisms that are vital to the food chain, protects shorelines and riparian systems. In the past few decades, the demand for construction grade sand has been increasing exponentially, due to rapid economic development and growth of construction activities.

However, mining and removal of large amount of natural sand from river banks can have adverse

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consequences to the environment, as it destroys the habitat of organisms residing in the eco system, destabilizes river banks and beds affecting the natural flow of rivers and streams leading to increase of floods causing destruction of bridges and crop damages. The demand and supply gap has also led to illegal mining and selling practices through dubious channels. In 2017, annual sand demand in India was around 700 Million Tonnes and demand will increase in the years ahead. To address these challenges, sector organizations are looking towards viable alternatives to river sand.

On 18.04.2019, National Green Tribunal (NGT), in an interim order, directed "The Andhra Pradesh Government should prohibit all unregulated sand mining in the river and initiate stern action against the persons responsible, including conniving officers, and recover the money and use it for restoration of the river". NGT clearly asked that sand miners to compensate damage from sand mining and wants that sand miners to pay for rejuvenating the environment after the sand removal has taken a toll on riverine eco-systems and the river water.

STEEL SLAG AS ALTERNATIVES TO SAND AND AGGREGATE

Due to rapid development and activity in construction of roads/highways, buildings, Metro Rails etc, the per capita steel consumption in India is likely to be increased from existing level of 68 kg to 160-180 kg by 2030-31.To ensure sustainable development of the steel sector and to meet continuously growing demand of steel from the domestic sources, National Steel Policy 2017 (NSP-2017) has been issued. This will require increasing steelmaking capacity from present level of 125 Million Tons Per Annum (MTPA) to 300 MTPA by 2030-31.

To produce steel, removal of excess silicon and carbon from iron is achieved through oxidation by adding limestone and coke. The steel slag contains higher amount of iron and its physical characteristics are similar to air-cooled iron slag. The LD slag is cooled, crushed and screened. The fines are utilised in sinter making and lumps are charged in the blast furnace.

The iron content is the major basic difference between BF slag and steel slag. In BF slag, FeO is around 0.70%, whereas in case of steel slag, total iron content varies from 16 to 25%. JSW Steel has set up a unique BOF slag granulation plant, producing slag with lower free lime content and is vigorously pursuing with BIS.

Steel slag has a great potential as a replacement for natural aggregates in road construction. Steel slag processing has been developed to enable its use as product acceptable by the construction industry.

Steel slag aggregate meets all important physical characteristics of aggregates laid down in Ministry of Road Transport and Highways (MoRTH) specification for Road and Bridge Work 2013 for preparation of bituminous concrete mixes. Currently, use of steel slag as aggregate is limited within few hundred kilometers around the steel plant, mainly due to the logistics issues. Although, field trials have been conducted for assessing the suitability of processed weathered BOF slag for use as rail track ballast, but due to presence of lime the safe utilization could not be established till date. Pilot scale study has been conducted for "Development of process for steam maturing of BOF slag" so that the issues of lime can be addressed and acceptability of slag as an aggregate or rail ballast can be improved.

Besides, steel slag can be used for amending acidic soils for soil neutralization and as source of growing agents. India is having nearly 40% of arable land as acidic and thus steel slag can be the best and cheapest source for such soil to correct the acidity as well as improve the crop productivity. This necessitates conducting field level trials to develop steel slag based cost effective ecofriendly fertilizers for sustainable agriculture and inclusive growth.

TYPES AND CHARACTERSTICS OF STEEL SLAG

Steel slags are produced at Steel Melting Shop during steel manufacturing. To produce steel, removal of excess silicon and carbon from iron is achieved through oxidation by adding limestone and coke. This slag is a byproduct from steelmaking

processes in which the components of pig iron and steel-scrap are modified in order to produce steel that is so highly valued for excellent toughness and workability. Steelmaking slag consists of converter slag that is generated by LD (Linz– Donawitz) - Converter and Electric Arc Furnace (EAF) Slag that is generated during the Electric Arc Furnace (EAF) steelmaking process using steel-scrap as the raw material.

- **LD Converter Slag:** Converter slag is cooled slowly by natural cooling and water is sprayed in a cooling yard. It is then processed and used for various iron and steel slag (converter) applications. Approximately 110 kg of slag is generated for each ton of Converter Steel.

  These slags are a well mixed aggregate of FeO, lime, silica and MgO generated at the LD converter. They are in the form of di-calcium and tri-calcium silicates. These slags also contain free lime and metal creating problems due to expansion characteristics.

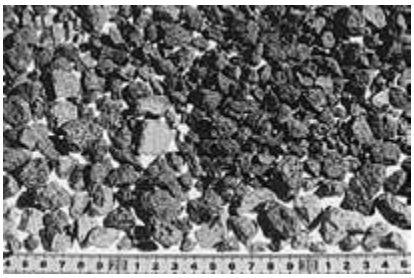
- **SGP Slag:** LD slag is subjected to granulation through a quenching technology. Due to sudden quenching of the molten slag, contraction of metal and slag occurs and results in good separation of metal and slag. Adequate granulation takes place and leads to good stability of the final slag. Process can be described as an accelerated ageing process that reduces the free lime content. Because of rapid cooling, it generates more glassy structure. Removal of free lime also confirms its volumetric stability. The steel slag contains higher amount of iron and its physical characteristics are similar to air-cooled iron slag. The LD slag is cooled, crushed and screened. In steel slag, total iron content varies from 16 to 25%.

- **Steel Slag:** These slags vary in composition with respect to the varied treatment. The common steel slags are fused calcium aluminates with less than 2% (FeO + MnO). These readily crumble to dust due to allotropic phase transformation at lower temperatures and are difficult to manage.

- **Electric Arc Furnace Slag:** Electric Arc Furnace(EAF) slag is generated when iron scrap is melted and refined. It consists of oxidizing slag that is generated during oxidation refining and reducing slag that is generated during reduction refining. Approximately 70 kg of Electric Arc Furnace oxidizing slag and 40 kg of reducing slag are generated for each ton of Electric Arc Furnace Steel. Primary characteristics and applications of iron and steel slag are furnished in Table No.1.

USE OF STEEL SLAG IN JAPAN AND EUROPE

Fine aggregate



Course aggregate

Use of Steel Slag in Japan

Steel slag aggregate is an industrial product that is manufactured under extensive quality management and contains no organic impurities, clay, shells, or similar materials. For both fine particles and course particles, the chemical composition is completely uniform. In addition, this aggregate contains no reactive silica, which is one cause of chemical reaction with alkali aggregates. It reduces environmental impacts; preserves precious natural resources needed to maintain ecosystems and can reduce the energy that is consumed in mining, stone crushing, and other activities.

Course Aggregate and Fine Aggregate

The two types of concrete aggregate that are manufactured using steel slag as a raw material and are covered by Japanese Industrial Standard (JIS). Course aggregate is a mechanically stabilized aggregate created by slowly cooling the molten slag after it is removed from a Blast Furnace or Electric Arc Furnace. Fine aggregate is a mechanically stabilized aggregate created by using water, air, or other means to rapidly cool the molten slag after it is removed from the furnace.

Recognized Advantages

JIS standards were formulated for blast furnace slag course aggregates in 1977 and for fine aggregates in 1981.These standards have been incorporated into recommendations for a variety of practices by the Architectural Institute of Japan and the Japan Society of Civil Engineers and these aggregates have earned a place as an important construction material.

A JIS standard was also formulated for Electric Arc Furnace oxidizing slag aggregates in 2003 and these also have been formulated into a design and practice recommendations by the Architectural Institute of Japan and the Japan Society of Civil Engineers.

Iron and steel slag aggregates have a number of advantages, including containing no organic impurities, clay, shells, or other substances that can affect concrete durability; little variation in quality; and no expansion due to alkali-aggregate reaction. In addition, the density of Electric Arc Furnace oxidizing slag aggregate under oven-dry conditions is approximately 3.6 g/cc which is higher than other aggregates. This characteristic is put to use in applications such as radiation shielding concrete and heavy-weight concrete Contributing to environmental preservation as a replacement for natural aggregate.

In recent years, with restrictions on dredging of marine sand and the stopping of sand imports from overseas, there has been a growing need in society for measures in response to the exhaustion of natural aggregate. This has resulted in a rapid increase in demand of amount of concrete slag aggregates that are sold. Blast furnace slag aggregates became a designated procurement item under the Green Purchasing Law in 2002, while electric arc furnace oxidizing slag aggregates were designated in 2005. These materials are highly regarded as environmental materials that can protect the environment by limiting exploitation of natural resources and reduce the amount of energy consumed in the mining of natural resources.

Superior Durability and Cost Performance

Iron and steel slag used in road construction is manufactured by crushing and mechanical stabilization of Blast Furnace slag and Steel slag for use as paving material. These two types of slag are used in base course materials that are produced from them individually or in a mixture and steelmaking slag is used as an aggregate for asphalt mixtures.

In 2002, base course material containing iron and steel slag and asphalt mixture containing iron and steel slag were designated as a designated procurement item under the Green Procurement Law, and are widely recognized as materials that can contribute to environmental preservation:

Agricultural Benefits

Agricultural Slag (Ag-Slag) can help grass grow by adding micronutrients to the earth, by neutralizing soil acidity, by conditioning the grass and helping to retain moisture. Slag has been proven to be a valuable replacement for agricultural lime. It can help increase crop yield and improve soil texture by breaking down clay-like soil. According to studies as far back as 1927 by Penn State University, Ohio State University, U.S. Department of Agriculture, Auburn University and Canadian research, Agricultural Slag (Ag-Slag) applications have been equivalent to limestone and dolomite in increasing crop yields at equal levels of fineness. Both blast furnace and steel slag have chemistries that make them suitable as liming materials. Slag serves not only as a liming agent, neutralizing soil acids, but it also contains important micro-nutrients often lacking in soils. Ag -Slag corrects soil acidity basically in the same manner as limestone. Calcium

Carbonate Equivalence (CCE) ratings can be directly compared.

Use of Steel Slag in Europe

Slag use is subject to strict regulations and standards in Europe. The use of slag is clearly regulated for particular applications. For instance, production of aggregates is carried out in accordance with the European Construction Product Directive and harmonized, European standards are as follows:-

- EN 12620:2013/aggregates for concrete
- EN 13043:2002/aggregates for asphalt and surface treatments for road, airports and other traffic zones
- EN 13242:2013/aggregates for unbound and hydraulically bound mixtures for use in engineering and road construction.

WAY FORWARD

Iron and Steel Slag Market 2019 Research Report contains a qualified and in-depth examination of Iron and Steel Slag Market. It provides current Iron and Steel Slag business situation along with a valid assessment of the Iron and Steel Slag business. The construction industry is the primary driver of demand in the global iron and steel slag market. In order to stay ahead of the curve in the global iron and steel slag market, keen players are seeking out partnerships with different end-use industries, namely building and construction, railways, fertilizers, rock wool, etc. They are also leveraging latest technologies and value added services in specialized products to outsmart their competitors. Geographically, this report is segmented into several key regions, with sales, revenue, market share and growth rate of Iron and Steel Slag in these regions, from 2014 to 2024, covering the following:-

- North America (United States, Canada and Mexico)
- Europe (Germany, UK, France, Italy, Russia and Turkey etc.)
- Asia-Pacific (China, Japan, Korea, India, Australia, Indonesia, Thailand, Philippines, Malaysia and Vietnam)
- South America (Brazil etc.)
- Middle East and
- Africa (Egypt and GCC Countries)

CONCLUSION

Today, iron and steel slag is used in many fields where its unique characteristics can be put to effective use. As a result of growing environmental awareness, iron and steel slag is highly regarded as a recycled material that can reduce impacts on the environment due to its resource-conservation and energy-saving effects.

Slags from the iron and steel industries are sometimes erroneously classified, and often looked upon, as industrial waste materials. In fact, these by- products/ co-products are valuable and extremely versatile construction materials. The need for maximum utilization for economic and environmental reasons has led to rapid development of slag utilization. Primary characteristics and application of Iron and Steel Slag are shown in Table 1.

Slag may assist in attaining LEED credits by the Green Building Council for new construction because of its recycled/renewable resource content. There is an urgent need to utilize this by-product/ co-product effectively by promoting researches as well as adopting already proven technologies worldwide.

Highlighting the importance of recycling all the stakeholders must adhere to the "golden mantra" i.e. the mantra of 6 R's-Reduce, Reuse, Recycle, Recover, Redesign and Remanufacture. This will significantly help to minimize the waste.

MRAI (Material Recycling Association of India) and KPMG worked together as a domain knowledge partner for the preparation of the National Material Recycling Policy of India.

Niti Aayog has initiated the work on the Material Recycling Policy draft and the same is now available for Union Cabinet discussion and further approval.

We can conclude saying that when human ingenuity and technology meet, they have the power to solve some of the biggest environmental challenges as an existential crisis.

Table 1 : Primary Characteristics and Applications of Iron and Steel Slag

Types of Slag		**Characteristics**	**Applications**
Blast Furnace slag	Air-cooled slag	Hydraulic property	Road base course material
		No alkali-aggregate reaction	Coarse aggregate for concrete
		Low Na_2O and K_2O	Cement clinker raw material (replacement for clay)
		Thermal insulation and sound absorption effects when made into a fiber	Raw material for rock wool
		Fertilizer component (CaO, SiO_2)	Calcium silicate fertilizer
	Granulated slag	Strong latent hydraulic property when finely ground	Raw material for Portland blast furnace slag cement
			Blending material for Portland cement
			Concrete admixtures
		Low Na_2O and K_2O	Raw material for cement clinker (replacement for clay)
		Latent hydraulic property	Material for civil engineering works, ground improvement material (Backfill material, earth cover material, embankment material, road subgrade improvement material, sand compaction material, ground drainage layers, etc.)
		Lightweight, large angle of internal friction, large water permeability	
		Does not contain chlorides.	Fine aggregate for concrete
		No alkali-aggregate reaction	
		Fertilizer component (CaO, SiO_2)	Calcium silicate fertilizer
			Soil improvement
Steel slag	Converter slag, Electric Arc Furnace slag	Hard, wear-resistant	Aggregate for asphalt concrete
		Hydraulic property	Base course material
		Large angle of internal friction	Material for civil engineering works, ground improvement material (Material for sand compaction piles)
		FeO, CaO, SiO2 components	Raw material for cement clinker
		Fertilizer components (CaO, SiO_2, MgO, FeO)	Fertilizer and soil improvement

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TECHNICAL SESSION III:
CONSTRUCTION MANAGEMENT TOOLS

SUSTAINABLE BUILDING DESIGN AND CONSTRUCTION

A.K. JAIN*

Abstract

Every building involves decisions regarding site layout, building design, density, floor area ratio, construction and infrastructure development. These are to be based on sustainability, which include passive design, optimum use of land, compact and dense form, minimising the building footprint, envelope and skin area, and minimising the cost of construction, roads and services. Sustainability increases with the use of solar energy/energy efficiency and trigeneration, water conservation and wastewater recycling, natural light and ventilation, use of low-energy resources and recycling of building materials.

The paper explains the basic principles of sustainable building design that obviates outdoor and indoor pollution, avoids use of high energy and high carbon materials and makes optimum use of space and resources.

INTRODUCTION

A common perception of urbanism and buildings is that they are energy guzzling, use much water and natural resources. The design of a building must aim to maximize the use of low-embodied energy building materials and construction practices, optimize the use of on–site sources, use of energy efficient lighting and air–conditioning, renewable energy, efficient water management and provide a comfortable and hygienic environment. The following aspects are critical in the design of sustainable buildings:

- Urban matrix
- Sustainable site planning and building form
- Parametricism for redevelopment with ecological conservation
- Passive bio-climatic design
- Building envelope
- Building skin-design,
- solar heat gain coefficient and U factor
- Sustainable resources

URBAN MATRIX

Every building is a part of urban ecology and has a footprint. As such, a building has to be designed in the context of ecology and environment, mobility, bio-diversity and natural resources, social and physical infrastructure, mobility, communication and local culture.

Decisions regarding site layout, building design, density, floor area ratio, construction and infrastructure development are to be based on the urban ecology and sustainability. A compact development can significantly help in saving fossil fuel consumption, climate change and environment.

In this regard, various ideas, such as green roads for e-vehicles, the regulation of traffic and pedestrian flow through live data, the demotion of freight and parking in underground tunnels, shaded pavements, self-sorting pneumatic refuse chutes and data-powered purge of the urban space can be explored. Future policies of infrastructure, technologies must encompass inclusive and multi-level social, economic, technical and spatial dimensions, which are based on scalability of digital, geo-referenced data.

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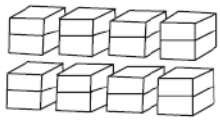
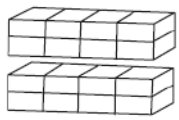
Planning and design should allow intensification of built space over a smallfootprint. The building type should permit more useable floor-space, to make better returns from the land, put more goods, and more people in one place. The environmental justification is that the concentration of activities enables the reduction of energy consumption in buildings, transportation and services. The built-form should be a result of the optimization of land costs and building economics, the locational preferences and the interventions of architectural and engineering design.

Table1: Comparison of the surface area, heating energy consumed and construction costs for eight building unit, in different configurations. the lower the footprint and envelope area, the more energy--efficient is the building.

Building form	 *8 separate houses (ground floor plus basement)*	 *2 terraces of 4 house} (ground floor plus basement)*	 *block of 8 flats (2 storeys plus basement)*
Site area	100 %	70 %	34%
Envelope surface area	100%	74 %	35%
Heating energy	100 %	89 %	68 %
Construction costs	100%	87%	58 %

Source: Presig H.R, et al (1999) OkologischeBaukampetenz, Zurich

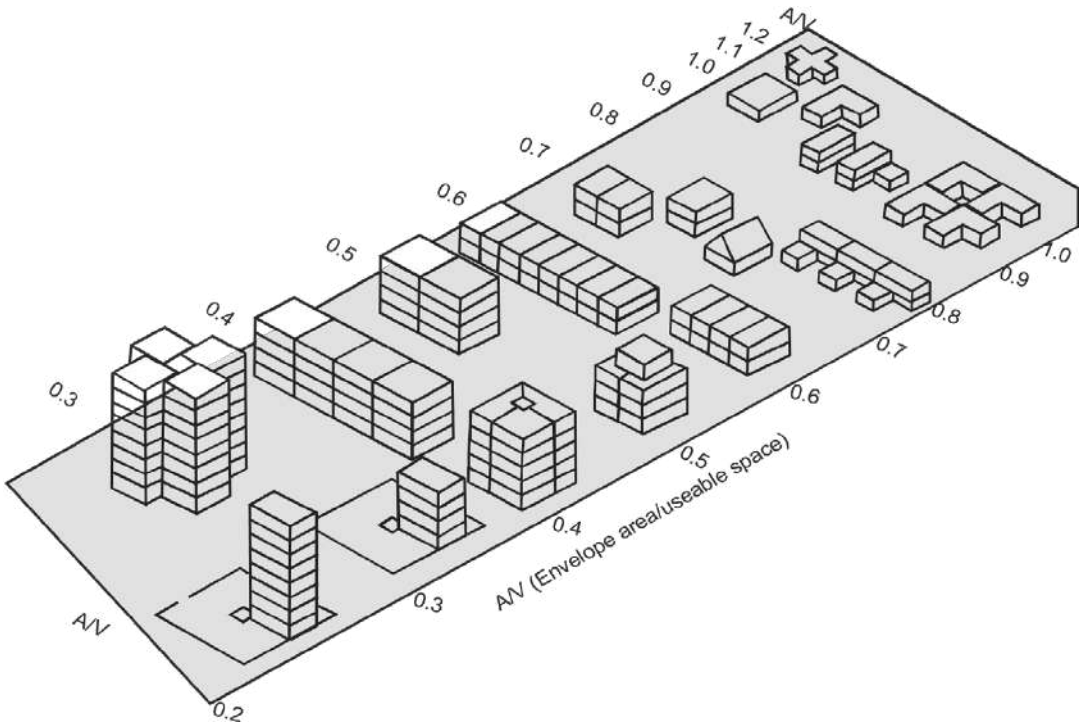


Fig. 1: Comparison of low-density/ far and high-density /far in terms of land efficiency, building footprint, envelope and costs

Source : Solarburo. Dr. Peter Goretzki, 1997

As an example, for accommodating 10,000 dwelling units at 100 Du/Ha, 100 Ha of land will be required. By increasing the density (and also FAR) to 200 Du/Ha, the land requirement will be half. As land cost in a mega-city is as much as a 70 to 80% of the cost of dwelling unit, it means reduction of housing cost by 35 to 40%. All service lines-water system, electricity, cables, sewerage, drains, roads and pathways will be reduced by half, thus making the development and services economical. The transmission leakages and losses and manpower required will also be much less. Table 1 and Fig. 1 illustrate this concept.

Local climate has a significant connection to the overall benefits that can be expected from urban heat island mitigation strategies. For example, areas with cooler mean temperatures and more cloudy days would likely have less energy savings compared to the areas with reduced cloud cover and rain and higher temperatures. Also, the effect of breezes in dispersing pollutants may affect potential air quality benefits. Tradeoffs between roofing types and insulation may also be influenced by the local climate.

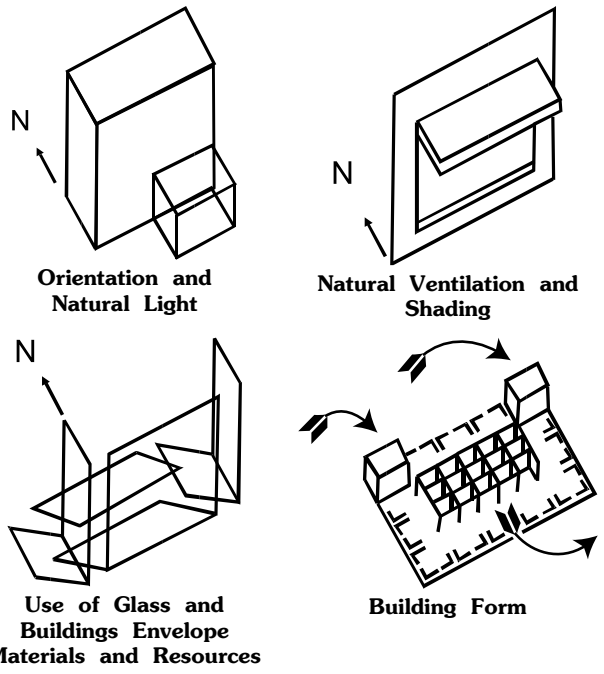
Natural ground forms are best accepted as given. They are the resolutions of myriad forces at work over a long span of time. To adapt to them is to harmonise with the forces and conditions by which they have evolved. By means of site reconnaissance and soil hydrology surveys the most productive land can be designated for lawns, gardens or crop production or can be preserved in its natural state. Areas of thin soil, poor or excessive drainage, or underlying rock are the prime candidates for projected development.

SUSTAINABLE SITE PLANNING AND BUILDING FORM

In hot climate the objective of site planning and building form is to minimize solar gain and to reduce the need of cooling thus reducing the demand for energy. As such to reduce surface area for heat transfer, it is necessary to avoid elongated thin forms and spread out low-rise housing. Compact and dense forms are preferred with multiple use/ mixed uses. Landscaping can enhance the ecology and aesthetics and cool the buildings. Apart from ground planting, vertical landscaping, patios and roofs can be landscaped.

Ten basic principles of sustainable site layout and building design (Fig.2) include the following:

- Passive design, optimum densities, mix land use, compact and dense form
- Reduce building footprint and maximise greens, play areas, patios, green roofs, vertical landscaping and public areas
- Minimise building envelope and skin area to usable space
- Site planning to minimise road length and service lines
- Using tools of Floor Area Ratio (FAR), accommodation reservation, transferable development right for provision of public facilities, roads and greens in private lands
- Solar energy/energy efficiency and trigeneration
- Water efficiency and wastewater recycling
- Orientation for natural light, ventilation and shading
- Use of low-energy resources and recycling of building materials.



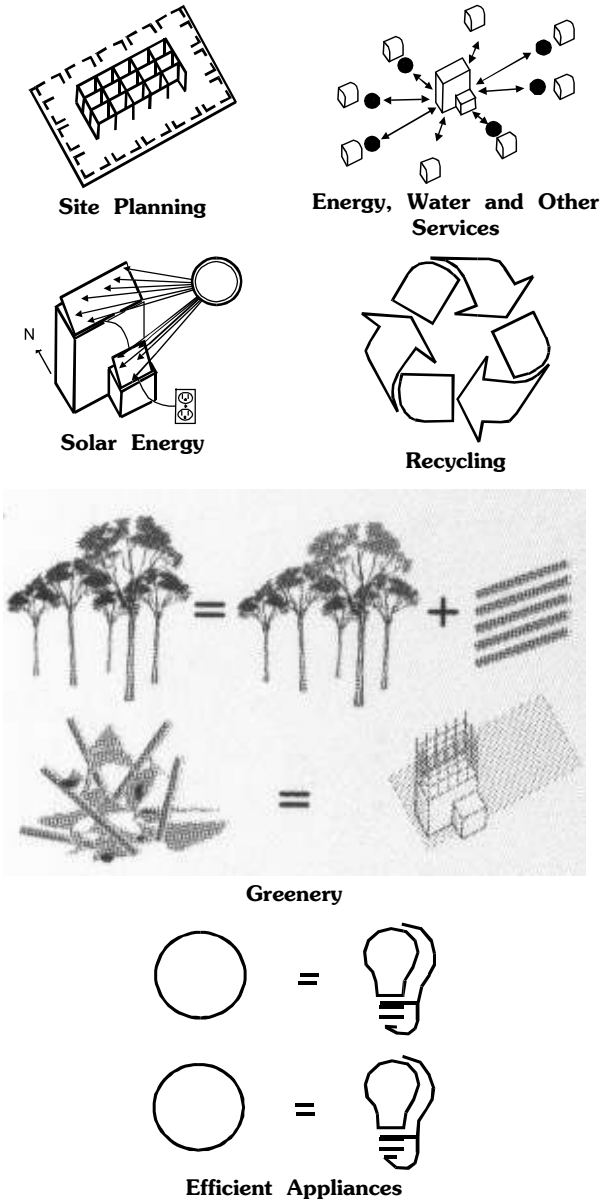


Fig. 2: Ten Basic Principles of Green Building Design

PARAMETRICISM

There is ample scope to re-plan and re-densify the existing built-up areas at a site with existing trees. As a basic principle, no tree should be cut down which may be treated like a human being. The cutting of trees is the failure of conventional planning. The new parametric model of planning allows for every tree as an asset and accordingly adjustments are made in road alignment, building footprint as per existing vegetation, climate and culture. The planners and architects can take advantage of this tool to relate their proposal with the existing site conditions, landscape, energy, water and other services and systems.

Also parameterised are the service networks and transportation, which are the critical factors in urban carbon footprint. Against the Data Model, the parametric model is crucial tool for integrated performance of green and smart built environment.

PASSIVE BIO-CLIMATIC DESIGN

Passive design strategies such as day lighting, natural ventilation and an appropriate building fabric, should be integrated into the design to reduce energy consumption. Sustainable design and construction should not suffer from the impacts of a changing climate—be it hot summer, floods, storms, or rising sea levels.The design of green building revolves around a concern for extending the life span of natural resources, providing human comfort, safety and productivity and reduction of operating costs like energy and water.

The pathway of building design, construction and operations include the following:

- Passive and intensive design of building for climatic comfort (e.g. bio-climatic skyscraper)
- Optimum use of energy and reducing its need by day lighting, courtyards, green roof, ventilation, etc.
- Water conservation and waste water recycling
- Solid and waste management, treatment and reuse
- Energy efficient, non-polluting construction, fuels, building materials and transport.
- Efficient building systems, construction and maintenance.

According to Ken Yeang "intensive development and tall buildings are inevitable in our cities, the bio-climatic skyscraper will contribute to reduced energy consumption in the built environment and will be more ecological, beneficial than the conventional skyscraper since this achieve passively. At the same time, the bioclimatic skyscraper provides a more aesthetically fulfilling humane and safer high-rise built environment for its occupants (Fig.3)."

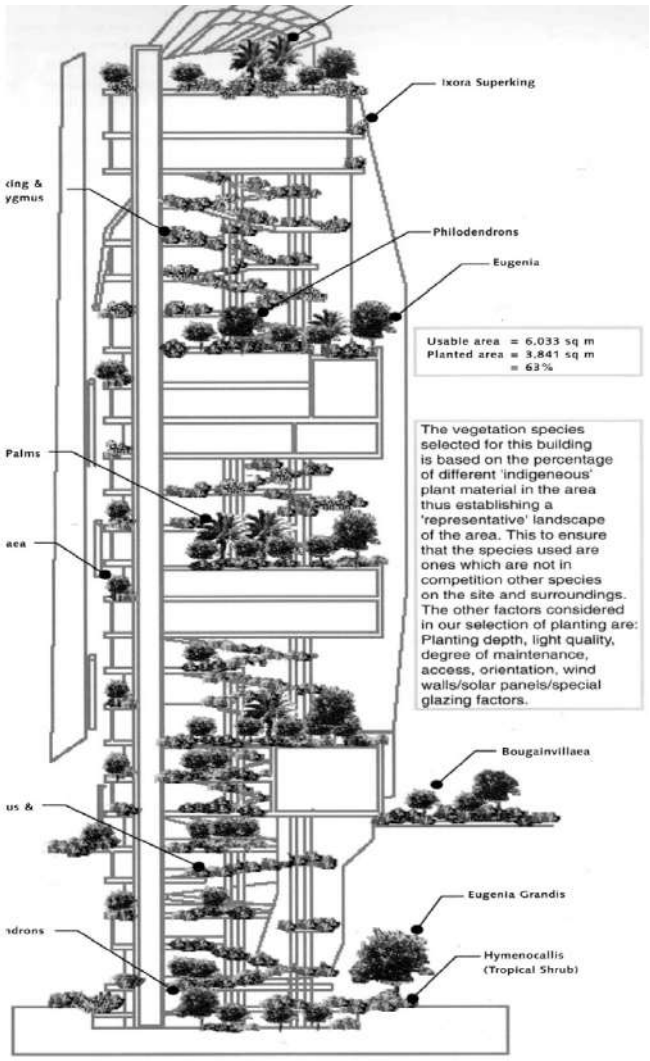


Fig. 3: Bio-Climatic Skyscraper: Climate Zones and Precipitation Regions determine the Development of Building Design, its Modelling of the Fabric and Features-Vertical, Spiral/ Hanging Gardens, Terraces, Courts, Atriums, Louvers, Tiered Sun Shades and Shaded Envelope Combined with Bionic Controls and Intelligent Systems

Source :Yeang Kenneth, 1999, the Green Skyscraper, the Basis for Designing Sustainable Intensive Buildings, Prestel, New York

BUILDING ENVELOPE

The building envelope (Fig. 4) refers to the exterior facade and comprises opaque components and fenestration systems. Opaque components include walls, roofs, slabs on grade, basement walls, and doors. Fenestration systems include windows, skylights, ventilators, and glazed doors. The envelope protects the building's interior and occupants from the weather conditions and shields them from other external factors, e.g. noise, air pollution, etc.

Envelope design strongly affects the visual and thermal comfort of the occupants, as well as energy consumption and heat transfer (conduction, convection and radiation) in the building. Heat transfer takes place through walls, windows, and roofs in buildings.

Buildings are exposed to external temperatures and radiant heat. Accordingly, building orientation has an important bearing on energy conservation, such as arranging the building and its openings facing north and south helps in reducing air-conditioning load, on the building envelope solar shading, brise-soleil, louvers, adjustable glazing and balconies or recesses can act as 'sun spaces' and collecting solar heat.

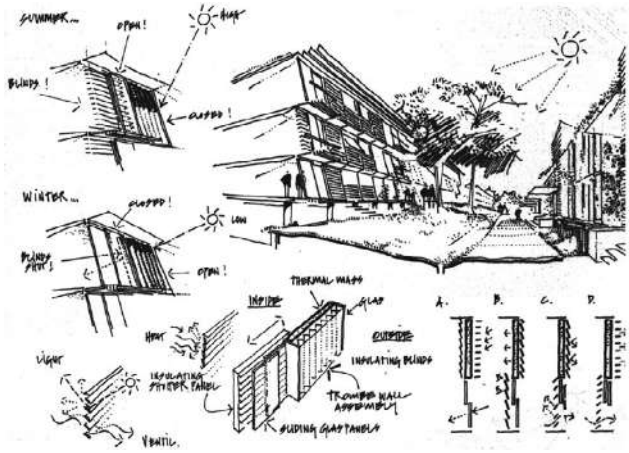


Fig. 4: Envelope Study with Trombe Facade for Housing at Solar City, Linz Pichling (Austria), Architect, Sir Norman Foster.

The building envelope forms the outer skin of a building and expresses its image and creative intent. They are also important environmental moderators. A thoughtfully designed building envelope can make a building work more effectively for its users, occupants and environment. It can also transform the performance of an existing building and can effectively control the physical environmental factors such as heat, light and sound, thus improving the occupant comfort within a building.

Cutting edge technological advancement is leading to the fasade design that is responsive to environment, changing dynamically with the weather and seasons, aligning with nature, nurturing

the green environment and is constantly evolving. These technologies are instruments of visual drama that present a play in the urbanscape and building facade.

The material of high-rise fasade is exposed to mechanical, weather and maintenance related loads. The use of high-performance materials assumes an economic and ecological relevance. Titanium, for example, is a possible choice because of its resistance to wear by friction and to the weather. High alloy special steel (ferrite austenite steel) is another option for high-rise fasade.

BUILDING SKIN DESIGN

The building skin is the first layer of protection for the occupants against sun, wind, and rain and at the same time it has to provide comfort along with:

- Natural ventilation
- Better acoustic insulation and noise protection
- Reducing energy requirements and exploiting solar power

To achieve energy efficiency, the following measures can be adopted:

- Minimize exposure on the south and west
- Use simulation tools and techniques that can help in designing the building orientation to minimize heat energy.
- Designing lighting levels for the expected activities keeping into consideration the type of activity, its duration and spaces where they are needed
- Designing with effective and efficient luminaires and using them in conjunction with fenestration/ windows with controls for sunlight and skylight.
- The colour and finishes on ceilings, walls, floors and furnishings, and flexibility in controlling the lighting, switching devices/dimmers, etc. for areas that need varying lighting levels.
- Designing fenestration/windows in a manner that reduces heat producing radiation entering spaces and choosing lighting devices/fixtures that have low heat/radiation.

In the modern buildings with sealed envelopes, almost all building processes are mechanically run and controlled, leaving little scope for manipulating the external and internal micro-climatic environments. This results in significant loss of energy. Humidity control is another element that need due consideration through the design of heating and cooling system, and the design of fenestration. As a thumb rule, in non-domestic buildings, the window area should be about 20 per cent of the floor area to provide sufficient light to a depth of about 1.5 times the height of the room. Various switching sensors like timer control, daylight control, occupancy linked control, etc. can be adopted.

SOLAR HEAT GAIN COEFFICIENT (SHGC) AND U-FACTOR

SHGC is the ratio of the solar heat gain (Fig.5) that passes through the fenestration to the total incident solar radiation that falls on the fenestration. The solar heat gain includes directly transmitted solar heat and absorbed solar radiation, which is then re-radiated, converted, or conducted into the interior space. SHGC indicates how well the glazing/glass and fenestration products insulate heat caused by sun falling directly on the glass.

In hot climates, SHGC is more important than the U-factor of the glazing. A lower SHGC means that lesser heat can pass through the glazing. The SHGC is based on the properties of the glazing material, whether the window has single, double, or triple glazing, and the window operation (either operable or fixed). Glazing units with a low SHGC helps to reduce the air conditioning energy use during the cooling season.

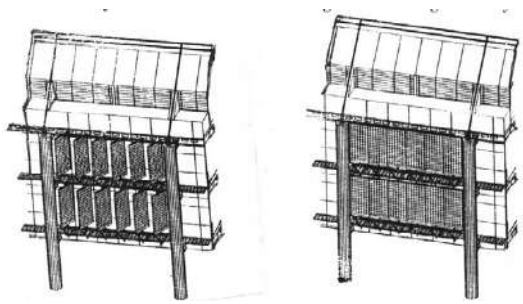


Fig. 5: The "Smart" Fasade Filters Sunlight according to Internal Temperatures, thus regulating Solar gain and Light effects. The automatically controlled system can also be manually driven

Heat transfer across glazing or fenestration (windows, door, and skylights) is similar to the heat transfer that takes place across walls and roofs through conduction and convection. So, U-factor of glazing is analogous to the U-factor of wall assembly. In addition, direct solar radiation contributes to the solar heat gain through the fenestration system.

Fenestration and doors must be rated using procedures and methods specified in the ECBC. Three fenestration performance characteristics are significant in the ECBC: U-factor, SHGC, and Visible Light Transmittance (VLT).

SUSTAINABLE RESOURCES AND CONSTRUCTION

A lot of energy is expended in building materials from their extraction, production and finally transport to the construction site. This is called the embodied energy of materials. Material extraction from quarries and mines as well as their processing process can also have adverse environmental impacts.

For specifying sustainable and 'green' materials, the key considerations are:

- Locally sourced materials require less energy for transportation to the site and relate to the context of the surroundings.
- Low embodied energy and preferably natural materials.
- Promote use of recycled materials, especially, for high embodied energy materials like steel and aluminum.
- Recycled use of C&D waste, such as recycled bricks and blocks for foundations, paths, parking, landscaping and construction

The strategies to achieve these objects include the following:

- Reduction in the amount of materials consumed
- Promotion of reuse and use of recycled materials
- Use of materials that reduce the environmental impact and substitution of materials and processes that have less impact on the environment.

Over-designed structures, footings, etc. may result in a waste of materials. Consider alternative foundations and structures, where appropriate. Specify timbers form sustainable forests. Minimize the use of chemicals and hazardous materials and adopt less toxic alternatives. Specify the reuse of materials arising from demolition on site and recycled materials. Shuttering should be reused, where possible, rather than destroyed on completion. Allocate space for the future recycling of construction and demolition wastes and a composting facility, where appropriate.

CONCLUSION

The building links the sustainability of the built environment, human health, bio-diversity and natural resources. To create sustainable built environment, it is necessary to use less energy and water, generate less greenhouse gases, use the resources and building materials more efficiently, and produce less wastes. A sustainable building responds to the micro-climate and varying conditions of natural ventilation and light. The design obviates outdoor and indoor pollution, avoids use of materials with high energy demand and optimises use of space, water renewable energy and innovative and intelligent systems.

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COMMUNICATION – AN IMPORTANT TOOL IN PROJECT MANAGEMENT

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Abstract

A construction project is an endeavor undertaken by a project team on behalf of owner/client to create a built facility suited to the defined functional objectives. Communication serves as an important tool in hands of the project manager to ensure that the responsibility entrusted to them in respect of timely delivery of the project within the cost and with specified quality is achieved.

Communication involves transfer of information, a generic term that embraces meaning such as knowledge, processed data, skills and technology. Role of communication becomes more important on a complex undertaking like a construction project where there are many project participants who collaborate in project formulation, its planning and execution and subsequent commissioning of installations. Quality of communication directly effects the efficiency and effectiveness of the construction process as more open communication could lead to better decision making, innovations and better technical solutions, facilitate teamwork and minimize scope of misunderstandings.

INTRODUCTION

A construction project is an endeavor undertaken by a project team on behalf of owner/ client to create a built facility suited to the defined functional objectives. Communication serves as an important tool in hands of the project manager to ensure that the responsibility entrusted to them in respect of timely delivery of the project within the cost and with specified quality is achieved.

Communicating effectively requires significant skills. Communication and documentation bind the project together from start to finish, as the backbone of sound project management. Successful planning and execution of a project is dependent, to a great extent, on effective Communication Management planning and its implementation. One of the things that separates effective project managers from relatively ineffective ones is how much forethought they put into communication and documentation from the very beginning of their project.

COMMUNICATION AND ITS NEED

Communication involves transfer of information, a generic term that embraces meaning such as knowledge, processed data, skills and technology. Role of communication becomes more important on a complex undertaking like a construction project where there are many project participants who collaborate in project formulation, its planning and execution and subsequent commissioning of installations. Quality of communication directly effects the efficiency and effectiveness of the construction process as more open communication could lead to better decision making, innovations and better technical solutions, facilitate teamwork and minimize scope of misunderstandings.

Communications is the foundation of every project. Regardless of the business at hand, if one is not able to get his ideas across clearly then problems arise. But communications, ironically, can become part of the problem when it blocks the completion of the project tasks with unnecessary clutter.

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The collaborating participants or organizations may be located in dispersed geographic locations. In present scenario, collaborating organizations could also be located in different countries and working in different time zones. Each project participant has varying role, responsibilities, goals, work practices and culture. This creates special communication challenges, as collaborating organizations are required to efficiently exchange large number of technical documents and correspondence items during the life cycle of the project. Cooperation between participants with different backgrounds and working practices makes it important that effective communication processes and systems are established for sharing the most up-to-date information in order to carry out day-to-day tasks with least errors, reduced time delays and less time spent on redesign and process management. It requires establishing clear channels of communication and documentation of the project communication, defining systems for adequate documentation system for recording communications and control of communications. This facilitates completion of construction projects as per estimated time, within budget, as per specifications and with minimum risk.

COMMUNICATION REQUIREMENTS

One should review the infrastructure decisions and determine how all formal communications will be done. Internal reporting required for the project team and external communication for sponsor, stakeholders and others needs to be defined and responsibility for all product communications and schedule routine communications to support project plan execution to be assigned.

If the project involves confidential or proprietary information, Project Manager need to document how it will be handled.

STRUCTURE OF THE COMMUNICATION

Structure of the communication will depend upon the purpose of communication. For effective communication one should strive to be concise, pay attention to spelling, grammar, sentence structure, and composition. When communicating—particularly in written communication, following should be kept in view:

- **Avoid distractions:** Consider everything that may distract the recipient from getting the full impact of the communication and strive to reduce or eliminate them. Choose the right timing and physical setting. Make sure that your conduct isn't distracting.
- **Consider long-term effects:** We often think of communication as being immediate and short-lived. However, that's not always the case. What if your e-mail note gets forwarded to the wrong person? What if you fail to include someone in a critical communication? Such matters may have long-term implications.
- **Follow up:** It's a good practice to follow up on your communications. Check if the person received the message and understand it? Do they have any questions?

COMMUNICATION METHODS

The way a message is communicated can often be just as important as the message itself. Choosing the best way to communicate in a particular situation is a very important decision.

Develop a plan for archiving project data and communication in a project management system (PMIS), including project definition documents, project plans, status reports and presentations, logs of project issues, approved changes and project closure reports. If data will be stored online, determine what you may need to do to permit or restrict access.

- Verbal Communication
- Written Communication
- E-Mail communication
- Online Collaboration

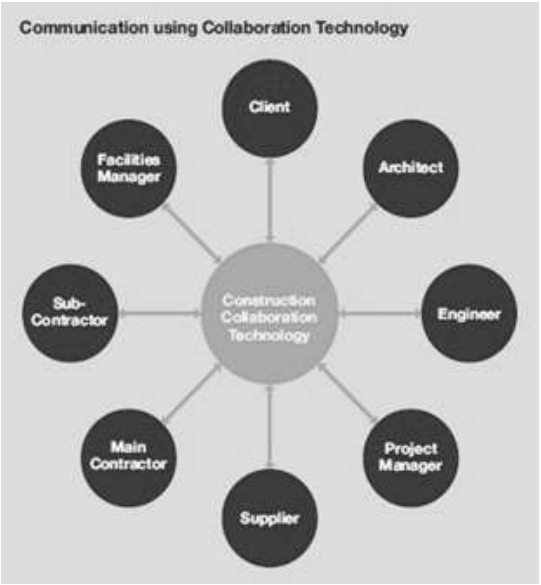
Communication in global teams is both formal and informal. If formal communication (performance reporting, documents, scheduled meetings, presentations and product reviews) is ineffective, people have little information and project performance will suffer. If communicating informally (conversations, emails, social interactions

and memos) is inadequate, problems will surface too late when they are difficult to solve. Preferences differ, so Project communications are required to be balanced to support the project and provide communication that serves everyone's needs

Most effective communication is in-person communication, but all the methods available that are suitable for the team should be used. Because verbal communication is so difficult on global projects, after daily conferences, meetings and conversations it should always be followed up in writing.

ONLINE COLLABORATION SYSTEM

Since control and management of information is very crucial to the construction industry, online collaboration systems are increasingly being used to aid collaboration between geographically dispersed project team members. These web-based information management solutions store project information online so that documents and correspondence are available in a single, shared environment that is secure and accessible to all authorized team members. This enables participants to view, track, share, and archive their information from any location, at any time, using a standard web-browser. The difference between using the technology and not is illustrated in Fig. 1.



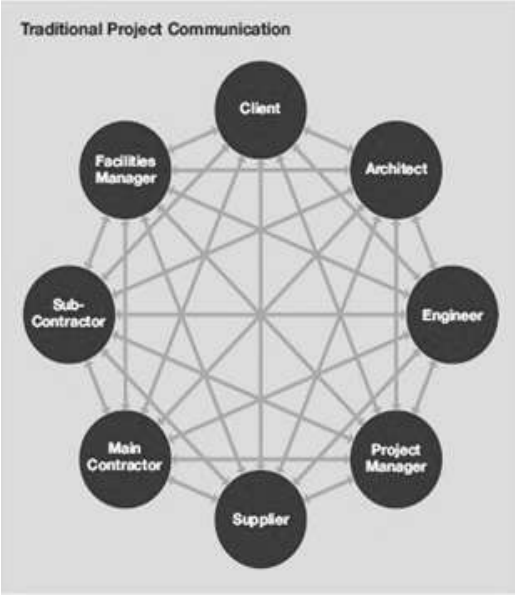


Fig. 1: Extracts from IS 15883 (Part 9): 2016

In practice, this means that all documents and drawings including feasibility studies, approvals, schedules, specifications, standards, procedures, etc., can be viewed online. Team members can add comments, issue notices, instructions and requests for information. Then documents can be published singly or in batches. When documents are superseded, revision numbers are updated meaning that everyone works on the most up-to-date, accurate and relevant information, with older revisions safely archived.

BEST COMMUNICATION MEDIUM

As choices are plentiful, considering which basic approach will work best in a given situation can help guide in determining the best medium of communication.

E-mail: Very popular and some contend it to be an overused medium. It automatically provides a permanent record for sender as well as receiver which may be good or bad. Also, as with any written message, e-mail messages are subject to misinterpretation. And the ease with which e-mail notes may be forwarded to other parties forces you to be careful about what you put in the message and how you word it.

Email is essential, but even too much of a good thing is dangerous, which is why one has to strictly regulate. Set up guidelines for co-workers, such as

only emailing when something needs immediate attention. By reducing daily email one can free up time to get real work done.

Telephone: Calling someone on the phone can be an immediate (if they answer!), interactive method of communicating without creating a permanent, written record. Phone conversations allow you to hear voice inflections. Although an upbeat phone call is considered "warmer" than a written note, it doesn't have the same effect as a personal visit or any other face-to-face interaction. Unanticipated phone calls are subject to the same shortcomings or advantages of impromptu communications.

Voice Mail: When people don't answer their phone, you are often forced to use voicemail. As you are required to use monologue it may not be as effective as you had intended to be. The message may not be received in a timely manner.

Handwritten Notes: Probably the most informal of all communication methods, short notes written by hand are an excellent way to provide positive recognition and convey "the personal touch" much more than verbal approaches or formal memos or e-mail messages. Among the drawbacks of these types of notes is that they're geographically limited.

Printed and Mailed Memos and Letters: Memos and letters are now generally reserved for more formal or official communication. They're slow and one-sided, but good when formal signatures are required and a permanent record is desired. Hence, printed, mailed memos and letters are still used frequently in contractual situations.

Informal Visits: A visit is ordinarily an informal and personal way to maintain communications with an individual and can often lead to a more valuable or productive communication session than you might get from a formal one-on-one or a group meeting. Informal visits are also appropriate when confidential, personal, or sensitive subjects need to be covered.

Formal Presentations: Formal presentations are often used in situations where the distribution of information may be enhanced by an explanation or the information is too complex for written documentation. Formal presentations are often done in a group setting, thus ensuring that everyone gets the same level of understanding. They allow for impressive graphical displays of information, but often require a lot of preparation. They're effective when you're trying to promote understanding, enlist support, or expedite a decision (e.g., management approval to proceed).

Remote Updating through Project Management Software: This method of communicating is unique to project management. Enables team members to provide project status to the project manager without any need to meet face to face. This communication method may be a boon for geographically dispersed teams but should not be a substitute to meet with team members regularly. This electronic marvel should not be allowed to replace opportunity to look team members in the eye and ask them how they're coming along on their activity.

EFFECTS OF DISTANCE AND LANGUAGE

Different primary languages for global team members may make the communication very difficult. Even when the members share proficiency with a written language, spoken communication can cause misunderstandings and lead to problems. Even sharing a language may not be enough; English in different parts of the world uses the same words to describe different things. Project communication planning requires minimising of jargon, acronyms and idioms and demands unambiguous contents in project documents.

National and regional culture affects communication but these are not the only forms of culture that can pose challenges. Company culture and differences between job functions also matter. How people ask for things, come to agreement and interact can very great deal on any team.

COMMUNICATION STYLES

Global teams also differ in communication preferences. While some team members may be more social and talkative other team members will be more terse and business oriented. Choose

leadership and communication styles that will work. Whenever you are asking questions in writing carefully reread them. Even innocently written questions may seem insulting or rude to the people receiving them. Best way to proceed and establish good teamwork and one to one rapport with the distant team members and conduct a face-to-face start-up workshop. That way minor issue will remain minor and will not escalate significant problems.

TYPES OF COMMUNICATIONS

It is important that the stake holders (Client / Project-in-charge / Project Manager / Architect) agree on basic communication protocols with the other participating organisations. Before choosing the best medium, you should consider what would be the best approach. Delivering a message in person sends a signal: it may suggest a greater urgency to the message or a higher level of concern or consideration for the recipient. Face-to-face communication affords you the opportunity to observe body language and other nonverbal communication. Communication can be:

- Written or oral
- formal or informal
- one is to one or in a group

Written or Oral?

The best choice depends on your needs. Preparing a written message affords you the opportunity to rework the message until you feel it's right; however, text messages are subject to misinterpretation because tone, inflection, and feeling are difficult to convey in writing. Verbal communication allows for more immediate back-and-forth communication; with that immediacy, however, comes the risk of saying the wrong things or saying things wrong.

In written correspondence precautions should be taken to ensure that the choice of words is clear and unambiguous; and the message flow in a way that others can easily follow train of thought. Avoid the use of slang and colloquialisms and use correct grammar?

Formal or Informal?

Your level of formality may also send a signal. Formal communications may suggest a lack of familiarity, comfort, or friendliness with the other party. Formal communications also send a signal that the content of the message is official. Most contractual dealings are relatively formal

Advanced Preparation or Impromptu?

This issue is most relevant in face-to-face communication. If a situation requires thoughtful input, it may be best to make arrangements in advance, so both parties are aware of the subject and the timing of the communication. A person who is taken by surprise may provide inappropriate or low-quality responses. Impromptu communications may provide a more candid response or offer the opportunity to observe a reaction.

In a Group Setting or One on One?

Delivering messages to groups has two advantages: it's efficient and it ensures that everyone hears exactly the same message delivered in exactly the same manner. An obvious exception to this approach occurs when there is some sensitivity to the message, such as situations where some members are personally affected or when proprietary information should not be shared with everyone.

PROJECT 'KICK OFF' MEETING

Project-in-charge or Project Manager should conduct this meeting at project site, just before start of execution stage of the project. It should be attended by representatives of all agencies involved in the project till that time. This would benefit the project, as:

- It would allow people to get to know each other. This is likely to lead to better communication and less confrontational attitudes as the work progresses.
- It would provide the opportunity to discuss 'Communication Management
- Plan with all team members together.
- Salient features of the project, important aspects that have to be kept in view and

reporting protocol would be decided so that all members of team are on one level of understanding.

- It would provide the opportunity to define points of contact at each organization.
- It can be used to ensure that all people have the contact details for others working on the project.
- Methods of communication and documentation will also be decided in the kick-off meeting

COMMUNICATION PROTOCOLS AND STORAGE

Communication protocols (Like who writes to whom, who signs on outgoing memos/ correspondence, who prepares/ reviews/ uploads reports, who drafts/ reviews/ approves minutes, etc) should be established at the beginning of the project and should be adhered to in all respects. A 'Communication protocol Format' specifically addressing the documentation matters should be developed for Head Office as well as Project site and distributed to all concerned. All project related communication shall be kept in project files under the relevant project file number. Annex B in IS 15883 (Part 9): 2016 shows a generic format for maintaining communication protocol information of a construction project. It can be customized for specific requirements of individual projects.

MEETINGS

Meetings can be a very effective way to conduct business. They bring people together for a relatively short amount of time so that large amounts of information can be shared. One should conduct core team meetings regularly to promote a steady flow of information to and from team members. Meetings are a critical form of communication.

Schedule a meeting, by all means, but only if the problem cannot be resolved by other, simpler and less time-consuming ways. Then, only invite those people to the meeting who are essential to resolving the problem at hand. To ensure best results:

- Determine whether a meeting is even required.
- Be clear on the purpose of the meeting.
- Conduct all meetings in an organized and systematic manner.
- Prepare for the meeting.
- Personally and visibly kick off the meeting.
- Ensure attention and participation.
- Close the meeting.
- Perform necessary follow-up.

Team Meetings

Meetings with your teams are not a waste of time. These are great ways to control the information you want to get out and make sure it reaches the right people. Therefore, you'll want to have regular meetings, weekly, even if they're short. Provide status updates, set goals, deliverables and timeframes. Make sure everyone buys in, is on the same page and motivated. That's how you communicate effectively and get the job done.

Discussions

It's important that you speak with your co-workers, to disseminate information, wrestle with ideas or problems and just remain social and keep the morale high. You can plan discussions, too so that these are not blocking productivity and you're not interrupting colleagues who may be immersed in more critical activities at the time.

Reports

Project manager, is responsible for generating a lot of project reports on a regular basis throughout the lifecycle of your project. That's one way to keep the work on schedule. The team and customer and sponsor need them as well. There's no way to cut back on these reports, however, they're a great tool for getting clear and precise information out to those who need to see it, whether you are deviating from a plan and reassigning tasks to your team or explaining the reasoning behind the move to your client.

DRAWINGS AND DOCUMENTS

Drawings: Drawings play a crucial role in producing good quality construction and are effective planners to execution team. Therefore,

careful attention must be paid as to how drawings are going to be created, checked and distributed. It is important to ensure that the drawings which are complete in all respects are only issued to the persons concerned and receipt thereof is acknowledged. It is not uncommon that the drawings keep getting revised while the work proceeds and hence it should be ensured that all stakeholders have the latest drawings only and the old drawings are withdrawn from the site and from different persons working on them. Register of drawings with issue dates and revisions must be maintained at site. It is a good practice to keep a box at site where superseded drawings are stored after withdrawing from site staff.

Documents: Documents form an important component of Information for management of construction projects. A document is usable if it can be quickly located, retrieved and accessed. Also, the usability of a document depends on the ability to link it with other documents related to it. Some communication documents specific to construction projects are: Diary / Daily Diary, Site Order book, Hindrance Register, Cement Register, Request for Information (RFI), Transmittals of submission of drawings and specifications, Test Reports, Daily Progress report, Change Note, Incident report etc.

CONCLUSION

To ensure harmony and effective team spirit in the Project team while getting full support from all internal and external stake holders, use of different channels of communication, elaborated above, and proper documentation will prove to be most desirable and will lead to smooth sailing of construction Projects.

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DEVELOPMENT OF PROBABILISTIC COST MODEL FOR THE INCORPORATION OF UNCERTAINTIES IN COST ESTIMATES

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Abstract

A study of construction projects across India indicate that "more than 60% of projects experienced up to 200 % time overrun and 75 % cost overrun". For a long time, these failures have been attributed to the non-performance of concerned management and construction teams but the extent, prevalence and persistence of such overruns puts a question mark on the reliability of the estimates prepared, and the estimating process adopted for their preparation.

This paper intends to understand the reasons responsible for cost overrun and rank them in accordance with their probability of occurrence, and severity of impact; and to ascertain the parties responsible for these causes. It also tries to find out the project-wise, overall and detailed item-wise extent of cost overruns in Indian Construction Industry and their variations with respect to building type and contract amount. The paper attempts to ascertain the sufficiency of contingency funds allocated to case study projects and in turn, devise a probabilistic cost model for the incorporation of future uncertainty into project estimates.

INTRODUCTION

Cost Overrun can be defined as "An instance in which the provision of contracted goods or services are claimed to require more financial resources than was originally agreed between a project sponsor and a contractor"[1]or "The amount by which actual costs exceed the baseline or approved costs".[2]For the purpose of this paper, the difference between the actual project completion cost and the contracted amount[4] will be utilized as the working definition of 'Cost Overrun'.

The extent of cost overruns depend upon the level of uncertainties involved in the project. The degree of uncertainty is more during initial stages of a project and it gradually decreases as the project progresses, owing to progressively increasing clarity regarding the required information.[9]

CAUSES OF COST OVERRUN

The construction activity being multi-disciplinary in nature, involves multiple parties such as client, consultants, suppliers, contractors, etc. and hence, the project cost and its variation (escalation) is affected by a range of factors dependent on prevailing market conditions and the characteristics of the project and the team handling it. The major causes leading to cost overruns in Indian construction industry can be categorized on the basis of issues associated with construction material, equipment, workforce, site conditions, on-site management, design aspects, project management, contractual obligations, institutional relations, project and client specific attributes and external circumstances[3]. These broad categories can be further sub-divided as has been summarized in Table 1.

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EFFECTS OF COST OVERRUN

The Cost Overruns can have adverse impacts on key stakeholders, in particular and for the entire construction industry, in general. These can result into:

- **For clients:** Added costs over and above initially agreed upon amount and diminished returns on investment.
- **For end users:** Increased rental/lease costs or prices.
- **For professionals:** Loss of capacity, reputation and confidence amongst clients to deliver value for money.
- **For contractors:** Loss of profit and adverse impact on future contracts.
- **For industry:** Reduction in construction activity (no. of ongoing projects), loss of reputation and difficulty in securing project finances at reasonable rates; with adverse consequences for the viability and sustainability of the industry as a whole.

The major effects of cost overrun[4]include delayed completion, budget shortfall, adversarial relationship between project stakeholders, increased contract administration and supervision costs, delayed payments, poor workmanship, dissatisfaction for clients and end users, loss of reputation, reduced sectoral contribution to national economic growth, skewed urban development, reduction in investor's confidence and scepticism regarding new construction projects.

QUESTIONNAIRE SURVEY

The postal questionnaire method was used for ranking the causes of project cost overruns and ascertaining responsible parties for the same. The questionnaire was carefully designed in order to achieve a high response rate from the respondents. Questionnaires were mailed to various stakeholders accompanied by a cover letter. The responses to questions were sought on a 5-point Likert scale to assess their chances of occurrence and severity of their impacts, along with a probable list of responsible parties for each cause. In the analysis, the relative importance of cost overrun causes was ascertained using "Mean Score" method by using the following formula:

$$MS = \frac{\sum (f \times S)}{N}$$

where,

MS = Mean Score

f = Frequency of a particular score

S = Scores ascribed to a factor (from 0 - 4)

N = Number of responses to a cost overrun factor

The results of the Questionnaire Survey are listed in Table 1.

Table 1: Results of the Questionnaire Survey

Factor ID	Cause of Cost Overrun		Agreement with cause		Chances of Occurrence		Severity of Impact		Responsibility**
			Rank	M.S	Rank	M.S	Rank	M.S	
1	**Materials**		4	2.31	8	2.09	5	2.54	CI(8.05%), Cn(41.38%), Cs(9.20%), Go(36.78%), Ot(4.60%)
	(a)	Delayed delivery on site	ii	2.20	ii	2.25	iv	2.25	CI(19.05%), Cn(71.43%), Cs(4.76%), Go(0.00%), Ot(4.76%)
	(b)	Scarcity of materials in market	iv	2.05	iv	1.60	iii	2.40	CI(5.26%), Cn(10.53%), Cs(10.53%), Go(57.89%), Ot(15.79%)
	(c)	Poor quality of materials	iii	2.20	iii	2.20	ii	2.55	CI(8.33%), Cn(70.83%), Cs(16.67%), Go(4.17%), Ot(0.00%)
	(d)	Increase in the price of materials	i	2.80	i	2.30	i	2.95	CI(0.00%), Cn(8.70%), Cs(4.35%), Go(86.96%), Ot(0.00%)

2	**Equipment**		3	2.40	5	2.15	3	2.65	Cl(3.92%), Cn(70.59%), Cs(25.49%), Go(0.00%), Ot(0.00%)
	(a)	Poor planning	i	2.55	i	2.40	i	2.80	Cl(3.70%), Cn(59.26%), Cs(37.04%), Go(0.00%), Ot(0.00%)
	(b)	Break-down or low productivity	ii	2.25	ii	1.90	ii	2.50	Cl(4.17%), Cn(83.33%), Cs(12.50%), Go(0.00%), Ot(0.00%)
3	**Workforce**		5	2.28	3	2.23	10	2.33	Cl(12.00%), Cn(76.00%), Cs(12.00%), Go(0.00%), Ot(0.00%)
	(a)	Poor planning / inadequate labour	i	2.85	i	2.60	i	2.85	Cl(8.33%), Cn(83.33%), Cs(8.33%), Go(0.00%), Ot(0.00%)
	(b)	Lack of skills	ii	2.15	ii	2.25	ii	2.40	Cl(4.00%), Cn(76.00%), Cs(20.00%), Go(0.00%), Ot(0.00%)
	(c)	Lack of motivation	iii	1.85	iii	1.85	iii	1.75	Cl(23.08%), Cn(69.23%), Cs(7.69%), Go(0.00%), Ot(0.00%)
4	**Contractor management**		2	2.74	2	2.58	1	2.88	Cl(8.26%), Cn(68.81%), Cs(22.02%), Go(0.92%), Ot(0.00%)
	(a)	Poor coordination and supervision	ii	2.90	ii	2.70	ii	3.00	Cl(8.00%), Cn(72.00%), Cs(20.00%), Go(0.00%), Ot(0.00%)
	(b)	Construction errors	iii	2.55	iii	2.60	iii	2.85	Cl(0.00%), Cn(68.97%), Cs(31.03%), Go(0.00%), Ot(0.00%)
	(c)	Unqualified technical personnel	iv	2.40	iv	2.25	iv	2.40	Cl(8.33%), Cn(70.83%), Cs(20.83%), Go(0.00%), Ot(0.00%)
	(d)	Delay in completion	i	3.10	i	2.75	i	3.25	Cl(16.13%), Cn(64.52%), Cs(16.13%), Go(3.23%), Ot(0.00%)
5	**Site conditions**		10	2.05	11	1.85	11	2.27	Cl(49.28%), Cn(10.14%), Cs(27.54%), Go(5.80%), Ot(7.25%)
	(a)	Unforeseen geological and geotechnical factors	i	2.35	i	1.95	i	2.75	Cl(18.18%), Cn(9.09%), Cs(50.00%), Go(0.00%), Ot(22.73%)
	(b)	Site access difficulties	ii	2.00	ii	1.85	ii	2.10	Cl(62.50%), Cn(16.67%), Cs(16.67%), Go(4.17%), Ot(0.00%)
	(c)	Site restrictions	iii	1.80	iii	1.75	iii	1.95	Cl(65.22%), Cn(4.35%), Cs(17.39%), Go(13.04%), Ot(0.00%)
6	**Client related issues**		6	2.28	4	2.16	6	2.48	Cl(62.96%), Cn(15.56%), Cs(11.11%), Go(10.37%), Ot(0.00%)
	(a)	Site unavailability/ Change in location	iii	2.25	iv	1.75	iii	2.45	Cl(77.27%), Cn(4.55%), Cs(4.55%), Go(13.64%), Ot(0.00%)
	(b)	Delay in payments	ii	2.35	i	2.60	ii	2.75	Cl(76.00%), Cn(20.00%), Cs(4.00%), Go(0.00%), Ot(0.00%)
	(c)	Change orders	i	2.60	ii	2.60	i	2.80	Cl(70.37%), Cn(11.11%), Cs(18.52%), Go(0.00%), Ot(0.00%)
	(d)	Accelerated works	v	2.05	iii	2.10	v	2.15	Cl(50.00%), Cn(33.33%), Cs(16.67%), Go(0.00%), Ot(0.00%)
	(e)	Executive bureaucracy	iv	2.15	v	1.75	iv	2.25	Cl(48.39%), Cn(6.45%), Cs(9.68%), Go(35.48%), Ot(0.00%)
7	**Design team performance**		7	2.27	6	2.15	4	2.61	Cl(13.39%), Cn(12.60%), Cs(74.02%), Go(0.00%), Ot(0.00%)
	(a)	Extreme complexity of the design	v	1.90	iv	1.95	v	2.35	Cl(22.22%), Cn(3.70%), Cs(74.07%), Go(0.00%), Ot(0.00%)
	(b)	Incomplete drawings and details	ii	2.45	i	2.35	iii	2.65	Cl(0.00%), Cn(9.52%), Cs(90.48%), Go(0.00%), Ot(0.00%)

	(c)	Norm violations	iv	2.20	v	1.85	i	2.85	Cl(24.14%), Cn(20.69%), Cs(55.17%), Go(0.00%), Ot(0.00%)
	(d)	Delay in drawings	iii	2.25	ii	2.30	iv	2.50	Cl(15.38%), Cn(7.69%), Cs(76.92%), Go(0.00%), Ot(0.00%)
	(e)	Errors in quantity estimation	i	2.55	iii	2.30	ii	2.70	Cl(0.00%), Cn(20.83%), Cs(79.17%), Go(0.00%), Ot(0.00%)
8	**Project management**		8	2.20	7	2.12	7	2.42	Cl(25.32%), Cn(26.58%), Cs(45.57%), Go(0.00%), Ot(2.53%)
	(a)	Lack of planning and co-ordination	ii	2.50	ii	2.35	i	3.20	Cl(12.50%), Cn(34.38%), Cs(50.00%), Go(0.00%), Ot(3.13%)
	(b)	Lack of end user involvement	iv	1.95	iv	1.80	iv	1.95	Cl(47.83%), Cn(13.04%), Cs(39.13%), Go(0.00%), Ot(0.00%)
	(c)	Inflexible attitude	v	1.80	v	1.65	v	1.85	Cl(34.38%), Cn(28.13%), Cs(34.38%), Go(0.00%), Ot(3.13%)
	(d)	Problem identification and rectification	i	2.55	iii	2.35	ii	2.60	Cl(9.09%), Cn(30.30%), Cs(57.58%), Go(0.00%), Ot(3.03%)
	(e)	Poor communication	iii	2.20	i	2.45	iii	2.50	Cl(28.95%), Cn(23.68%), Cs(44.74%), Go(0.00%), Ot(2.63%)
9	**Institutional relations**		1	2.75	1	2.65	2	2.80	Cl(28.13%), Cn(3.13%), Cs(37.50%), Go(31.25%), Ot(0.00%)
	(a)	Licenses, approvals and permissions	i	2.75	i	2.65	i	2.80	Cl(28.13%), Cn(3.13%), Cs(37.50%), Go(31.25%), Ot(0.00%)
10	**Project specific**		11	1.80	9	2.03	12	1.90	Cl(27.12%), Cn(54.24%), Cs(18.64%), Go(0.00%), Ot(0.00%)
	(a)	Other contractors on site	i	2.05	i	2.40	i	2.05	Cl(34.21%), Cn(42.11%), Cs(23.68%), Go(0.00%), Ot(0.00%)
	(b)	Utility reposition	ii	1.55	ii	1.65	ii	1.75	Cl(14.29%), Cn(76.19%), Cs(9.52%), Go(0.00%), Ot(0.00%)
11	**Contract related issues**		9	2.06	10	1.94	8	2.40	Cl(36.75%), Cn(39.32%), Cs(23.08%), Go(0.85%), Ot(0.00%)
	(a)	Inappropriate selection of contract	iv	1.80	iii	1.75	ii	2.40	Cl(36.36%), Cn(33.33%), Cs(30.30%), Go(0.00%), Ot(0.00%)
	(b)	Foreclosure of Contract	iii	1.95	iv	1.65	i	2.55	Cl(44.83%), Cn(41.38%), Cs(13.79%), Go(0.00%), Ot(0.00%)
	(c)	Clause for extra items, deviations in qty.	i	2.50	i	2.50	iii	2.40	Cl(331.03%), Cn(34.48%), Cs(34.48%), Go(0.00%), Ot(0.00%)
	(d)	Escalation clause	ii	2.00	ii	1.85	iv	2.25	Cl(34.62%), Cn(50.00%), Cs(11.54%), Go(3.85%), Ot(0.00%)
12	**External factors**		12	1.72	12	1.52	9	2.35	Cl(4.90%), Cn(2.94%), Cs(0.00%), Go(48.04%), Ot(44.12%)
	(a)	Adverse weather conditions	i	1.95	i	1.85	ii	2.40	Cl(0.00%), Cn(0.00%), Cs(0.00%), Go(0.00%), Ot(100.00%)
	(b)	Force majeure	ii	1.90	ii	1.70	iii	2.35	Cl(0.00%), Cn(0.00%), Cs(0.00%), Go(0.00%), Ot(100.00%)
	(c)	Change in Foreign exchange rates	v	1.50	iii	1.55	v	2.00	Cl(10.00%), Cn(5.00%), Cs(0.00%), Go(85.00%), Ot(0.00%)
	(d)	Legal & regulatory amendments	iii	1.65	iv	1.30	iv	2.05	Cl(14.29%), Cn(4.76%), Cs(0.00%), Go(80.95%), Ot(0.00%)
	(e)	Archaeological findings	iv	1.60	v	1.20	i	2.95	Cl(0.00%), Cn(4.76%), Cs(0.00%), Go(71.43%), Ot(23.81%)

** Where, M.S. = Mean Score, Cl = Client, Cn = Contractor, Cs = Consultants, Go = Government and Ot = Others

COST OVERRUN ANALYSIS OF CASE-STUDY PROJECTS

The detailed study of cost related data retrieved from project documents such as contract documents, project estimates, project reports, payment certificates, completion documents, etc. of 14 completed or nearly completed building construction projects was conducted to understand:

- Extent of overruns prevalent in Indian Construction Industry and their relationship with project cost and building typology.
- Detailed item-wise cost overruns.

The cost variance (in both absolute and relative terms) was calculated using the following formulas:

Cost Variance (CV) = Actual Completion Cost (ACC) – Estimated Cost (EC)

CV=ACC-EC

% Cost Variation (CV%)= (Cost Variance (CV)/ Estimated Cost (EC)X100

CV%=CV/EC*100

The project-wise cost variations are presented in Table 2 and the item-wise cost variations are presented in Table 3. The cost variations w.r.t. building type and contract amount are presented in Table 4 and Table 5 respectively.

Table 2: Cost Overruns for the Case Study Projects

Sr. No.	Case Study	Estimated Amount (in lakhs)	Actual cost on completion (in lakhs)	Cost Variance (in lakhs)	% cost variation
1	Case Study - 1	2512.73	2964.34	451.60	17.97%
2	Case Study - 2	1685.14	2049.69	364.54	21.63%
3	Case Study - 3	160.64	254.40	93.76	58.37%
4	Case Study - 4	211.37	244.18	32.81	15.53%
5	Case Study - 5	95.02	116.98	21.95	23.11%
6	Case Study - 6	1195.53	1349.86	154.33	12.91%
7	Case Study - 7	1342.85	1629.80	286.95	21.37%
8	Case Study - 8	201.51	248.53	47.01	23.33%
9	Case Study - 9	298.07	386.63	88.56	29.71%
10	Case Study - 10	2211.93	2562.92	350.98	15.87%
11	Case Study - 11	862.78	1066.40	203.61	23.60%
12	Case Study - 12	93.27	85.37	-7.90	-8.47%
13	Case Study - 13	697.53	810.00	112.47	16.12%
14	Case Study - 14	218.35	240.23	21.88	10.02%
	Total	11786.78	14009.40	2222.62	18.86%

Table 3: Item-wise Cost Overruns for the Case Study Projects

Sr. No.	Category	Unit	Estimated Amount (in lakhs)	Actual cost on completion (in lakhs)	Cost Variance (in lakhs)	% cost variation
1	Earth work	cu.m.	283.67	322.30	38.63	13.62%
2	Cement Concrete	cu.m.	383.69	395.13	11.44	2.98%
3	R. C. C.	cu.m.	5429.30	6377.45	948.14	17.46%
4	Brick work	cu.m.	964.99	911.07	-53.91	-5.59%
5	Stone work	cu.m.	193.36	195.76	2.40	1.24%
6	Marble work	sq.m.	111.86	119.81	7.94	7.10%
7	Wood work	varies	550.07	528.55	-21.51	-3.91%
8	Steel work	kg.	342.23	370.07	27.83	8.13%

9	Flooring	sq.m.	854.54	893.98	39.44	4.62%
10	Roofing	sq.m.	123.43	135.28	11.84	9.60%
11	Finishing	varies	928.61	1034.84	106.22	11.44%
12	Road work	sq.m.	299.18	329.50	30.32	10.13%
13	Sanitary installations	varies	289.17	315.96	26.78	9.26%
14	Water supply	varies	168.79	186.11	17.32	10.26%
15	Drainage	varies	83.20	89.06	5.86	7.05%
16	Pile work	nos.	88.98	126.19	37.20	41.81%
17	Aluminium work	varies	269.36	304.87	35.51	13.18%
18	Water proofing	sq.m.	217.05	237.56	20.51	9.45%
19	Miscellaneous works	varies	205.22	198.89	-6.33	-3.09%
	Total cost		11786.78	13072.47	1285.69	10.91%
20	Extra items			936.92		7.95%
	Grand total		11786.78	14009.40	2222.62	18.86%

Table 4: Building Type Vs Extent of Cost Overrun

Sr.	Building Type of Project	No. of projects	Estimated Amount (in lakhs)	Actual cost on completion (in lakhs)	Cost Variance (in lakhs)	% cost variation
1	Residential Buildings	4	5187.63	6079.46	891.82	17.19%
2	Office Buildings	4	4227.60	5092.74	865.14	20.46%
3	Institutional Buildings	4	1951.67	2348.42	396.75	20.33%
4	Utility Buildings	2	419.86	488.76	68.90	16.41%
	Total	14 Nos.	11786.78	14009.40	2222.62	18.86%

Table 5: Contract Amount Vs Extent of Cost Overrun

Sr.	Contract Amount	No. of projects	Estimated Amount (in lakhs)	Actual cost on completion (in lakhs)	Cost Variance (in lakhs)	% cost variation
1	Below 5 crores	9	1278.25	1576.36	298.10	23.32%
2	5 - 10 crores	1	1560.32	1876.41	316.09	20.26%
3	10 - 15 crores	2	2538.38	2979.67	441.29	17.38%
4	15 - 20 crores	1	1685.14	2049.69	364.54	21.63%
5	Above 20 crores	1	4724.67	5527.26	802.58	16.99%
	Total	14 Nos.	11786.78	14009.40	2222.62	18.86%

CONSTRUCTION CONTINGENCY

Construction contingency is provided in contracts to cater for unaccounted / contingent expenses and variations from contracted sum during execution of the project. The accuracy of Construction Contingency i.e. Contingency Accuracy (CA) can be assessed "by comparing construction contingency and approved contract variations, expressed as a percentage of Award Contract Value".[6]

$CA = \Sigma V\% - \Sigma C\%$

where,

ACV = Award Contract Value i.e. the contract amount

C% = Construction Contingency

V% = Variations

A positive percentage indicates the sufficiency of Contingency allowances while a negative value points to the contrary. The accuracy of allocated construction contingency can also be expressed as the ratio of project contingency (C%) to cost variation (V%), expressed as a percentage:

$$CA_2 = \frac{C}{V} \times 100$$

The construction contingency on an average was 4.10% of ACV, whereas the cost variation among case study projects was found to be 18.86% of the contracted amount. This indicates that 14.76%of these unanticipated expenses i.e. 78.26% of approved contract variations, leading to cost overruns were not covered by contingency provisions. The calculated value of contingency accuracy and the prevalence of cost overruns indicate that proper contingency allowances are not incorporated while preparing estimates.

DEVELOPMENT OF PROBABILISTIC COST MODEL[7]

The need for the development of probabilistic models for the incorporation of uncertainties in project estimates arises because of following reasons:

- The non-availability of reliable and requisite information during pre-construction phase hampers the preparation of reliable estimates.
- The uncertainties associated with construction activities may impact the original estimate to an extent whereby they become redundant and obsolete. These estimates are utilized not only for awarding but also for evaluating projects after their completion.
- These estimate forms the very basis for project tendering, construction agency's subsequent revenue streams and client's investment related decisions.
- The tendency to underestimate project costs in order to grab contracts and project approvals severely jeopardize the reliability of such estimates.
- The estimates for most projects are falling short of project completion within budget.

Creating Random Variables for Individual Tasks

The best way to create random variables for developing a probabilistic cost model is to collect, collate and analyse as much historical information as possible for each individual task and generate random variables. The limitations of this approach are as follows:

- Uniqueness of tasks constitutive of any project.
- Even with similar projects under similar circumstances, the varying external environmental conditions and peculiarities restrict the comparability and compatibility of identified variables.
- Achieving desired accuracy in the collection and collation of project data is very difficult.

The alternatives available are as follows:

- The procedure prescribed under Program, Evaluation, and Review Technique (PERT) can be utilized in cases with lack of adequate precedent information wherein the PM professional, based on experience is required to estimate Optimistic, Pessimistic and Anticipated costs for each variable. These three estimates or parameters can then be used for calculating more reliable estimates.
- Through experiments under controlled conditions.

Assumptions

The development of probabilistic cost model is based on a basic assumption that cost overrun data from projects follow a normal distribution. The total project cost can be expressed as sum total of individual cost components / variables associated with each task. The total project cost can be written as:

$$C = \sum_{j=1}^{n} c_j \quad \ldots\ldots\ldots \text{(i)}$$

where,

c_i = A random variable denoting the cost associated with individual task.

n = No. of individual tasks in a project.

C = Total project cost (A probabilistic model).

The variable c_i is N ($\mu_{c,i}$, $\sigma_{c,i}$)

The following section attempts to develop three types of probabilistic cost models that can used under different circumstances:

- Simple Probabilistic Cost Model

- Probabilistic Cost Model using Normal Distribution
- Probabilistic Cost Model using Triangular Distribution

SIMPLE PROBABILISTIC COST MODEL

This model attempts to incorporate uncertainty in project estimates by utilizing cost performance data from past projects. This method with simple and fewer calculations can be used for approximating contingency allowances but cannot be utilized for accurate results. The steps involved are as follows:

Step 1: Tabulation of Cost Overrun data from case study projects.

Step 2: Calculation of Mean Cost Overruns for each item.

The Mean (μ_i) of cost overruns for i^{th} item is given by the formula:

$$\mu_i = \frac{\sum_{j=1}^{m} x_{ij}}{m} \qquad \text{.....(ii)}$$

where,

μ_i = Mean of cost overruns for i^{th} item

x_{ij} = j^{th} value (corresponding to j^{th} case) of cost overrun variable for i^{th} item

m = No. of cost overrun values from case studies

Step 3: Calculation of actual mean cost for each item

Actual Mean Cost = Base Cost + Mean of Cost Overruns(%)

Step 4: Determination of allowance for the incorporation of uncertainty.

The PM professional is required to calculate an allowance for each item, on the basis of overruns in case study projects, standard deviation, complexity of item i.e. uncertainty involved and his past experience.

Cost Per Unit =Actual Mean Cost +%Allowance

Step 5: Preparation of Total Cost Estimate of the Project.

The estimated cost for an individual task can be calculated by multiplying per unit cost of task with estimated quantity. The summation of all individual Estimated Task Costs will provide a Total Cost Estimate.

Total Cost Estimate =Σ Estimated Task Costs

Step 6: Determination of allowance for extra items to get New Designed Estimate.

The PM professional is also required to estimate an allowance for extra items (a percentage of estimated project cost) on the basis of historical data and past experience.

Revised Estimate = Total Cost Estimate +% Allowance for Extra Items

Probabilistic Cost Model using Normal Distribution[8]

The historical information documented regarding cost performance of the previous projects will be used for the estimation of reasonably accurate random variables by considering it as following normal distribution.

Step 1: Determining the Basic Cost Model.

The basic probabilistic cost model as represented by Equation (i) will be used for the purpose. If the cost related data is separately available for duration and quantity based costs, then combine the two components to get the single total costs of individual items (tc_i). The Total Cost Model can be expressed as;

$$C = \sum_{i=1}^{n} (tc_i) \qquad \text{..... (iii)}$$

The variable $tc_i$is $N(\mu_{tc,i}, \sigma_{tc,i})$

Step 2: Calculation of Mean and Standard deviation for cost overruns associated with each item.

The Mean (μ_i) of cost overruns for i^{th} item can be calculated using equation (ii). The Standard Deviation of cost overruns (σ_i) for i^{th} item is given by the formula:

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{m}\left(x_{ij} - \mu_i\right)^2}{m}} \quad \ldots\ldots\ldots\ldots \text{(iv)}$$

where,

σ_i = Standard Deviation of cost overruns for i^{th} item

x_{ij} = j^{th} value (corresponding to j^{th} case) of cost overrun variable for i^{th} item

m = No. of cost overrun values from case studies

Step 3: Calculating Alpha Values (Interaction Effect).

The $\alpha_{tc,i}$ values capturing the interaction effect of cost overruns of individual items can be calculated using:

$$\alpha_i = \frac{\sigma_i}{\sqrt{\sigma_1^{\,2} + \sigma_2^{\,2} + \sigma_3^{\,2} + \ldots\ldots + \sigma_n^{\,2}}} \quad \ldots\ldots \text{(v)}$$

The α_i value is calculated to find the impact of deviations of other items on a particular item and is done by including standard deviations of cost overruns of all tasks in denominator.

Step 4: Calculating Partial Factors for incorporating a Desired Level of Reliability.

The Alpha values calculated in previous step and the Beta values (corresponding to a desired level of reliability) can be used to calculate a partial factor. The following formula can be used:

$$\xi_i = \mu_i \times \left[\frac{1 + \alpha_i \times \beta \times \left(\sigma_i / \mu_i\right)}{dx_i}\right] \quad \ldots\ldots \text{(vi)}$$

Where

ξ_i = the partial factor corresponding to task i

dx_i = the characteristic cost overrun value (= μ_i, in this case)

β = desired reliability level (For, desired reliability = 85%, β = 1.04 and if, desired reliability = 80%, β = 0.848).

Thus, the previous equation can be reduced to:

$$\xi_i = 1 + \left[\frac{\alpha_i \times \beta \times \sigma_i}{\mu_i}\right] \quad \ldots\ldots \text{(vii)}$$

Step 5: Multiplication of Mean cost overrun values by the Partial Factors.

The desired level of reliability can be incorporated in Cost Multiplication Factors by multiplying mean cost overruns for individual tasks by respective partial factors.

$$\Pr_i = \xi_i \times \mu_i \quad \ldots\ldots\ldots \text{(viii)}$$

where,

$\Pr_i$ = Cost Multiplication Factor

Step 6: Multiplication of Estimated Base Costs foreachitem by respective Cost Multiplication Factors.

The Cost Multiplication factors are multiplied with estimated base cost of respective tasks to obtain estimated item-wise costs for an upcoming project with a desired level of reliability:

$$Er_i = \Pr_i \times C_i \quad \ldots\ldots \text{(ix)}$$

where,

Er_i = Estimated item cost

C_i = Estimated base cost for individual items

Step 7: Calculation of Total Project Cost Estimate

The new project estimate incorporating an expected level of reliability (C_β) can be obtained by summing up estimated costs of individual items.

$$C_\beta = \sum_{i=1}^{n} Er_i \quad \ldots\ldots \text{(x)}$$

Step 8: Add a suitable Allowance for extra items.

The Revised Estimate can be obtained by adding a suitable allowance for extra items on the basis of data collected from past projects and experience to the total cost estimate obtained in previous step.

$$TC_\beta = C_\beta + EA \quad \ldots\ldots \text{(xi)}$$

where,

TC_β= Revised Estimate incorporating desired level of reliability

EA = Allowance for extra items expressed as a percentage of total cost estimate.

Probabilistic Cost Model using Triangular Distribution

In this method, the PM professional, based on his / her experience is required to estimate the following:

- Optimistic cost (Best Case)
- Pessimistic cost (Worst Case)
- Anticipated cost (Anticipated case)

These three estimates or parameters can then be used for calculating more reliable estimates by utilizing triangular distribution for the creation of random variables. This method can be used where reliable or sufficient data from the past projects is not available and the concerned person is capable of assuming / estimating the three required variables with reasonable accuracy.

Step 1: Determining the Basic Cost Model. (Equation i)

Step 2: Assume or calculate the Optimistic (a), Pessimistic (b) and Anticipated (c) cost overruns for all the items.

Step 3: Calculation of Mean and Standard deviation for cost overruns associated with each item

The Mean (μ_i) of cost overruns for i^{th} item is given by the formula:

$$\mu_i = \frac{a_i + b_i + c_i}{3} \quad \ldots (xii)$$

The Standard Deviation of cost overruns (σ_i) for i^{th} item is given by the formula:

$$\sigma_i = \sqrt{\frac{a_i^2 + b_i^2 + c_i^2 - a_i * b_i - a_i * c_i - b_i * c_i}{18}} \quad \ldots .. (xiii)$$

The steps for the calculation of Alpha values, Partial Factors, Cost Multiplication Factors, Estimated individual item costs and Revised project estimates for a desired level of reliability (Beta values) and with suitable allowances for extra items can be followed as described in the previous model.

Validating the Model

The models developed in previous section of this paper need to be applied on multiple new cases for their validation but given the time and resource constraints, the models were applied on 14 case study projects and a new project (CS-15). The revised estimates calculated using proposed cost models were compared with the Actual Completion Costs. The comparison (Fig.1 and 2) indicates a significantly reduced cost overrun if the project estimates would have been prepared using these models.

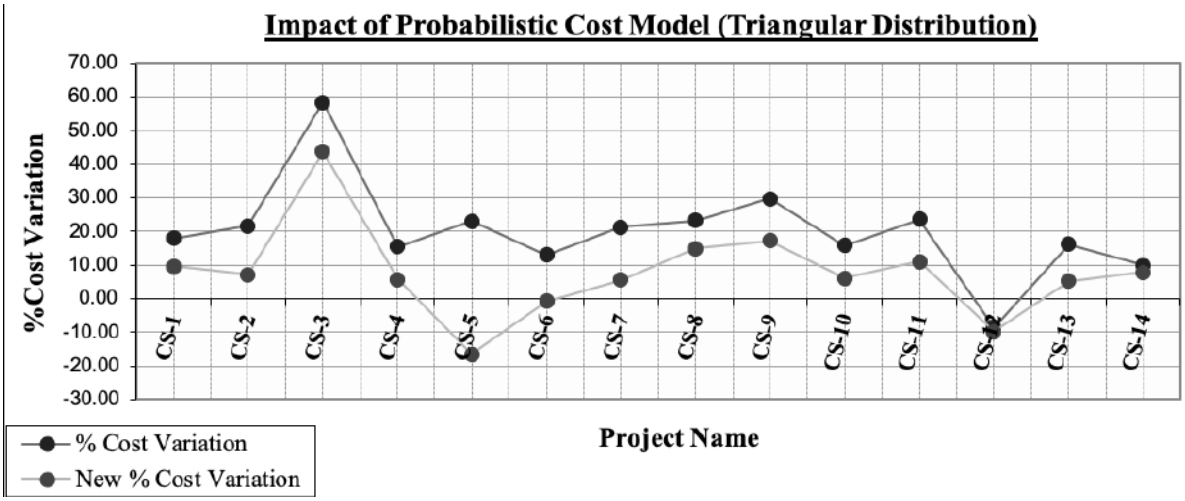

Fig. 1: Effect of using Probabilistic Cost Model (Normal Distribution) on the case study projects.

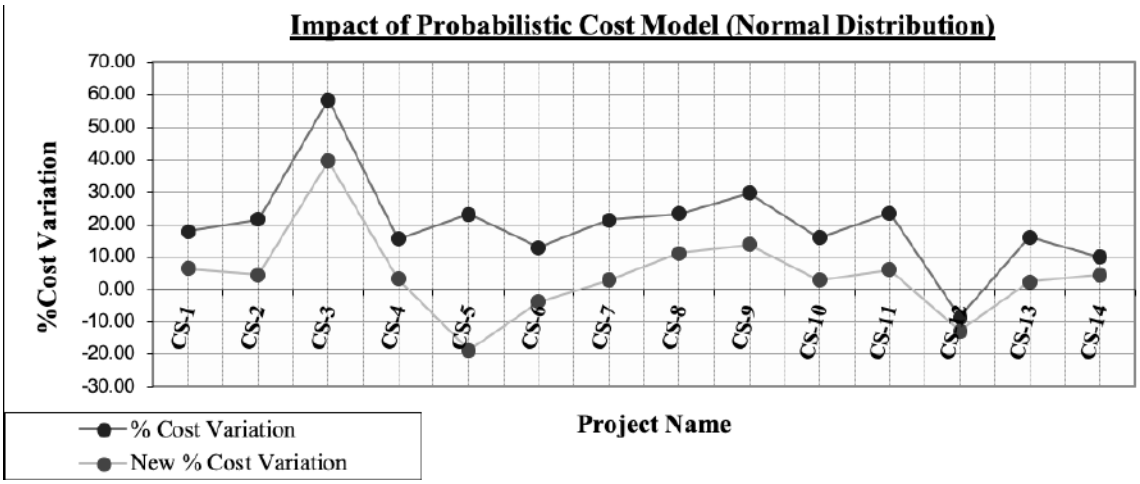

Fig. 2: Effect of using Probabilistic Cost Model (Triangular Distribution) on the case study projects.

The application of these models on a different case study "CS-15" validates them, as the actual overrun in the project was 19.25% and if the estimates would have been prepared using these models, the expected overruns are as follows:

- Using Normal Distribution : 1.62%
- Using Triangular Distribution : -0.06%

LIMITATIONS

The non-availability of historical data and excess reliance on predicting and analytical abilities of PM professional for making experience-based guessed estimates may lead to certain amount of unaccounted / over-accounted for uncertainties, based on optimistic / pessimistic estimates by the PM professional.

CONCLUSION

Cost Overruns are very frequent in Indian Construction Industry and their extent puts a question mark on the reliability of estimates prepared and the methodology used to prepare these estimates.13 out of 14 building projects (92.86%), considered for the purpose of this study suffered cost overrun during execution and its quantum varied from -8.47% to 58% of the contract amount. The extent of cost overruns was found to be lesser for projects with higher contract amounts and even exhibited variations across building types – utility buildings experienced lowest cost overruns while office buildings suffered the highest. These results can only be presented with some confidence if arrived at through analysis of a sample with large N characteristics.

The study also attempted to identify and rank the causes responsible for cost overruns and their consequent effects. The respondents considered contractors as most responsible for cost overruns, followed by consultants and clients. The clients and end users are most severely affected by such instances but with equally adverse impacts for other stakeholders and even the national economy, as a whole.

The construction contingency on an average was 4.10% of Award Contract Value, whereas the cost variation among case study projects was found to be 18.86% of the contracted amount. The calculated value of contingency accuracy and the prevalence of cost overruns indicate that adequate contingency allowances are not incorporated while preparing estimates, in Indian Construction Industry.

This study attempts to devise methods for the incorporation of uncertainty during preparation of project estimates. The estimates prepared using such probabilistic models incorporate uncertainty based on data from past projects and hence, facilitates the incorporation of effects of a known factor on a project cost in the form of percentage disruption variables and estimation of risk allowances that needs to be accommodated while preparing estimates. The proposed models cannot be considered as a one-step solution and

their success rely on the continued updation and extension of databases. A larger role still needs to be played by PM professional for estimations associated with newer tasks and extra items. The application of these models on 14 case study projects and a different project indicates that the overruns would have been much lesser if the estimates would have been prepared using these probabilistic models. Under such circumstances, instead of lump sum contingency calculations, an item-linked approach with variable allowances for different items of work can be explored for catering to differing uncertainties and risks associated with different activities. The authors suggest the refinement of proposed models and their validation on entirely different and multiple projects as a future scope for research.

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COMPARATIVE STUDY OF THE CYCLE TIME OF TALL STRUCTURE BASED ON CPM AND DSM METHODS – A CASE STUDY

BHASKAR DUTTA*

Abstract

Cycle time of tall buildings is a critical element of the project which determines the project duration. To understand the dependencies of each activity is of paramount importance. Till date project schedules are more into time and work centric. These conventional methods such as CPM and PERT ignore the flow of information which dictates the work sequence and duration of the projects at large. Thus many times it has been observed that in spite of detailed schedule, project fails in terms of time, cost and quality. The rework and unnecessary work is one of the prime reason for time and cost overrun. Thus application of design structure matrix i.e. DSM helps to identify the interdependencies of construction activities. This will reduce the rework and unnecessary works. Application of DSM methods helps to have more controlled and coordinated approach towards the project deliverables. These methods will reduce the rework and unnecessary work. DSM method could be a better way of controlling cost and duration of the project.

In this paper author made a comparative study of cycle time of 40 storied building based on CPM and DSM methods.

INTRODUCTION

Large complex projects such as construction of tall buildings need a well planned project schedule. Success of the projects largely depends on the planned construction sequence of the projects. In construction of tall buildings, logical sequence of activities and constraints are the key element for the project deliverables. But in construction of complex structure understanding of the flow of information and rework of each activity is also of paramount importance. Traditional project management tools for the preparation of schedule such as CPM and PERT are based on logical sequence of construction activities along with expected time required for the completion of each activity. The relationship between each activity is only based on the relative time frame of each activity. Generally each activity related to other activity based on the four defined relationship i.e. start to start, start to finish, finish to finish and finish to starting. These traditional methods of scheduling fail in complex projects such as construction of tall buildings. The traditional methods of scheduling do not consider the importance of information flow in the construction management. Flow of information is the key for success of any process or product development. Scheduling based on the design structure management (DSM) considers the flow of information which is of paramount importance in the modern day complex construction projects. DSM method helps project manager to understand the nature of dependencies of each activity. The graphical representation of relationship between each activity helps to reduce the rework. It also helps to element unproductive work. There by reducing the delay and cost overrun of the project. It has been observed that rework increases the project cost by 10%. The rework not only increases the project cost but it also delay the project to a great extent. In this paper author made an attempt to

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study the cycle time of a floor of 40 storied building by using the CPM in MS project software. The cycle time of same floor was analyzed by using DSM. This is a case study of a project named URBANA at Kolkata. The project comprise of 5 no 40 storied building and 2 no 45 storied building. The project is having three level basement surrounded by the seven towers. The single floor area of the basement is approximately 1 Lakh sq.ft. DSM helps to analyze the dependencies of each activity. DSM method was used in design phase of a construction and product development project. First time attempt was made to use DSM methods in construction of tall buildings. The better understanding of the relationship between each activity by using DSM method will make the usage of CPM method more practical and realistic.

LITERATURE SURVEY

Despite the preparation of detailed project planning schedule, cost overrun, delayed project and poor quality became the common phenomenon in most of the projects. Growing demands of tall buildings with committed cost, time and quality made this subject of study more relevant to the modern days. The traditional methods of planning are more focused on construction sequence and duration of each activity ignoring the effect of interdependence of each activity based on flow of information. The complex tall structure constructed with new material and construction technology requires well coordinated flow of information within different components of project.

Larsen made a study on factors affecting the schedule, cost overrun and poor quality level in public construction projects. It was concluded that preplanning of the projects prior to the design stage is of paramount importance for the successful completion of the project. It has been observed in last 70 years that cost overrun of the projects globally is 28%. Optimistic expectations of time and budget have, as a consequence, been found to decrease quality and productivity during construction and in the final product. Athira Prasad and Jeevan Jacob have applied the DSM in the building design process. It has been suggested that building design process can be considered as two separate functions; design work and management work. The poor performance of design falls into two categories, first is the poor design of the building itself and second the organizational failures which results in poor design. For example, foundation design always requires knowledge of column loads and soil parameters, whilst space heating requires information on room size, "U" values and the internal external temperatures. Although the parameters such as the magnitude and accuracy of the information changes from project to project and from building to building, the category on information does not. Bar charts and network analysis are unable to cope with the level of abstraction and detail needed to plan the design phase of a project with any measure of success. In other words conventional methods of scheduling are not enough to understand the interdependency of each activity. Till date DSM method was applied in design stage of construction. In this paper author made an attempt to apply DSM method in construction schedule of tall buildings and how application of DSM method can give more clarity to the interdependency of each activity in gantt chart based on flow of information. This will help to make more realistic project schedule.

CASE STUDY

DSM and CPM method was applied in construction schedule of forty storied tall building. The study was restricted to the slab cycle time of one pour of typical floor of the buildings. The brief history of the project is given below:

Name of the project: URBANA

Location: Kolkata

Number of Towers: 7

Number of 40 storied towers: 5

Number of 45 storied towers: 2

Basement: three levels

Type of project: Residential

Structural member: Shear wall, beam, slab and pile

Type of shuttering: Aluminum shuttering

The tower considered in this study was divided into four pours. The floor area of the tower is more or less 10000 sq. ft. In order to reduce the cycle time of the project, rebar cage of the shear wall was fabricated on the ground and then it was lifted to its location for installation. Electrical conduit pipe was fixed in rebar cage while it was fabricated on the ground. Arrangement of the rebar in the junction of shear wall was made in such a way that prefabricated reinforcement can be placed in its location without any hindrance. Aluminum shuttering was used as a shuttering material which has a considerable impact on the reduction of cycle time of the tower. Considering these mentioned criteria, a construction schedule was prepared in MS project 2007. Gantt chart is showing the critical path and critical path duration. The critical path duration is 9 days. The same task was considered for making the DSM. In this paper combine usage of network analysis and DSM method was made for better understanding of the flow of information made in the complex world of construction management. The Gantt chart is given below. The CPM method only highlights the duration of the task and its relationship with other task in terms of start and finish time of the said activity. The eight tasks were considered in the schedule. All the activities are critical activity except the activity "H" i.e. laying sleeves in beam and slab. But it gives no information regarding any factor affecting the execution of the critical activity. Thus DSM was created in order to understand the flow of information affecting the progress of the critical activities. The list of activities represented by A,B,C,D,E,F,G,H are given in Table 1.

Table 1: List of Activities in casting of Floor Slab

Sl	List of Activity
A	Fixing of Rebar in Shear wall
B	Laying of electrical conduit and boxes
C	Aluminium shuttering of Shear wall
D	Aluminium shuttering of slab and beam
E	Reinforcement in slabs
F	Fixing of sleeves in beam and slab
G	Laying of electrical conduit in slabs
H	Concreting

The Fig. 2 shows the DSM method. In DSM method the area shown in blue mark is the feedback region where information flows from the activity marked 1 in the box to the activity represented by red colour box in the diagonal. For example for execution of activity A needs information from activity B. In other words for successful completion of the activity A needs feedback from activity B. The area shown in the yellow color in DSM is the feed forward of the information from the activity represented by red color box to the box marked 1 in the blue color zone. For example successful completion of activity A provides information to activity B. Thus activity A and B is interdependent to each other. The activity A and B cannot be executed if the flow of information fails to exist between the two activities. In DSM methods these activities are known as coupled activity. The rebar fixing for shear wall and laying electrical conduit in shear wall are the couple activity. Incomplete information or lack of information can delay the progress of work significantly.

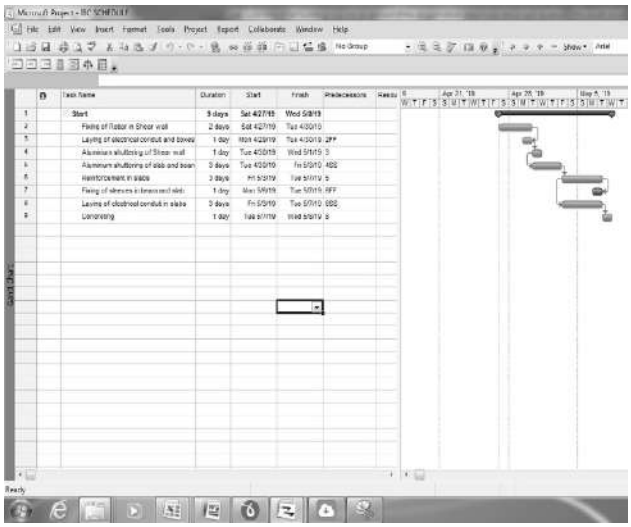

Fig. 1: Construction Schedule of Floor Slab Casting in MS project

Similarly other activity such C, D and E,F are the couple activity. Aluminum shuttering of shear wall and aluminum shuttering of slab, beam are interdependent with each other. The aluminum shuttering begins with the shuttering of shear wall and it starts from one of the corner of the building. Once the shuttering works of shear wall of one of the room gets completed, shuttering work of slab and beam can be started. Thus construction

sequence of shuttering works clearly indicates the interdependency of these two activities i.e. C and D. In DSM method we can observe that activity C i.e. aluminum shuttering of shear wall needs feedback from the activity D i.e. aluminum shuttering of slab and beam. The activity C feed forward the information to D. The same has been explained in the Fig. 2. The laying reinforcement in slab and beam is very much related to the activity F i.e. fixing of sleeves in beam and slab. Activity E needs feedback from activity F, G and Activity E feed forward the information to activity F, G. Thus graphical representation of these activities in DSM methods clearly indicates the criticality of flow of information between these activities.

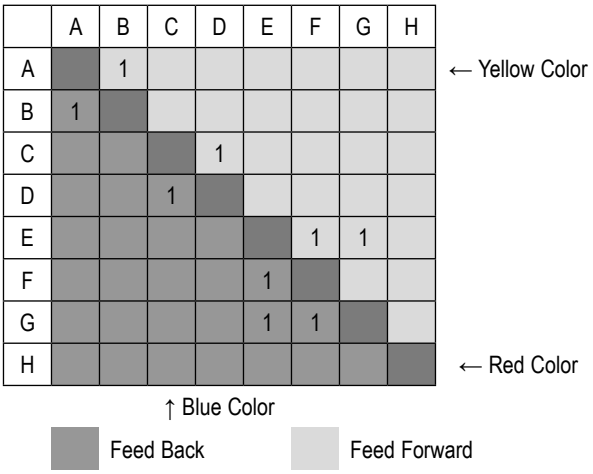

Fig. 2: Design Structure Matrix

One fact can be noted down from the Gantt chart is that fixing of sleeves in beam and slab is a non critical activity where as DSM method indicates that any delay in flow of information from activity F i.e. fixing of sleeves in beam and slab can delay the laying of reinforcement in slabs which lies in critical path of the schedule. So use of DSM methods along with the CPM method gives better understanding of construction sequence. It modifies the understanding of the relationship between the construction activities. The graphical representations of the relationship between activities are given below in Fig 3, Fig 4, Fig 5.

The activity shown in Fig. 3 is the coupled activity. The mutual flow of information takes place in between the coupled activity. The activity shown in Fig. 4 is the independent activity. These activities can be started without getting information from subsequent activity. Thus these activities are referred as independent activity or parallel activity.

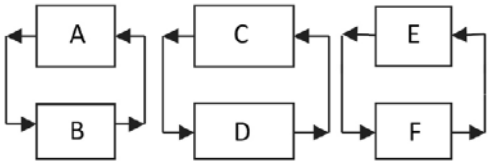

Fig. 3: Coupled Activity

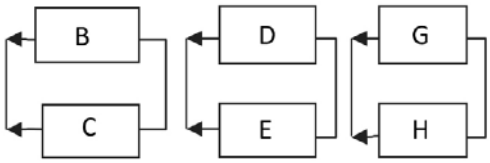

Fig. 4: Independent Activity

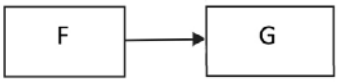

Fig. 5: Dependent Activity

The activity shown in Fig. 5 is the dependent activity. The activity F i.e. fixing of sleeves in slab and beam provides information for laying of electrical conduit in slabs and beam. The drawing showing the location and size of sleeves are required before laying the electrical conduits. Non availability of drawing and specification regarding sleeves will delay the start of the activity G. These are the activities lying in critical path and any delay or rework of activity G will increase the slab cycle time of the project. The drawing showing the reinforcement details in slab and beam are also the essential information required for the start of the activity G. Non availability of material like reinforcement will also delay the execution of the activity G. Thus project team can also track the material procurement by using the DSM method.

CONCLUSION

The conventional method of making construction schedule only indicates about duration and construction sequence of the projects. The standard relationships defined in the CPM methods i.e. FF, FS, SS, SF are only the results of the complex relationship among the subtasks which mainly depends on the flow of information within the construction activities. The conventional methods of scheduling such as CPM, PERT does

not consider the effect of the flow of information on the IRON triangle which comprises of three vertices such as cost, time and quality. Thus cost overrun and delayed project become a common phenomenon in the complex projects like construction of tall buildings. Steward in the year 1981 introduced the DSM to identify dependencies and relations between items to find the most efficient way of sequencing tasks or activities. DSM methods consider the flow of information between the activities. In this paper author made an attempt to study the construction schedule of typical floor slab cycle time of a forty storied building by using CPM and DSM method. After going through the various literature and case study, it was found that combine application of CPM and DSM methods in construction schedule gives better understanding of interdependencies of each activity. This will reduce the rework and unproductive work of the project. DSM method was applied only in design stage of a construction projects. The study made in this paper also highlights that DSM method can be applied to the construction phase of the projects. Application of DSM methods to all the construction activities of a project can be a topic of further study and research. The different components of information effecting the cost, time and quality of projects can be a subject of further research work.

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PROJECT PERFORMANCE MEASURING AND FORECASTING: AN EXTENSION OF EARNED VALUE MANAGEMENT

ANITA SUSAN VARGHESE* AND DR. V. THIRUVENGADAM**

Abstract

Effective management of a project is the key to its successful completion [1]. Earned Value Management (EVM) evolved as an efficient project management tool used for evaluating a project's performance by integrating its scope, time and cost [2]. EVM uses 'work-in-progress' as the indicator to predict 'work-in-future'[3]. Although being widely accepted, EVM has its limitations. The evolution of Earned Schedule (ES) and Earned Duration (ED) techniques are extensions to the traditional EVM, as an attempt to overcome the limitation of EVM in schedule performance measurements. Instead of measuring schedule performances using cost data, ES and ED uses time [4].

This paper briefly elaborates on these three concepts, and demonstrates its application on a live case example to evaluate the best suited method for project schedule performance measurement and forecast.

INTRODUCTION

Risks and uncertainty are a typical nature of construction projects [3]. Effective monitoring and control of a project helps complete it within the scheduled time and budgeted cost [12]. Proper analysis of project performance allows project managers to identify and mitigate the forthcoming obstacles within a project. The introduction of PERT and CPM in the early sixties led to the evolution of theories in project planning and monitoring. Gantt charts were used to oversee the physical and financial progress of the project.

Alternately, EVM was developed by the US Defense Department, and was identified as an effective tool for measuring project performance indicators. Although EVM was originally developed for cost control, it later became a tool which was used for project cost and schedule forecasting. The limitation of the EVM technique, however lies in its weakness on the schedule performance measurements. Earned Schedule was developed to overcome the EVM shortcomings[5]. Earned schedule determines the time at which the Earned Value accrued, should have occurred. However, the use of cost based data to measure schedule performance led to certain anomalies. Earned Duration is based on solely using time based data as project progress indicators [6].

This study is an attempt to explore the difference in the schedule performance measurement of Earned Schedule and Earned Duration from the conventional EVM techniques. The performance results using Earned Value, Earned Schedule and Earned Duration will be validated upon a live case study to examine which among the three methods, is best suited to forecast the estimated time of completion for a construction project.

EARNED VALUE MANAGEMENT

EVM is an integrated monitoring technique that provides a quantitative measure of a project's performance [7] using cost and time parameters. It analyses a project's planned and

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actual performance, to calculate cost and schedule variances and performance indices; and forecasts the project's cost and time results on completion [3]. Based on a project's past performance, it provides early warnings on the project's expected outcomes of cost and schedule.

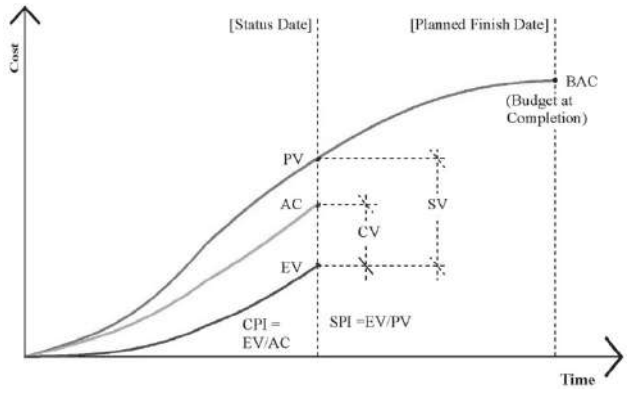


Fig. 1: EVM Curves

EVM uses three S-curves (plot of cumulative costs vs time) as the basic elements for the performance measurements (Fig.1):

- Planned Value (PV), known as the Budgeted Cost of Work Scheduled (BCWS) is the approved cost for achieving the planned work.
- Earned Value (EV), known as Budgeted Cost of Work Performed (BCWP) is the value of work that is finished.
- Actual Cost (AC) is the actual costs incurred in achieving the completed work.

From the above three S-curves, other parameters can be derived, as in Table 1.

Table 1: EVM Parameters

VARIANCES	Cost Variance (CV): Difference between Earned Value and Actual Cost	CV = EV – AC	CV is positive: Cost under budget CV = 0: Cost on budget CV is negative: Cost over budget
	Schedule Variance (SV): Difference between Earned Value and Planned Value	SV = EV – PV	SV is positive: Project ahead of schedule SV = 0: Project on schedule SV is negative: Project behind schedule
EFFICIENCY INDICATORS	Schedule Performance Index (SPI) : Ratio between the work completed and the work planned	SPI = EV/PV.	SPI > 1: Project ahead of schedule SPI = 1 : Project on schedule SPI < 1 Project behind schedule
	Cost Performance Index (CPI) is the ratio between the work that was completed and the amount that was used to complete the work.	CPI = EV/AC	CPI > 1: Cost under budget CPI = 1: Cost on budget CPI < 1: Cost over budget

FORECAST PARAMETERS	Budget at completion (BAC) is the total cumulative budgeted cost of all the project activities as per the planned schedule. It is the total base line cost and is the end value of the planned value curve.	–	–
	Estimate to complete (ETC) is the cost estimate to complete the balance work as on review date.	ETC = (BAC – EV) / CPI ETC = EAC-AC	–
	Estimate at completion (EAC) is a new revised cost estimate at completion.	EAC = BAC / CPI EAC = AC + (BAC – EV) EAC = AC + ETC	–

LIMITATIONS OF EVM

The EVM method uses cost curves as the criteria to measure project performance in terms of both time and cost [1]. Thus the major weakness of EVM lies in schedule performance forecasts.

The main contention is that, schedule efficiency cannot be realistically measured on the basis of costs, rather it should be based on the time measures of the schedule. While the schedule performance measured at the early phases of the project may be correct, its prediction nearer to the project completion is erroneous. Narbaev and De Marco (2013) analyzed EVM parameter Estimated Costs at Completion (EAC), revealing that they were unreliable in the later stages, nearing project completion [7]. On project completion, the quantum of work will be equal to the planned quantum and since the budgeted rates are same under Planned Value and Earned Value, the schedule variation shown will be nil, although the project might have been completed beyond the planned schedule with delay. While EVM makes a detailed analysis of the current performance, its primary theory that the future performance can be extrapolated from the past performance trend need not be necessarily true [6].

EARNED SCHEDULE

Earned schedule (ES) was developed as an advancement to EVM to resolve the EVM drawbacks. It uses the same S-curves, but in contrast to the cost indicators from EVM, ES indicators are in time units [8].

Lipke (2003) introduced the idea of measuring schedule variance SV(t) horizontally and expressing it in time units. Earned Schedule (ES) can be graphically calculated by projecting the EV curve onto the PV curve, to calculate the time within which the Earned Value accrued, should have occurred. Vanhoucke and Vandervoode (2008; 2010; 2011; 2014) compared the reliability of SPI and SPI(t) on a notional project, and confirmed that the Earned Schedule method outperformed traditional EVM technique. They also observed that forecasts on projects with serial activities were more accurate than predictions of projects with many tasks running in parallel [8] (Fig.2).

The parameters of ES (Table 2) analogous to its EVM counterpart. In most cases, the ES term is the EVM term appended by the suffix "(t)" for time [8]. The same S-curves from EVM are used for computation of ES.

- Actual Time (AT) is the duration from the beginning of the project to status date.
- Schedule at Completion (SAC) is the original planned completion duration of the project.
- Earned Schedule (ES) is the duration from the beginning of the project to the date on which PV should have been equal to the current value of EV. ES = % Complete x SAC.

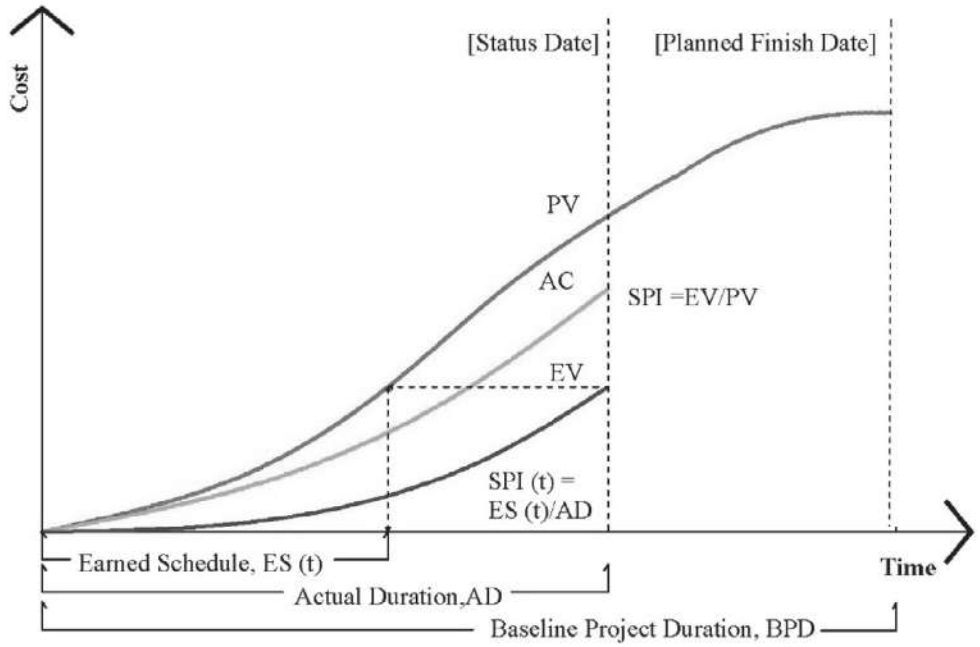


Fig. 2: Earned Schedule Curves

Table 2: Earned Schedule Parameters

VARIANCES	Schedule Variance (SV): Difference between Earned Schedule and Actual Time	SV (t) = ES-AT	SV is positive: Project ahead of schedule SV = 0: Project on schedule SV is negative: Project behind schedule
EFFICIENCY INDEX	Schedule Performance Index SPI(t) : Ratio between Earned Schedule and Actual Time	SPI(t) = ES/AT	SPI > 1: Project ahead of schedule SPI = 1 : Project on schedule SPI < 1 Project behind schedule
FORECAST PARAMETERS	Time at Completion: This gives the time estimate at completion with the same rate of doing work for the remaining project.	TEAC = SAC / SPI	–
	Schedule Variance at Completion (SVAC): The time variance at completion gives an indication of the estimated amount of time that the project will be completed ahead or behind schedule.	SVAC = SAC – TEAC	–

LIMITATIONS OF EARNED SCHEDULE

Since ES uses EVM curves, which are basically cost curves, used as proxies for measuring time, Schedule Performance Index can demonstrate a significant dependency on monitory values. Hence, the values of SPI(t), don't indicate the gravity of delays, especially when critical activities are being delayed.

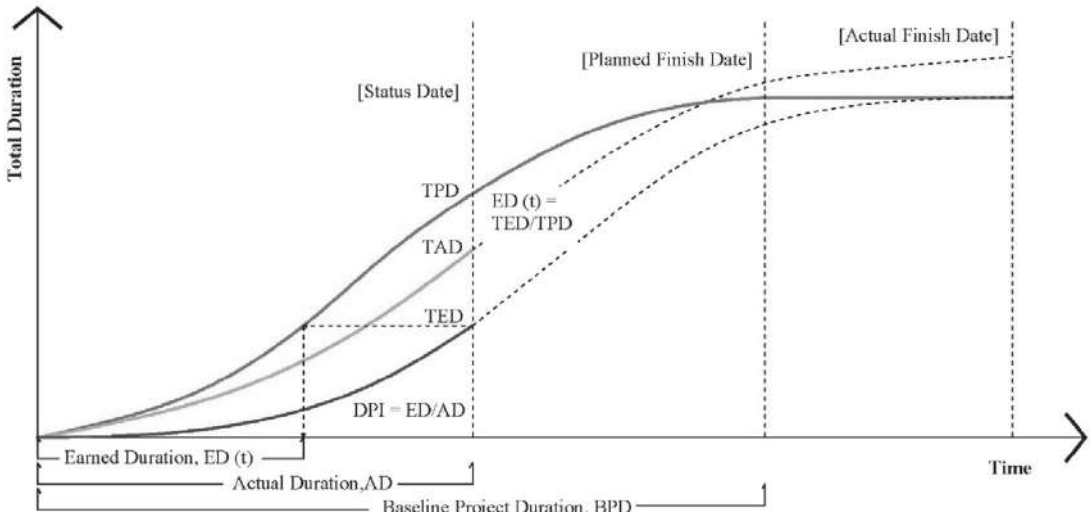
EARNED DURATION

The concept of Earned Duration (ED) was introduced to overcome the limitations of Earned Schedule. ED focuses on exclusively using time data for measuring schedule performance. Thus, schedule measurement values become free from any influence from cost parameters[8]. The similarity between the ED and ES parameters are illustrated in the Table 3.

Table 3: Summary of ES and ED Terminologies

Earned Schedule Parameters	*Earned Duration Parameters*
Planned Value- PV	Total Planned Duration- TPD
Earned Value- EV	Total Earned Duration- TED
Actual Cost- AC	Total Actual Duration- TAD
Earned Schedule- ES	Earned Duration- ED
Schedule Performance Index- SPI(t)= ES/AT	Duration Performance Index- DPI=ED/PD
-	Earned Duration Index- EDI=TED/TPD
Schedule Variance= ES-AT	Total Duration Variance= TED-TPD

(Source: Introduction to ED)



(Source: Introduction to ED)

Fig. 3: Earned Duration Curves

- Actual Duration (AD) is the actual duration of each activity.
- Planned Duration (PD) is the scheduled duration for each activity. Total Planned Duration (TPD) is the sum of the planned duration of all activities.
- Earned Duration (ED) is the product of Actual duration (AD) and Schedule Performance Index (SPI) ED = AD x SPI D = PD/AD

Total Earned Duration (TED) is the sum of the individual earned duration for all activities. Total

Duration replaces cost parameter on the Y-axis. Total Earned Duration (TED) substitutes EV and Total Planned Duration (TPD) substitutes PV[8].

Similar to Earned schedule, Earned Duration can be derived from the Fig.3, as illustrated below. Therefore,

$$ED = t + \frac{TED - TPD_t}{TPD_{t+1} - TPD_t} \times 1(UC)$$

METHODOLOGY

To understand and analyse the variations in schedule performance indices, the three methods- EVM, ES and ED were applied on a live case example. A G+9 apartment tower with an estimated completion time of 31 months, whose construction began in June 2016 was identified for case study. The project's proposed completion date as per schedule is 12th of January 2019.

The baseline schedule and the schedule as on April 2017 (status date) are used for obtaining the Planned Value and Earned Values. For the purpose of this study, only the construction phase of the project was taken under consideration. The data for the actual start and completion dates, as well as cost data, were duly collected from the site. The cost data is based on the productivity of the labour, the materials and equipment used. This data was obtained from weekly and monthly reports prepared by the contractor.

The schedule is prepared in MS Project and the Gantt Chart is obtained. The resources were loaded in terms of man, material and machinery, along with their budgeted costs. The budget allocation for each activity was completed. Once the Baseline schedule was set, the tracking for each activity was done, the progress of the project is measured and schedule updated on a regular basis. The actual start and finish dates, percentage complete and actual cost for each activity was recorded.

The schedule performance will be compared for Earned Value, Earned Schedule and Earned Duration techniques, to understand which method is most accurate for schedule forecasting.

RESULTS AND DISCUSSIONS

Earned Value

The project cash flow for the project was obtained in order to establish a time phased budget. The cumulative budgeted cost is illustrated in Fig. 4, and is the Planned Value (PV) for the project. The Budget at Completion (BAC) indicates the total budgeted cost for the project.

The performance measurement of the project can be observed by calculating the EV metrics, i.e., Planned Value (PV), Earned Value (EV), and Actual Cost (AC) from the schedule.

The monthly cumulative values for Planned Value, Earned Value and Actual Cost as generated by MS Projects, and the calculated SPI values are given in Table 4.

Table 4: Monthly Cumulative PV, EV, AC and SPI Values

Month	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
PV	564228	2300518	8918642	19153054	30990418	33364119	35801905	38558089	41534927	43891055	45840849
EV	337352	2300518	8718642	19153054	30990418	33364119	35801905	38437757	40582080	43734219	44461022
AC	628105	2112718	8120109	20582587	32921703	35308211	37759557	40418664	42596570	45699536	46485404
SPI	0.60	0.92	0.98	1.00	1.00	1.00	1.00	1.00	0.98	0.99	0.97

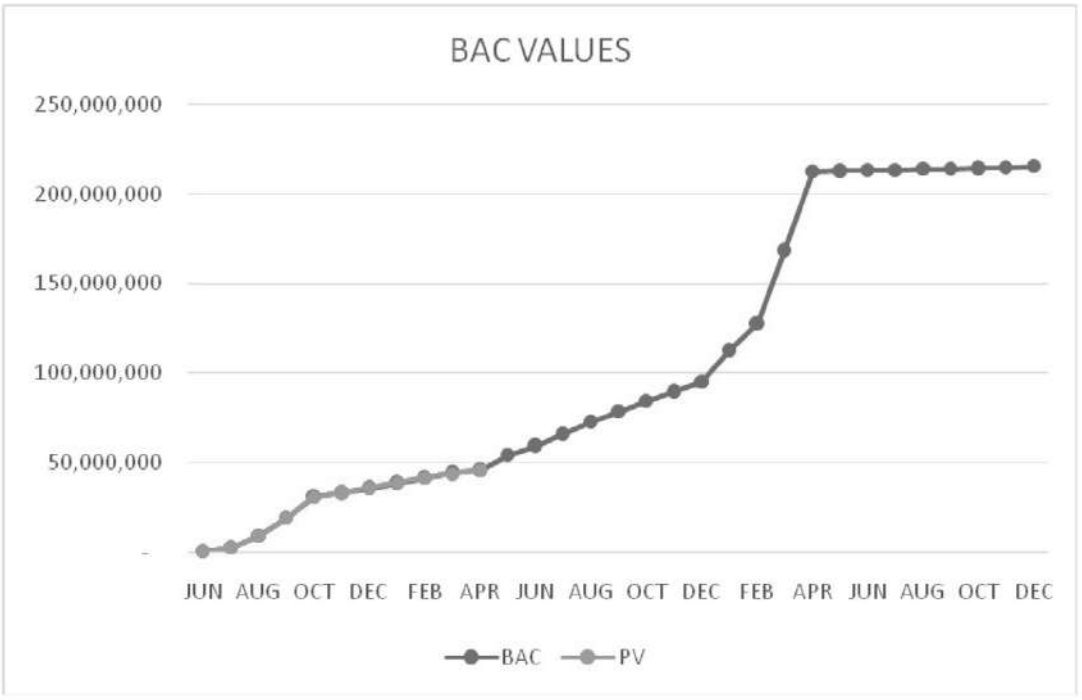


Fig. 4: PV and BAC Curve

The Fig. 5 below shows a graph of the earned value analysis on a monthly basis from June to April.

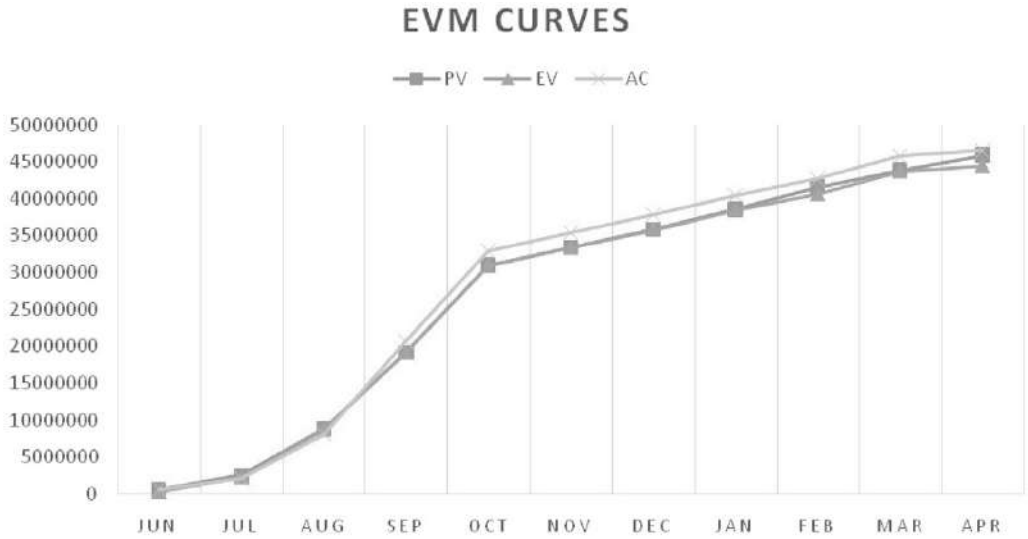


Fig. 5: EVM Curves [10]

From the above,

CV=Rs. -2024381.9, SV=Rs. -1379826.799

As CV and SV is negative, the project is over budget and behind schedule.

CPI= 0.96, <1 indicates the project has over spent.

SPI= 0.97, <1 indicates that the project is behind schedule.

Earned Schedule

Earned schedule uses the same cost curves developed by EVM, but the SV and SPI indicators are expressed in time units (days). The monthly SPI(t) values for the generated EV curves are given in Table 5.

Table 5: SPI (t) values based on ES [10]

Month	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
PV	564728	2500518	8918642	19153054	30990418	43364119	55801905	68558089	81534977	93891055	105840849
EV	537352	2300518	8718642	19153054	30990418	43364119	55801905	68437757	80582080	93734219	104461022
AC	628105	2112718	8120109	20582587	32921703	45308211	57759557	70418661	82596570	95699536	106485104
SPI (t)	0.93	0.92	0.9	1	1	1	1	0.99	0.98	0.95	0.92

Thus, the Earned Schedule value for the project is as follows:

$$ES(t) = t + \frac{EV - PV_t}{PV_{t+1(calendar\ unit)} - PV_t} \times 1\ (calendar\ unit)$$

where, t= 10 months

EV- PV_{10} = 569966.97

PV_{11}- PV_{10} = 1949793.77

Therefore, ES (t) = 10.29 months and AT = 11 months

SV (t)= ES-AT = -0.707 months

SPI (t) = ES(t)/AT= 0.94, <1, showing that the project is behind schedule.

Earned Duration

Unlike Earned Schedule, Earned Duration uses only time based data to indicate the schedule performance of a project. Instead of PV, EV and AC, three time based parameters- Planned Duration, Earned Duration and Actual Duration are derived based on the number of days for each activity. The monthly cumulative durations from June '16 to April '17 are given Table 6.

Table 6: EDI and DPI Values Based on ED [10]

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
AD	11	38	62	92	125	158	192	228	285	351	366
PD	11	34.4	59.4	92.4	125.4	158.4	192.4	224.4	274.99	310.99	320.49
ED	10.7	38	73	107	140	173	207	240	296	360	383
DPI	0.97	0.91	0.81	0.86	0.90	0.92	0.93	0.94	0.93	0.86	0.84
EDI	1.00	0.91	0.96	1.00	1.00	1.00	1.00	0.98	0.96	0.89	0.88

The monthly DPI and EDI values for the generated cumulative monthly values of Earned Duration curves are indicated above.

The Fig.6 shows a graph of the Earned Duration analysis on a monthly basis from June to April. Here, both the X and Y axes are time indicators. X axis is expressed in months, and Y axis shows the number of days.

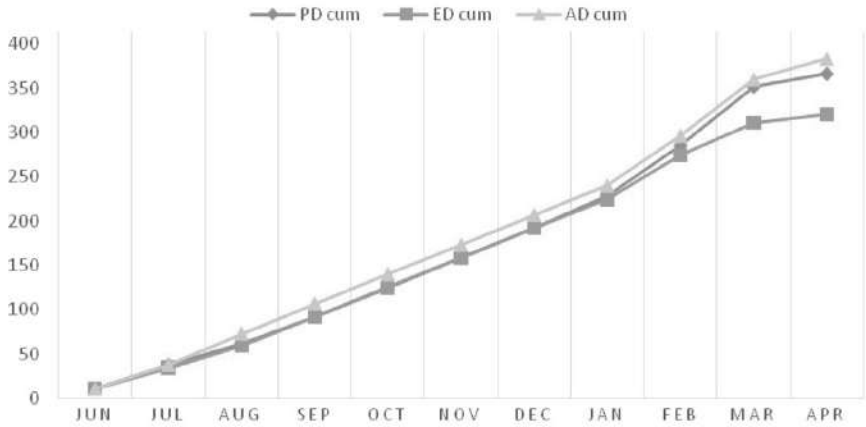


Fig. 6: Earned Duration Curves [10]

ED(t) gives the measure of the Earned Duration in days compared to what was planned to be done up to that point in time.

Thus ED for a given time, is calculated as:

$$ED(t) = t + \frac{TED - TPD_t}{TPD_{t+1(calendar\ unit)} - TPD_t} \times 1\ (calendar\ unit)$$

where, t= 9 months

TED-$TPD_{(9)}$ = 320.49-285= 35.49

TPD_{10}-TPD_9= 351-285 = 66

From the above, ED (t)= 9.53, EDI = 0.88 and DPI = 0.87

FINDINGS AND INFERENCES

The independent monthly SPI, SPI(t) and DPI values are calculated using EVM, ES and ED to evaluate which method gives a better schedule performance indicator. The Schedule Performance values and graphs are given in Table 7 and Fig. 7.

Table 7: Schedule Performance Values using SPI, SPI(t) and DPI [10]

Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
SPI	0.60	0.92	0.98	1.00	1.00	1.00	1.00	1.00	0.98	0.99	0.97
SPI (t)	0.93	0.92	0.90	1.00	1.00	1.00	1.00	0.99	0.98	0.95	0.92
DPI	0.97	0.87	0.71	0.97	1.00	1.00	1.00	0.97	0.90	0.56	0.41

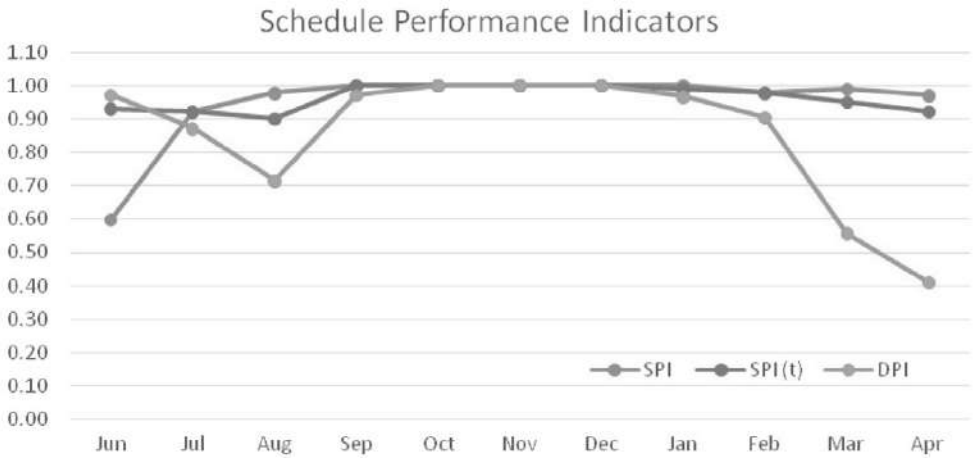


Fig. 7: Schedule Performance Graphs [10]

Table 8: MSP Schedule [10]

6	Civil Works	475 days	252.68 days	6/18/16	12/23/17	6/18/16	NA
7	Excavation	32 days	45 days	6/18/16	7/25/16	6/18/16	8/9/16
8	Raft foundation	28 days	27 days	7/26/16	8/26/16	8/5/16	9/5/16
9	Reinforcement	17 days	17 days	7/26/16	8/13/16	8/5/16	8/24/16
10	Shuttering	3 days	5 days	8/12/16	8/15/16	8/22/16	8/26/16
11	Concreting	10 days	10 days	8/16/16	8/26/16	8/25/16	9/5/16

Table 9: MSP Schedule [10]

66	Brickwork	289 days	69.39 days	1/21/17	12/23/17	1/23/17	NA
67	-2B Brickwork	13 days	19 days	1/21/17	2/4/17	1/23/17	2/13/17
68	-1B Brickwork	13 days	15 days	2/6/17	2/20/17	2/14/17	3/2/17
69	GF Brickwork	25 days	25 days	2/21/17	3/21/17	3/3/17	3/31/17
70	1F Brickwork	25 days	5 days	3/22/17	4/19/17	4/1/17	NA

The observations are noted to be as follows [10]:

- The SPI using EVM values start at a value of 0.6 in the month of June and gradually increase to 0.92 in July and 0.98 in August. From September to January, it remains at a steady value of 1.
- However, from the schedule (Table 8) it is evident that there has not been much of a delay in the month of June. The activity 'Excavation' was started in June as planned, but the actual duration (45 days) exceeded the planned duration (32 days), by which the activity which had to be completed on 25 July extended up to 9 August. Subsequently, the following activities of the casting of the raft foundation got delayed. It was scheduled to be completed on the 26th of August, but got extended up to the 5th of September.
- Thus the delay has been caused in the months of July, August and, September, not in June. However, the SPI values indicate the contrary. This is because the cost spent in the month of June is much lesser, due to preparatory activities, and hence the Earned Value in the month of June is much lesser, causing the anomaly.
- The SPI (t) start at 0.93 in the month of June, which is misleading as there is actually no delay in the month of June. However, unlike SPI it gradually reduces through the months of July and August, indicating that the schedule is getting delayed progressively. But then again, it is observed that in September the SPI(t) becomes 1 ignoring that the 'Raft Concreting' got extended into September by five days.
- DPI values on the other hand begin at 1, which is accurate as there are no delays in the month of June. It reduces to 0.87 and further to 0.71 in the months of July and August, indicating the delays. It shows a 0.97 in September illustrating the extension of the activity 'Raft Concreting'.
- Also, the values of SPI(t) for the months of July and August are 0.92 and 0.90. However, it is to be noted that the delayed activities in July and August are critical activities. The values of SPI (t) however do not indicate the criticality in its values, while DPI does.
- The schedule progresses as planned till the month of December. However, in January, (Table 9) it is observed that the activity '-2 Brickwork' whose planned start date was 21st January got delayed and started on 23rd January. Also its actual duration (19 days) exceeded the planned duration (13 days) causing a delay in the month of February.
- The SPI graph however shows the value to be 1 indicating no delays. The value of SPI (t) is 0.99, indicating a very negligible change. Only DPI (0.97) indicates an accurate schedule performance.
- Similarly, the SPI and SPI(t) values of February and March indicate a very negligible fall in the performance.
- The activities in April are ongoing and hence the values cannot be used for analyses.

Hence, it is observed that the values of Earned Duration are more accurate in terms of measuring the project's schedule performance.

FORECAST

The forecasts of Estimated Time to Complete may be done using all of the three methods. The forecast results are as follows:

- The Estimate at Completion (EAC) using EVM:

  EAC = Planned Duration (PD)/ SPI

  EAC=31/ 0.97 = 31.95 months
- The Independent Estimate at Completion (EAC) using Earned Schedule:

  IEAC(t) = PD/SPI(t)

  IEAC(t) = 31/0.94 = 32.97 months
- Estimated Duration at Completion (EDAC)

  EDAC= BPD/DPI or AD/PPI

  EDAC = BPD/DPI = 31/0.87= 35.63 months

  EDAC = AD/PPI = 11/0.30 = 36.66 months

Since it is observed that Earned Duration Technique gives a better indicator in terms of time, it may be considered more reliable.

CONCLUSION

This paper elaborated the various performance measurement techniques, with emphasis on Earned Value, Earned Schedule and Earned Duration.

It was observed that, EVM reports the schedule to be on time once the planned amount is spent. Thus if the project has a cost overrun, but is behind schedule, the EVM method will indicate the schedule performance to be on time. This can be a highly misleading.

Although Earned Schedule uses the same cost curves of EVM, Earned Schedule extrapolates the time in which the money is spent, and hence is more reliable in determining the schedule performance of the project. However the use of cost curves report anomalies in SPI(t) values, especially for critical activities.

Earned Duration was observed to be the most reliable technique, as they use time based data to measure the schedule performance, unlike Earned Value and Earned Schedule that uses cost based curves.

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APPLICATIONS OF 'INTERNET OF THINGS' IN VARIOUS DOMAINS AND SECTORS: A SMART CITY PERSPECTIVE

SAMEER JAIN*

Abstract

The term Internet of Things (IoT) was first coined by Kevin Ashton in the late 90s, but in reality, IoT goes back a lot further than that. At the beginning it was only a vision but today with the development of Information and communication technologies (ICT), and in particular wireless communications, it is becoming rapidly a reality in different domains and sectors. It is well known that smart IoT devices will have a big impact on our everyday life. With the development of ICT, billions of IoT devices are currently connected and it is expected there will be a few tens of billions connected devices within the next five years.

In this paper, we propose an IoT based wide range of applications in various sectors and domains. These applications can improve the ways people live, provide better interactions with the environment and facilitate the growth in the economy.

INTRODUCTION

According to Gartner, the IoT is "the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment. Smart cities will have IoT-enable services like water management and distribution, energy generation, transmission, distribution and billing, transportation and logistics, waste management, smart street-lighting systems, smart health care, and other smart services. With an ever-increasing population in cities worldwide, it has become a huge task to provide basic as well as enhanced facilities to city populations spanning all spheres of life. The number of urban residents is growing by approximately 70 million every year, and by 2050 it is estimated that people occupying just two percent of the world's land will consume three quarters of its resources. To provide a better and connected human settlement, the concept of smart cities is being explored in various parts of the globe as a viable alternative to the current state of metropolitan life. The concept of smart city aims to enrich life in cities in the near future through ICT-enabled and IoT services. Also, smart cities are being projected as information-economy hubs and secured underlying digital infrastructure that provides real-time data for all services and assisted living in the city.

LITERATURE REVIEW

The 'Internet of Things' (IoT) is defined as "the infrastructure of the information society" by the Global Standards Initiative on Internet of Things(IoT-GSI) in 2013. IoT is an emerging technology that enables interaction of uniquely identifiable computing devices that can be embedded with other interfaces like human beings and machines, linked via wireless and wired networks, to capture contextual data from the environment it has been exposed to and create an information network to provide new functionalities and digital business models. Internet of Things solutions in a secure fashion to manage a city's assets. The city's assets include, but are not limited to, local departments information systems, schools, transportation systems, hospitals, energy management, power plants, water management, waste management, and other community services. The IoT is the network of smart objects, physical

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devices, vehicle, buildings and things embedded with electronics, software, sensors, actuators and telecommunication connectivity that enable these objects to process data.

McKinsey & Company had defined the IoT as "sensors and actuators connected by networks to computing systems. These systems can monitor the health and actions of connected objects and machines. Connected sensors can also monitor the natural world, people, and animals."

The European Commission's digital agenda for Europe defines the IoT as a "technology and a market development based in the inter-connection of everyday objects among themselves and applications. IoT will enable an ecosystem of smart applications and services which will improve and simplify" human lives.

The International Telecommunication Union (ITU) has defined the IoT in Recommendation ITU-T Y.2060 (06/2012) as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on exiting and evolving interoperable information and communication technologies."

According to Cisco, IoT is the 'Internet of Everythings'which "links objects to the Internet, enabling data and insights never available before" and it predicts that "500 billion devices are expected to be connected to the Internet by 2030."

According to Goldman Sachs, the IoT "connects devices such as everyday consumer objects and industrial equipment onto the network, enabling information gathering and management of these devices via software to increase efficiency, enable new services, or achieve other health safety or environmental benefits."

The IoT is emerging as the third wave of Internet after the fixed internet wave of the 1990s and the mobile wave of the 2000s.

The five key attributes based on the 'S-E-N-S-E' framework (Goldman Sachs) that distinguish the IoT from the regular form of Internet are:

- Sensing – Leveraging sensors to generate contextual data
- Efficient – Enhances efficiency in productivity terms by adding intelligence to 'things'
- Networked – Creates a network of 'things'.
- Specialized – Ultimate use is focused on domain-based specialized offerings.
- Everywhere – Can be developed everywhere for a ubiquitous presence as per objectivity of use.

POTENTIAL APPLICATIONS OF THE INTERNET OF THINGS

SMART ENERGY

Smart energy systems are committed to supplying customers with the best standard of service and quality in the energy industry. We define smart energy (electricity, gas and water) in terms of energy generating, energy consuming, energy delivery and billing. Smart energy refers to using IoT and networking technologies to dynamically distribute energy in order to maximizes energy as well as minimize their cost, which involves decision-making and action-taking subsystems. In the smart energy network, metering devices pushed the usage data to and retrieved the billing information out from a number of energy providers intermittently. Residents are happy to know to their energy consumption at real time from a variety of devices such as personal computers, tablets or mobiles; together they can learn, share, adapt, optimize and reduce their energy usage.

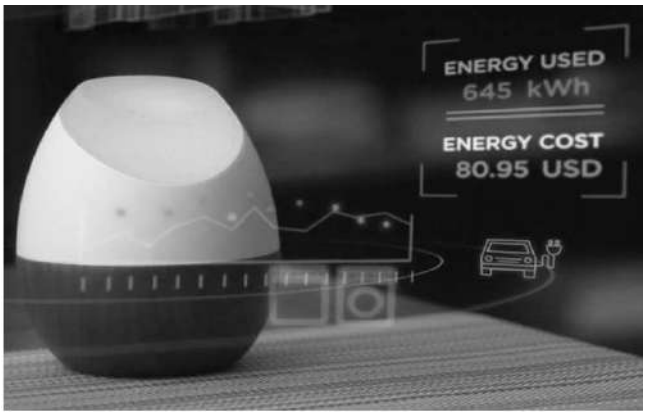

Fig. 1: Glow Smart-Energy Tracking Device

Smart Energy Home Tracker

Glow is a smart energy tracker that helps users understand how their homes are expending

energy as shown in Fig.1. This smart device uses a magneto-resistive sensing technology, and the sensor wirelessly measures the home's electric usage. The measured information is sent to an in-home display unit that changes color with the home's energy usage. Glow Home Smart Energy Tracker Can Help You Reduce Your Bills.

Smart Energy Initiatives in Smart Cities

The smart city of San Diego as shown in Fig.2, has partnered with GE for upgrading its streetlights as part of a transformation initiative to reduce energy costs and to integrate streetlights with a connected digital network. About 3200 smart sensors will be deployed in the city to create this digital network.

Fig. 2: IoT enabled Smart Energy Management in a Smart City

Barcelona, a smart city, has deployed about 20000 smart energy meters and more than 1000 LED streetlights with embedded sensors to monitor noise, weather and traffic. STARQ, a Catalonian company, has implemented smart solar streetlights in Barcelona that have zero emissions and can incorporate various smart city sensors as per the need of the urban environment in order to create an intelligent sensory and information hub. Similar initiatives are also being implemented in smart cities across the globe for a cleaner and greener living experience.

Smart Meter

The usage of smart meters as shown in Fig.3, is gaining popularity, as these devices can measure the usage of electricity in a home and display it with the billing amount on a smart display or app-based dashboard. The smart meter can automatically send its reading to the energy supplier for accurate billing, removing estimation- based billing.

Fig. 3: Smart Meters

Using smart meter, the user gets energy usage reports in near real-time, along with a break-down of values of consumption by hour, week, and month, with corresponding cost. It also helps users compare their energy usage with similar households in their region.

Smart Grid

The electric grid, comprising of a substation, transformers, a transmission network and meters, has been digitized and transformed into the 'smart grid'. According to International Energy Agency:

A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability.

With a smart grid, we have instantaneous data about the volume of electricity generated, consumed, demanded and available to help with agile planning for production and distribution as shown in Fig.4. Use of sensors, information technology and two-way communication between the utility provider and the consumers are prime features of a smart grid. Utilizing intelligence, automation and control, the smart grid will enable large-scale integration of renewal energy systems, real-time monitoring of grid operation and performance, reduced peak

demand for efficient demand-side management, reduced energy wastage and early warning for blackouts.

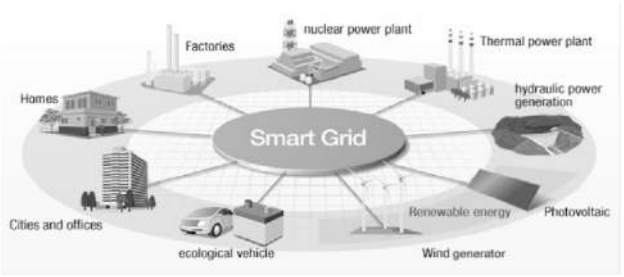

Fig. 4 : Smart Grid Dependent Systems

SMART OFFICE

Smart Office Tracker

The home is increasingly being used as an office by home workers and teleworkers employers, employees and the community can benefit from a number of advantages such as reduced cost, improved motivation, and freedom from traveling, and so on. Smart office is about aspects of business processes that drive daily operations in the office on the basis of projects and scheduled work tasks that are regularly performed by office employees. This sub network communicates with various regularly performed by office employees.

Fig. 5: Smart Offices

As shown in Fig.5, IoT enabled office spaces would look and 'act' quite differently from the present ones. For example, IoT connected appliances would actively contribute towards cost conservation and optimal utilization of resources, like lights in a meeting room going off as soon as people vacate it. Also, smart devices, with the help of motion sensors, would let employees find a vacant meeting room and locate their co-workers. Responsive environmental settings, on the other hand, ensure that employees experience a pleasant environment to work in, which boosts their motivation. For example, IoT-based thermostats not only adjust the room temperature based on the number of people working on the floor, they also monitor the air quality, triggering the air purifier automatically when needed.

CONCLUSION

Smart city aims to make full use of the urban informatics and technologies to meet city residents' needs and to improve the quality of life.A smart city should enable every citizen to engage with all the services on offer, public as well as private, in a way best suited to his or her needs. Smart-assisted living in smart cities includes features like smart infrastructure, smart energy management, smart transport and traffic management, smart water management, smart waste management, smart healthcare and smart education. The smart city has interdependent smart systems that can handle all major systems like water, energy generation and transmission, logistics, transport, garbage and waste disposal, green buildings, lighting systems, citizen-connected healthcare, online learning and education, people connected through smart phones, CCTVs, traffic systems and so on.

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PRIMAVERA SOFTWARE - BEST TOOL FOR PROJECT MANAGEMENT

O.P. GUPTA, VSM*, VIJAY GUPTA, CHANDAN GUPTA*** AND RAKSHA GUPTA******

Abstract

In today's ultra- competitive business environment, fast-paced, large- scale projects are becoming the standard. The problem is, many project managers don't have the assets to effectively plan, manage, and track all the components that come with these complex projects.

With limited visibility into scheduling, resources, and overall progress, project managers require a more advanced toolset to effectively take control of these responsibilities to ensure the project stays on track.

Oracle Primavera P6 stands out as one of the most easily recognized and useful tools in effective for construction project management. Oracle Primavera P6 gives unparalleled control, monitoring, and insight to planners, project managers, schedulers, employers, stakeholders, and any others who are involved in a given project.

Project management concepts are no longer theoretical but have got converted to technology driven means. There are many parameters of Primavera such as primavera architecture, calendars, scheduling, work breakdown structure, resource assigning, its analysis and leveling, updating, etc, but in this paper the authors have discussed the major parameters which effect the construction industry in a far bigger way. To divert the attention of non-participants of primavera, to show its proper utilization, applicability, the authors feel that the mentioned parameters discussed in this paper are sufficient, so that they can take initiative for their business or roles and responsibilities in their projects.

INTRODUCTION

Primavera was launched in 1983 by Primavera Systems Inc., which was acquired by Oracle Corporation in 2008. Primavera P6 is a software used by owned by Oracle. It is used by project management professionals and also can be linked with ERP systems. It handles multiple projects and can hold up to 100,000 activities with unlimited resources and an unlimited number of target plans.

It is primarily a visualization tool, which has improved the ability to exchange complex ideas among project participants. It has become easy to generate and reuse the information for construction projects. This is a 'CIEPM' (Computer Integrated Enterprise Project Management) concept which allows the meaningful extraction of project management data, information and knowledge from the participants beyond their imagination.

Project management software breaks down the complexity of a project via smaller projects and tasks. This encourages communication and collaboration among team members as well as ensures deliverability. Project management directs, regulates and supervises a project from beginning to end. Software ensures it stays on track and

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under budget. Software also helps users anticipate problems that could derail a construction project.

Construction Project Management Software

With effective construction project management software, contractors, architects, owners and other construction professionals can reap the following benefits:

- Control over the planning, design and estimating of future projects
- Cost control
- Scheduling optimization
- Accountability and visibility over the life of a project
- Accurate tracking and monitoring of project milestones and deadlines
- Reduction of miscommunication or misplaced documentation
- Workflow efficiency and optimization
- Process standardization

This software is different for small and large companies; however, there are several essential features that crop up across the board:

- Document management
- Team collaboration
- Resource allocation and management
- Time tracking
- Task management
- Business process reporting

Differences between Primavera P6 and MS Project in planning is given in Table 1.

For heavily involved in a project or multiple projects, and requiring to computerize every detail of project should go for Primavera P6 Professional Project Management. Otherwise working on a single project that doesn't require record details other than activity schedule, resource list, and assignment details, use MS Project as it is simpler.

Table 1: Differences between Primavera P6 and MS Project in planning

Sl.	Activity	Oracale Primavera P6	MS Project
1.	Unique ID	P6 is characterized by unique ID. For example, set the project to start from 1000 and increment by 10, so that the first activity entered will be assigned ID 1000, the second ID 1010 and so on. The activities keep their ID regardless of changes in position (unless to physically change them).	Microsoft Project, the first line is assigned ID 1, the second line ID 2 and so on. If a new activity Inserted between 1 and 2, the new activity becomes ID 2. Thus an activity's ID is determined by its position in relation to the others. For working in a big project and using activity ID system/ Identification, then Microsoft Project will not be the correct choice.
2.	Sorting	Sorting Can be done by date order, by Activity ID or any other factor which make the sorting very durable and easy.	It offers a bit more discretionary control in that individual activities are moved into the position to appear.
3.	Baselines	Unlimited baselines can be created	only 11 baselines can be created
4.	Start and Finish Milestones	Can define a milestone	can not define a milestone as either a Start or Finish milestone
5.	Multiple User Access	Allows to do that Even specify what features particular user can use, and which cannot.	doesn't allow multiple users to work on a single project at the same time
6.	Issues and Risks	can record issues and risks.	lacks the feature of tracking project issues or risks

7.	Web Support	plan, documents and other information can be converted to HTML directly from the software	doesn't have such option.
8.	Steps	allows to create sub-activities (steps) of an activity. Each step can have its own start and finish date, and a completed step can be marked as completed	This useful feature is missing
9.	Expenses	Besides Costs project expenses e.g training, travel, etc can also be added,	Expenses cannot be added.
10.	Custom Fields	allows to create custom fields, can create a blank field, but cannot set formulas to it, so users have to manually enter values in each in the field, for each column.	allows to create custom fields even allows to set complex formulas or use fields and add additional values to it, to use in the custom field.
11.	Columns	has many useful columns. It comes installed with over 200 columns, each giving different information. Some column category to name include EVM, Budgeting, Costs, etc.	there are only around 40 columns.
12.	Multiple Activity Relationships	more than one type of relationship can be established between activities e.g can have FF and SS between the same two activities.	only one relationship can be made between two activities.
13.	Project Website	can create a comprehensive website comprising of complete project details including activities, resources, reports, risks, issues, WBS, and everything that has been entered in the software.	This website is very valuable feature and is not present in MS Project.
14.	Multiple Project Creation, View and Tracking	Multiple Projects Can be created and Viewed, which covers Multiple Project tracking, multiple project or WBS comparisons, cost and units calculations can be created .	This can be done in MS Project too but since MS Project is not intended for multiple project use, it doesn't allow to do things like in primavera multiple project
15.	WBS	WBS is created separated from activities. Once WBS has been created activities can added with each WBS element	activities are indented to make them look like WBS.

BEST CONSTRUCTION PROJECT MANAGEMENT SOFTWARE SOLUTIONS IN 2019

There are 13 Construction Project Management Software Solutions in the year 2019 including Oracle Primavera P-6 as given here under: -

- Autodesk BIM 360
- Procore
- Touchplan
- Builder trend
- Corecon
- Spectrum
- Oracle Primavera
- Oracle Aconex
- Newforma Project Center
- GenieBelt
- Oracle Prime Projects Cloud Service
- CMiC
- Project DocControl

ORACLE PRIMAVERA P6

Oracle's Primavera P6 is one of the most powerful and comprehensive project management tools available on the market today. It is a project management software specifically designed to help manage complex projects. It's role-specific functionality helps organize projects in a way that satisfies each team member's needs, responsibilities, and skills.

Primavera P6 is not a single product, but a suite of products that helps manage a project over its entire lifecycle. It can be used to help manage risk versus reward, resourcing, and budget, among many other deliverables. With Primavera, organizations are able to better execute amid economic uncertainty, respond quickly to unexpected changes, and create value for their organizations and stakeholders.

Versions of Oracle Primavera P6

There are two versions of Oracle Primavera P6. Both versions provide robust, easy-to –use solutions for planning, managing, and executing projects. Selection of version for a project is largely dependent on accessibility.

- Professional Project Management (PPM)- This is a standalone, non-web based solution used to manage primarily smaller-scale projects (but is capable of managing up to 100,000 activities). Users can access the software from any machine it is loaded onto.
- Enterprise Project Portfolio Management (EPPM)- This is a 100% web-based tool to helpenterprises manage large-scale projects, or multiple projects at once. Because the tool isaccessible from any location with internet access, one can access data from anywhere, andshare with partners without requiring them to download the application. It also provides helpfulvisual aids such as graphs, charts, and pivot tables to allow managers to gain a comprehensiveview of project status quickly. This cloud-based solution also allows for more data storage forusers than the traditional Professional P6 tool.

Key Features

While many people think that key feature of Oracle Primavera P6 are limited to scheduling-only tool, but features give the ability to do much more than that, such as

- Scheduling: It includes an array of scheduling alerts and reporting tools to ensure the schedule is filled in appropriately,which help to keep the project onschedule and within budget
- Risk and Opportunity Management: It helps to conduct initial and recurring risk and opportunity analysis within the schedule, which helpsto identify when risks may occur and how drastically these risks may impact the project'sschedule and baseline.
- Resource Management: It can closely monitor the usage of resources and generate forecasts of changes in resource availability. which helps to identify what other resources may be diverted to keep the project on track. For EPPM users, one can take advantage of visualization tools within the program that transform raw data into easily understandable and shareable graphics.
- Contract Management: It allows organizations to maintain control over multiple tasks across several projects or programs. When a new project closely mirrors a previous project,

onecan copy information from the Oracle database in seconds.

Benefits of Oracle Primavera P6

Some of the benefits of Oracle Primavera P6 are discussed here under: -

Breakdown of Complex Projects: The size of a project can be overwhelming. Oracle P6 allows project managers to break large projects into smaller, achievable projects, tasks, and activities.

Increased Visibility: Visibility and compliance with political and environmental regulations are among the top priorities, Since Oracle Primavera P6 allows all data to be entered, tracked, and analyzed in one location, which ensure project does not pose any possible violations.

Mitigate Risks: When schedule has inconsistencies, errors, or overrun issues, project expenses will grow. This could mean cutting more vital aspects of the project to compensate for the excess costs. It helps identify and mitigate risks in the course of planning, managing, and completing a project.

Enhanced Communication and Col**laboration:** It enables executive:level staff tocommunicate with other workers, project managers, and planners easily. Furthermore, notes canbe made to the schedule in the software to ensure all users see the message.

Predict Unplanned Project Activities- As a project evolves, the project may require additional resources, activities, and tasks to meet stakeholder demands. It can create forecasts for resources, activities, and other project needs.

Optimize Resources: It allows all involved in a project to carefully monitorresource availability and adjust such resources to meet project demands. Furthermore, itcan also help identify areas where resource costs may be reduced by analyzing resource trends and costs.

Integrated into other Enterprise Software

It can be seamlessly integrated into other Software being used by the Management like solutions from Oracle or SAP's enterprise resource Planning System.

Implementing Oracle Primavera P6 For Successfull Implementation

The careful and correct implementation of Primavera will be able to leverage the wide range of valuable features.

It will require careful analyzation of several different variables, and a clear plan in place, while the implementation process is different for everyone, there are a few best practices that should be followed to increase chances of success.

One of the major tactics to use for successful Oracle Primavera P6implementation is a careful review of the ways in which the business is being done.

Most important thing for successful implementing Primavera P6 is to learn the fundamentals of the software. Despite its user-friendly setup, mastering the fundamentals of the software make implementation significantly less challenging and increase overall ROI.

Poor Implementation

- Poor implementation can result in consequences like expensive rework, non-value added bureaucracy, poor decision-making, or lack of adoption overall.
- Improper implementation can actually do more harm than good, depending on the situation.

System Configurations

The strengths of Oracle Primavera P6 is the ease at which it integrates into existingsolutions, one of the key tactics to use moving forward naturally involves reviewingcurrent environments to get an idea of the system configurations that will be using.

Oracle Primavera P6 is built to integrate with existing solutions, doesn't necessarily mean that it's as easy as pressing a button. Different organizations use different programsin slightly varying ways.To do make sure that to perform a technical review of things like web application server,database server,

and even the desktop clients that are being used to do the lion's share of work. Then, use this information to determine the best system configurations for the various Primavera modules like the Web Access and Compression Server, Project Management, and others for the best possible results.

Use of Primavera P6 Software in Civil Engineering

Primavera P6 is the Project Management Tool (software) that helps in planning theresources, monitor and control for a project. It is not only used inCivil Engineering but also other fields such as IT, HVAC, Electrical etc wherever there are projects.

It is based on Critical Path Method and hence understanding its basics is essential. Primavera helps in

- Generating the Critical Path quickly

Providing output for Resources such as material, machinery and man-power on daily, weekly and monthly basics.

- Forecasting as to when the project will be completing
- Earn Value Analysis (EVA) - that is whether the project is on time, ahead or behind and at what cost

However, it is important to note that Primavera P6 is the software only. Not Artificial Intelligence. which means one has to

- Manually enter the activities
- Link the activities
- Enter the duration
- Allocate the resources such as manpower, material and machinery etc.

Application of Primavera P6 in Construction Industry

Many studies have shown that the primavera application has positively impacted the productivity of planning processes and later its execution. Its potential impact on the entire life-cycle of construction project is to the fullest extent. Some high potential parameters (in primavera application), which significantly affect the project results (positively), are discussed here under:

Reluctance in Adopting this Technology

A number of viewpoints have been given by the researchers to the practitioners foradopting this new technology for their own benefits. However, there seems to be some reluctance on the part of the practitioners for adopting this technology, which will have to be overcome by the researchers.

Hesitate to Invest and Adopt Primavera P6 Tool

In fact, many architectural/engineering/ construction firms hesitate to invest and adopt in this primavera tool, because they don't have sufficient time to study and analyze this technology. The objective of this study is to validate its applicability to the entire life-cycle of construction projects, including planning, design, construction and operation, and maintenance phases.

Application of Primavera P6 for Project Management

Basically project management deals with project cost and resources. So this software enables an organization to deliver project on time and on budgets through reuse of best practices.

Primavera P6 uses standard windows interfaces, client/server architecture, web-enabled technology, network based (Oracle and Microsoft SQL server) databases. It stores all projects in a single database system, which allows greater flexibility, increasedefficiency, consistency and repeatability and hence saves organizations time and money.

Application of Primavera P6 for Enterprise Project Management (EPM)

For big complex and multi-level projects in any organization, it is necessary to have strong coordination and standardization, centralized resource management, higher-level reporting about projects and resources. And for all this one ideal solution available is PrimaveraP6 for Enterprise Project Management.

Enterprise Project Management (EPM)

Collective Portfolio for Better Decision

For a company's multi-level projects, a continual identifying, prioritizing and investing strategies have to be aligned. Which can be done by 'Managing projects as a collective portfolio' for better decisions.

Optimizing Resources

Human resources are the most valuable and often expensive assets. It is difficult to maximize the productivity and cost-effectiveness of human resources. Whereas in E.P.M., There are 'Optimizing resources across organization' for proper survival.

Communication

To achieve project success, clear and effective communication should be there withknowledge sharing team members. Project teams can meaningfully get connected and maintain coordination with quality, hence strengthen collaboration across the enterprise for improved productivity.

Organizational Breakdown Structure (OBS)

Application of Organizational Breakdown Structure (O.B.S.) –It represents the hierarchy in project for a responsible management. It usually shows the top to bottom level personnel in any business. After defining the hierarchy, one can associate responsible personnel on individual projects i.e. on EPS node and also projects within. So directly/indirectly one is assigning the responsibilities, accountabilities and authorities over the work heads. A proper and completed work breakdown structure must be defined in a project to assign a committee or person for each task. The OBS will mirror the structure of the WBS. Major category work will be assigned to senior committee members and lower level tasks to the groups or individuals. By doing this, project manager becomes the responsible person for the project and indirectly gets authority to re-assign groups or individuals working in it. The access and privileges to EPS/Project/WBS nodes are assigned through the OBS. A maximum of 25 levels can be created in primavera.

Application of Risk Parameter of Primavera

Categories and prioritize potential risks associated with specificWBS elements and resources through integrated risk management feature can be identified. Thereafter one can create risk plans and assign a probability of its occurrence. Also for each risk defined, an OBS can be assigned. This means a particular person or a project manager can be held responsible for defined risk. The risk type, priority level can be mentioned and also the particular WBS element and resources which will be impacted by that risk. It uses a risk's probability of occurrence, date of potential impact, and resource unit and expense estimates to calculate a risk's net exposure values. These exposure values are then used to determine the risk's impact on the project's cost, float and finish date. The current project data can't be changed. It calculates the risk's exposure values as, Exposure = Impact x Probability. The above calculated values are being applied to those activities which finish on or after the risk's impact date. The values do not include activities which are completed, locked or milestones. It then schedules the project according to the current scheduling preferences.

Application of Primavera Web

It is a web application that provides browser based access to a project, portfolio and resource data across the enterprise. Hence anyone working in an enterprise can access information whenever and wherever it is needed.

Relevance of Oracle Primavera P6 Software

Oracle Primavera P6 is used by all military and federal agencies in the US. In fact, statistics have shown the overwhelming majority, 375 out of 400, of top engineering companies in the US use Primavera P6. Oracle Primavera P6 popularity is rapidly growing for its ability to plan, manage, and control all facets of a project.

FIVE (5) THIRD-PARTY TOOLS FOR PRIMAVERA P6

Due to high Cost and complexity of Primavera P6, it is not possible for everyone to have a license. However, there are some third-party tools, or better said viewers,which provide the facility open at a very small cost. Among the most important benefits

of these tools are the cost-cutting, time-saving and more efficient use of resources. Therefore, the authors feel the necessity to give an overview of the tools that have proved to be most closely adapted to Primavera P6, focusing on their key features and advantages. Five such Tools are discussed here under: -

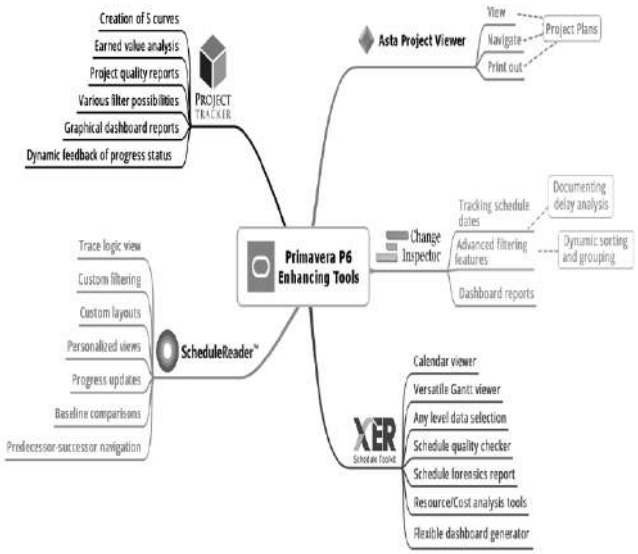

Fig.1: Key Features of Primavera P6

XER

Primavera P6 and similar software programs use. xer file extension These files are crucial when it comes to planning projects because they save important data such as resources, tasks, timelines, materials and other necessary requirements for a certain project. The software will not be able to function properly when it comes to planning and tracking project progress if it is not for the .xer files.

Schedule Reader

Schedule Reader is a cost-effective viewer designed for viewing. xer, xml and xls project files. Schedule Reader offers an overview which mean one of the project with Personalized Views and Custom Filtering.

There is the option to navigate through Predecessors and Successors activities in order to be able to analyses the relations between them.

Another important feature is the Trace Logic view that can be used for comprehensive analysis as it presents selected components of the project schedule visually. In addition, this Progress Update feature that allows you to make feedback proposals for progress updates on assignments and activities

XER Schedule Toolkit

The XER Schedule Toolkit is a tool used for converting files created with Primavera P6, Asta Power Project, and Microsoft Project. It is easy to use and enables to viewand analyse the information in a setting one will be definitely familiar with – MicrosoftExcel. The tool has been created with the purpose of improving the project planningprocess and contributing to the successful delivery of projects in regards to budget and time. Some of the features that this tool offers are the data selection of any level, a versatile Gantt viewer, a schedule quality checker, a calendar viewer, a report on schedule forensics, a flexible dashboard generator, and resource and cost analysis tools.

Project Tracker

This tool allows to import baselines and projects from Microsoft Project, PrimaveraP6, and Asta Power Project.Its main strengths are the creation of S Curves based onduration, cost or resource, which facilitate and improve the overview of a project'sprogress; earned value analysis of the project; graphical dashboard reports which help in the progress assessment; and project quality reports.

Change Inspector

Change Inspector is primarily a tool whose purpose is to serve as a solution for tracking schedule dates and documenting the delay analysis as its reports provide with detailed and transparent analysis. The tool works with Primavera Contractor XER, P6 XML, and Microsoft Project files. Its filtering features are at the same time advanced but simple to use and offer many possibilities with its dynamic sorting and grouping. Change Inspector produces reports that enable to locate the changes between two schedules and highlight the problem areas. Moreover, with this tool, one can create a dashboard where vital schedule information is displayed. One can even use the charts in reports to stakeholders as they simplify the schedule review.

VERSION 7 OF PRIMAVERA EXPEDITION

Version 7.0 of Primavera Expedition, is the first program able to provide a globalrespective ofa corporation's Multilanguage and multicurrency projects.

The new release also promises cross-project analysis, customizable uniform processes, and improved collaboration and contract management by project teams and it has come 13 years after the first introduction of the software.

Functions of versions 7.0 of Primavera

Expedition fuses client/server project control with Web-enabled collaboration through its Expedition Express software. The new release provides in-depth project tracking and analysis for project and other operations managers, while enabling other uses, such as job-site personnel or vendors to benefit from relevant project information. The software provides both new features and improved usability.

Primavera Expedition is the first project control software to provide secure access to project information for all project team members using custom, role-specific workspaces and capabilities.

The feature supports more consistent project workflows, uniform processes, and fasterdecision making.

Expedition tracks change requests, design reviews and approvals, and payment requisitions. It manages the design, specification, ordering, and delivery of all project materials.

Working Operation of Version 7 of Primavera

An updated, simpler interface enables operations and field workers to access only the project information and action lists they need to do their jobs. Two mouse clicks from anywhere in the program enables them to create new project documents

New Features of Expedition

Expedition Project Center. Provides a centralized view of all project information using graphics to highlight project and program performance. The role-based workspace creates action-oriented information and uses customizable thresholds and interactive alerts to flag critical issues. It enables users to track project and cross-project trends and to drill down into project details with a single click.

Project templates. Enables companies to establish best practices by cataloging such standard project information as contacts, drawings, submittals, and other project documents.

Global customization. Support more than 16 languages and 150 currencies. Users can easilycustomize headings and fields on all of Expedition's standard forms and more than 200 standard reports.

Microsoft Word integration. Expedition supports Microsoft Word templates to facilitatecreation of project documents in accordance with approved company standards.

Expedition Analyzer. Expedition Analyzer, an option, enables managers to studymultidimensional real-time project data to improve decision-making. Its online analytical processing (OLAP) technology integrates information from multiple projects for ad hoc queries and what-if analysis. Predefined data cubes allow immediate analysis without the need for training. Primavera Expedition 7.0 is a 32-bit application, built on a high-performance, scalable client/server architecture and SQL relational database. Clients require Windows 95/98/NT and 64 MB RAM. The server uses Windows 95/98/NT or Novell 3.1x or with 128 MB RAM.

CONCLUSION

Project management concepts are no longer theoretical but have got converted to technology driven means. There are many parameters of Primavera such as primavera architecture, calendars, scheduling, work breakdown structure, resource assigning, its analysis and leveling, updating, etc. but the primavera P6have parameters which affect the construction industryin a far bigger way.

Primavera P6 is a popular software for planning and managing projects, regardless of the industry, whether it is Construction, Oil and Gas, Manufacturing, Automotive, or Aerospace and

Defense. Each benefits a lot by using this software especially in regards to time, budget, and efficiency.

Oracle Primavera P6 is one of the most powerful and comprehensive project management tools available on the market today. Tools and features in Primavera P6 help all project management team members and staff understand the needs and activities of your project. Primavera P6 helps project managers identify and mitigate risks throughout the project by identifying early warning signs.

APPLICATION OF VIRTUAL REALITY (VR) TECHNOLOGY FOR EFFECTIVE DESIGN OF CONSTRUCTION PROJECTS

SIDDESH PAI*, K. NEELA WARDHAN AND N. ABHINEETH****

Abstract

Technological up gradation is now a days becoming a trend in all the modern industries. Coming to construction sector a lag in the technology upgradation is identified, where a lot of problems can be solved by innovative approaches. The major problems keep occurring due to the preliminary design defects, but the identification of these defects is observed only after the execution in the construction site. This effects the work progress and a huge loss for the companies. In order to eliminate such problems the concept of virtual reality technology can be implemented in order to get the work execution in the most accurate manner.

Virtual reality helps in visualizing the model in a real time environment. This system consist of a high configured display unit with a controller used for operating the model as per the required views. This system enables in constructing digital reality which resembles real life. The concept mimics the real world and takes the 3D design to the next level that is about to be executed in the real time. So based on this design validation becomes simple by comparing the actual plan with the conceptualized model, where in we get to know the errors in the design prior to the execution of the project.

INTRODUCTION

Changes in design is the most common cause for difficulty in execution of the projects. Design changes due to errors on projects can cost a lot of money and delay in the schedule for a long duration, depending on the severity, because these kinds of drawings will lead to miscommunications between the clients and employees. Virtual Reality (VR) technology also helps in a better communication for key personnel across the construction companies which helps for greater design visualization, contributing to a better understanding of the project. Using earlier with BIM in tracking and observing the designs flaws, VR is an automation to do both the activities. Any plan of a hotel, a luxury villa or hospital can load with VR in headset and can make a 3D Model and view it. Virtual Reality technology has made a good positive impact in gaming and virtual businesses, getting that technology into construction industry will boost up the design companies and make a good sense in the market. This kind of technology can be implemented in safety ensured practices to keep their standards higher, and can also be used to train the newly recruited personnel.

Architects and designers are investing in virtual reality technology that assists them in getting the fine details just right by putting them in the room they are designing.Thus it becomes easier to spot inaccuracies, errors specifically clashes between beams to columns and into slabs, make amendments and generally interact with the design.

Research Objectives

- To investigate how VR (and thereby 3D) can be used during the planning and design.
- To highlight the design clashes of construction projects using virtual reality technology.
- To demonstate cases on how VR can be practically applied in construction projects.

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METHODOLOGY

The case study was launched to explore and document the use of VR in a construction project by providing values achieved and good examples from how the client, design teams and planning teams have been using VR models as a complementary source of information to 3D CAD models and 2D CAD drawings in the construction drawing plans. The research objective was to provide new insights and knowledge about the values of using VR models in a construction projects with focus on the design and planning process. Clashes which are found in BIM Models, has to be resolved in 'REVIT ARCHITECTURE', but during the process of resolving the design, there may be a chance of getting the design changed entirely. But, in case of Virtual Reality there will be a chance to resolve the errors without making any major changes in design.

Types of Design Errors

1. Inadequate Structural Design
2. Poor Design Details
   - Abrupt Change in Section
   - Insufficient Reinforcement at Corners and Openeings
   - Inadequate Provision for Defelction
   - Inadeuate Provision for Drainage
   - Insufficient Travel in Expansion Joints
   - Incompatibility of Materials
   - Neglect of Creep Effects
   - Rigid Joints between Precast Units
   - Unanticipated Shear Strees in Piers, Coloumns or Abutments
   - Inadequate Joint Spacing in Slabs.

Causes

- Accuracy of drawings
- Number of design omissions and ambiguities
- Inadequacy within plans and specifications
- Quality of facility

APPLICATION OF VIRTUAL REALITY ON DRAWINGS/PLANS

Design Clashes

In design terms a clash occurs when the drawing of components are not equally drawn or balanced then these types of collisions will occur. In BIM process these clashes will be spotted in the design process and these can be resolved through the software. These are of two types Hard and Soft clashes.

A 'hard clash' refers to one building component physically yet unintentionally penetrating another building component; that is, two or more components compete for the same physical space. Fig. 1 illustrates a hard clash between pneumatic tube (purple) and waste and vent (W&V, red).

- A 'soft clash' known as Clearance Clashes, refers to components that are closer than a certain distance from one another. Fig. 1 illustrates a soft clash between pneumatic tube (purple) and fire pipe (red).
- A 'time clash' refers to spatial challenges (components potentially occupying the same space) anticipated when considering constructability or operability of the facility. A time clash may be modelled as a kind of clearance requirement, but one that has a temporal component to it.

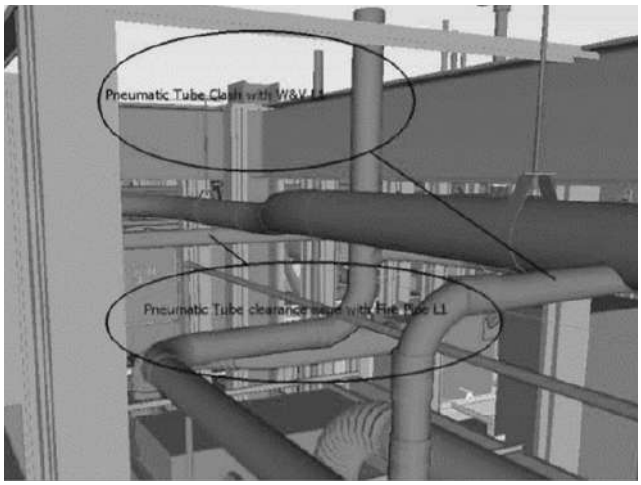

Fig. 1: Hard Clash between Pneumatic Tube (purple) and Waste and Vent (W&V, red), and Soft Clash between Pneumatic Tube (purple) and Fire Pipe (red).

(Source :Eric Ostering, Unger Construction)

VR Case

In a construction designs companies, drawing plans are drawn in AUTOCAD and transferred that to REVIT and 3DS Max for interior and exterior designs. Thereafter, the plan designs will be forwarded to the construction site to execute the work. During the execution of the work the miscommunication between engineer and designer may lead to improper way of construction which may effects the scheduling, cost and the whole planned process. By using Virtual Reality technology can resolve the errors which may occur during the designing process and understanding the drawings. Construction plans optimization will happen and virtual construction tests are applied to initial construction programme, some collisions are detected and effective actions for removal of collisions are taken. By using the Virtual Reality software's the BIM Models, 3D Models can be loaded into the VR setup or headset as shown below in the Fig. 2 to 7.

Fig. 2: Loading of CAD and BIM Models

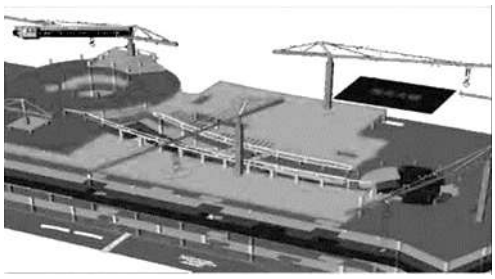

Fig. 3: Virtual Planin Virtual Reality

Fig. 4: Clashes between Mast and Cable

Fig. 5: Clashes between Bracket Beam and Mast

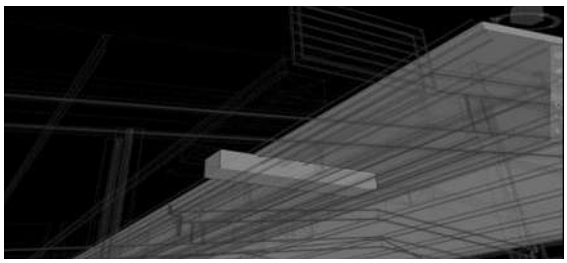

Fig. 6: Clashes Detecting

Fig. 7: System Plan Overview with Headset an Controller

SYSTEM EVALUATION

The process of the evaluation of the equipment by the overview of system plans with the headset, by using the equipment as shown in Fig. 8 is as follows with three different parameters - Rendering Performance, Navigation interface and the ability to support fast design iterations.

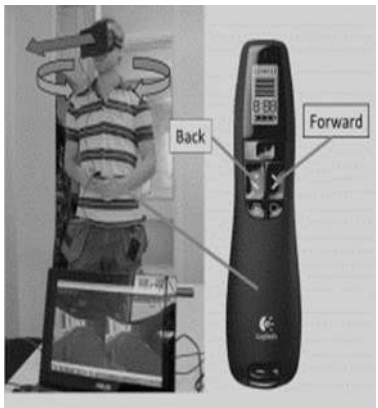

Fig. 8: System Evaluation

The model which we used in the BIM software to execute is the same as follows, however it does contain furniture and other interior equipment which was done in BIM software and that file will be loaded into the VR box through the VR Technology.

Virtual Reality design concept works on following basis

- Engineering Methods: Product, Organization, Process
- Analysis Methods: Model-based design, 4D interactions
- Visualization Methods

CASE STUDY

The Spectrum/Vertex project in San Diego, California was the first time when B. N. Builders utilized virtual reality modeling for a project. One of the reasons they felt justified to utilize a new technology, was because they were awarded the contract for both the core and the shell. This allowed them to heavily focus on coordination between the two parts of the project, which gave them the opportunity to limit clashes. According to Larsen, this lab will be the "lab of the future" based on the building's level of sophistication. Due to the infancy of this technology, all of the benefits of virtual reality in construction have not been fully identified. However, thus far on the Spectrum/Vertex project, the benefits are cost savings, design flaw identification, and the use of the model for facilities team management. From a cost savings standpoint, the virtual reality model saved the client money that would have gone towards making a mockup on exterior metal fins. The fins were a design feature that protruded from the wall and wrapped around the entrance of the building. Instead of spending the money to produce a mockup of the fins, Michael Dulberg was able to load them into the model and give an accurate representation of what the design feature would look like. According to Larsen, without the virtual reality model he would not have had the confidence to make two costly design decisions. One of the features on the project that he was skeptical about was a large mosaic wall detail. Because of the price tag on the piece, he was not certain he wanted to spend the money on the detail until he saw it in the virtual reality model. Another design flaw that was identified, was an obstructed exterior view due to a piece of lab equipment. The virtual reality model showed what the 2D plans could not. Without the virtual reality model, the feature would have gone unnoticed and rework would have occurred. One of the benefits that came about later in the project was the idea of using the model for the facilities management team. For many older buildings, it is difficult to locate certain aspects of the structure once the "skin" is put on. With the use of an iPad the facilities management team will be able to look underneath the drywall to identify building components. This will allow them to make live updates to the model if adjustments are made. This will also help make building improvements more quick and more cheap.

BIM METHODOLOGY WITH VR TECHNOLOGY

The usage of VR Technology in construction industry as an alternative innovative approach is connecting all the way in some aspects. It enables the user along with the 3D Model of plan in 1:1 scale. By the way, BIM is useful in getting the 3D Model of the plan and yet to be upgrading in solving and designing methods. VR can reduce the costs of clients and increase the productivity, and it can also be in all platforms models of BIM software. Interpreting the BIM methodology with VR Technology will be majorily useful in identifiying and reducing the clashes and the major advance in the technology is of the user can be able to touch the objects and efficiency in walk through aspects. By this technology it can enhance the current BIM technology in below mentioned areas.

- Clash Detection
- Insight Visualization
- Documentation
- Scheduling
- Quantification
- Tracking the project and many other.

Further Extensions of VR Technology applications

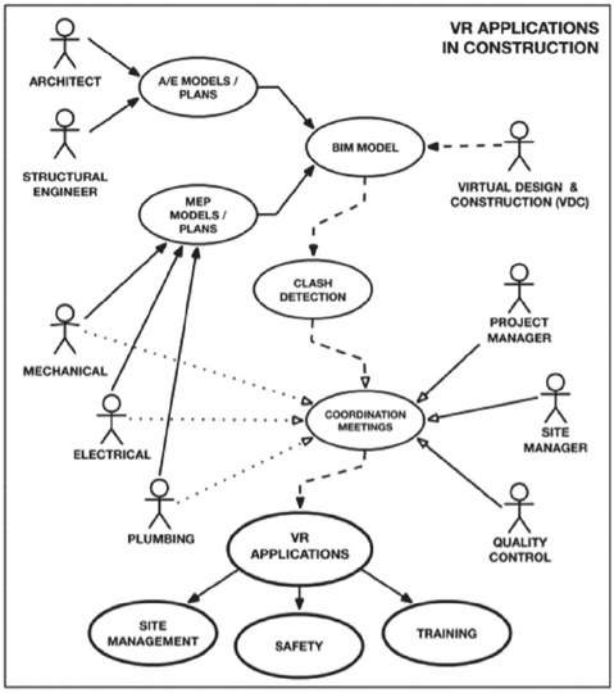

Fig. 9: VR Technology Applications in Construction Industry

By using the, VR technology in construction industry it will be helpful in all the activities by enhancing more productivity as outcome and work efficiency by coordinating with all the works. So, by introducing this trending technology into the industry, it has potential in driving the works in the industry. Other applications which VR can focus further are shown in the Fig. 9.

- Site Layout and Planning
- Reherasing and Erection seqences
- Progress and monitoring the construction processings
- Evaluation of Construction scenarios
- Inspection and Maintenance
- Fire Safety and Access Assessment

SCOPE FOR FURTHER RESEARCH

Merging the Augmented Reality with Virtual Reality can make resolve the issues in the design plans, any aspects of construction activity. With this kind of innovative approach, smoothening of the process makes effortless.

CONCLUSION

VR + BIM helps in better communication of designers with clients. Clashes detecting through the 3D Modelling with the most happening technology i.e. Virtual Reality makes the constructive of 3D Models and viewing before the construction phase and also by resolving the errors. Here the VR Model will interpret the plan as a model as the same as 2D drawing. It reduces the conflicts and increase productivity with accurate plans. It is integrated with technology up gradation, which constitutes people participation and virtual practice makes the project in a accurate manner.

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MODERN DEVELOPMENTS IN CONSTRUCTION PROJECT MANAGEMENT

Dr. Indrasen Singh*

Abstract

All construction projects need excellence in project management. Companies do not realize that the time frame can be minimized by proper strategic planning and competent execution of the project. Extended period of time for implementation of project does not lead to excellence in quality. Instead, it can result in repetitive mistakes. It is important to not only learn from our own mistakes, but also from the mistakes of others.

The foundation for achieving excellence in project management can best be described as the project management maturity model (PMMM). Good procedural documentation will accelerate the project management implementation process, project communication and foster support at all levels of management. The type of procedural documentation selected is based on whether we wish to manage the project formally or informally. It should show how to conduct project oriented activities in a multi-dimensional environment. The project management policies, procedures, forms and guidelines can provide some of the tools for delineating the process, as well as a format for communicating project related information in an orderly and standardized format. Project planning and tracking, requires the participation of the entire project team, including main contractor, sub-contractors and top management.

INTRODUCTION

All companies desire excellence in project management. Unfortunately, not all companies recognize, that the time frame can be shortened by performing strategic planning for project management. The simple use of project management, even for an extended period of time, does not lead to requisite quality. Strategic planning for project management is unlike other forms of strategic planning in that it is most often performed at the middle management level, rather than by top management. Executive management is invariably involved, mostly in a supporting role and provides funding together with employee release time for the effort. Executive involvement will be necessary to make sure that whatever is recommended by middle management will not result in unwanted changes. Proper strategic planning for project management is considered necessary. There are models that can be used to assist construction companies in performing strategic planning for project management and achieving maturity and excellence within a reasonable period of time.

The foundation for achieving excellence in project management can be as the project management maturity model (PMMM), which is comprised of five levels, as shown in Fig. 1. Each of the five levels represents a different degree of maturity in project management. When we talk about levels of maturity, there exists a common belief that all work must be accomplished sequentially. This is not necessarily true. Certain levels can overlap. For example, a company can begin the

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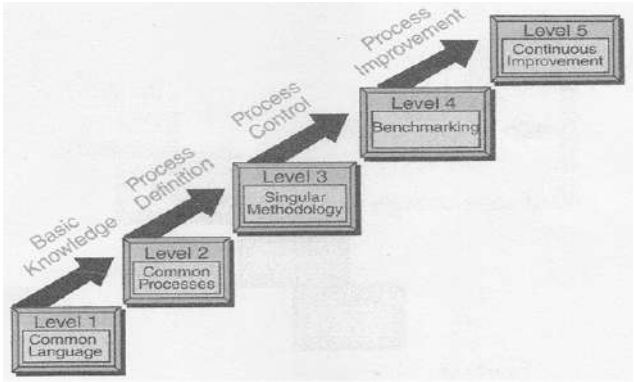

Fig. 1: The Five Levels of Maturity

developments of project management checklists to support the methodology while it is still providing project management training for the workforce. A company can create a centre for excellence in project management before benchmarking is undertaken.

Although overlapping does occur, the order in which the phases are completed cannot change. For example, even though Level 1 and Level 2 can overlap, Level 1 must still be completed before Level 2 can be completed. Overlapping of several of the levels can take place as shown in Fig. 2.

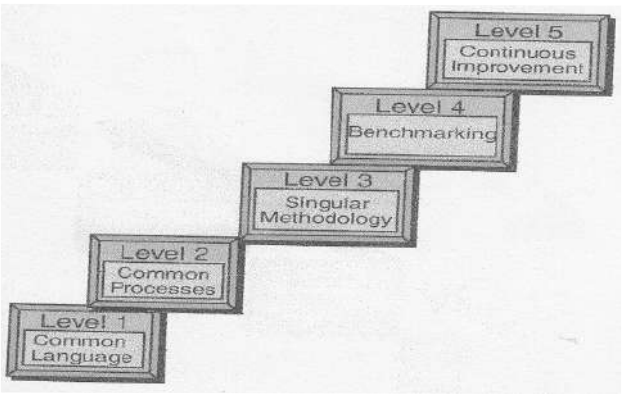

Fig. 2: Overlapping Levels

Level 2 and Level 3 generally do not overlap. It may be possible to begin some of the Level 3 work before 2 is completed, but this is highly unlikely. Once a company is committed to a singular methodology, work on other methodologies generally terminates. Also, companies can create a centre for excellence in project management early in the life – cycle process, but will not receive the full benefits until later on.

Risks can be assigned to each level of the PMMM. For simplicity's sake, the risks can be labeled as low, medium and high. The level of risk is most frequently associated with the impact on the company culture. The following definitions can be assigned to these three risks.

- **Level 1 - Low Risk**

  Virtually no impact upon the organisation culture or the organisation culture is dynamic and readily accepts change.

- **Level 2 - Medium Risk**

  The organisation recognizes that change is necessary but may be unaware of the impact of the change. Multiple-level reporting would be an example of a medium risk.

- **Level 3 - High Risk**

  High risks occur when the organisation recognizes that the changes resulting from the implementation of project management will cause a change in the company culture. Examples include the creation of project management methodologies, policies and procedures as well as decentralization of authority and decision making.

Level 3 has the highest risk and degree of difficulty for the organisation. This is shown in Fig. 3. Once an organisation is committed to Level 3, the time and effort needed to achieve the higher levels of maturity have a low degree of difficulty. Achieving Level 3, however, may require a major shift in the company culture.

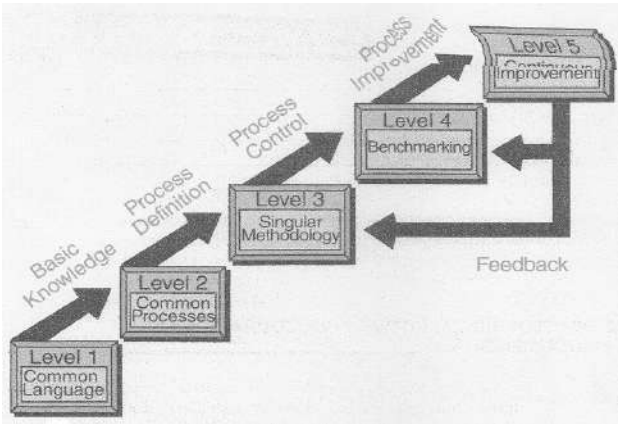

Fig. 3: Feedback between the Five Levels of Maturity

These types of maturity models will become more common in the future, with generic models being customized for individual companies. These

models will assist management in performing strategic planning for excellence in project management. Degrees of difficulty of the five levels of maturity is given in Fig. 4.

Level	Description	Degree of Difficulty
1	Common Language	Medium
2	Common Processes	Medium
3	Singular Methodology	High
4	Benchmarking	Low
5	Continuous Improvement	Low

Fig. 4: Degrees of difficulty of the Five Levels of Maturity

DEVELOPMENT OF EFFECTIVE PROCEDURAL DOCUMENTATION

Good procedural documentation will accelerate the project management maturity process, foster support at all levels of management and greatly improve project communications. The type of procedural documentation selected is heavily based on whether we wish to manage formally or informally, but it should show how to conduct project-oriented activities and how to communicate in such a multidimensional environment. The project management policies, procedures, forms and guidelines can provide some of these tools for delineating the process as well as a format for collecting, processing and communicating project related data in an orderly, standardized format. Project planning and tracking, however involve more than just the generation of paper work. They require the participation of the entire project team, including support departments, subcontractors and top management, which fosters unity.

Procedural documents help to; Provide guidelines and uniformity, Encourage useful, but minimum documentation, Standardise data formats, Unify project teams, Provide a basis for analysis, Ensure document agreements for future reference, Refuel commitments, Minimise paperwork, Minimize conflict and confusion, Delineate work packages, Bring new team members on board and Build an experience track and method for future projects.

CONTINUOUS IMPROVEMENT

All too often complacency dictates the decision making process. This is particularly true in organisations that have reached some degree of excellence in project management. They become complacent over a period of time, and then realise too late that they have lost their competitive advantage. This occurs when organisations fail to recognize the importance of continuous improvement. Fig. 5 illustrates why there is a need for continuous improvement. To remain effective and competitive, the organizations must recognize the need for continuous improvement, as shown in Fig. 6. Continuous improvement allows an organisation to maintain its competitive advantage.

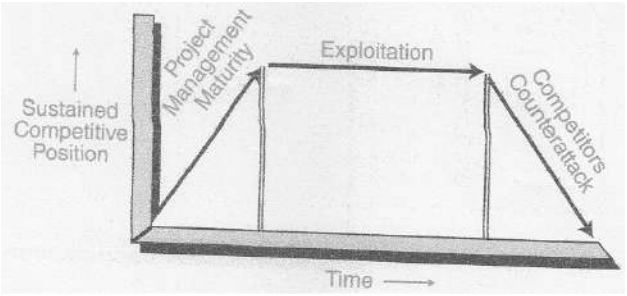

Fig. 5: Why There is a Need for Continuous Improvement

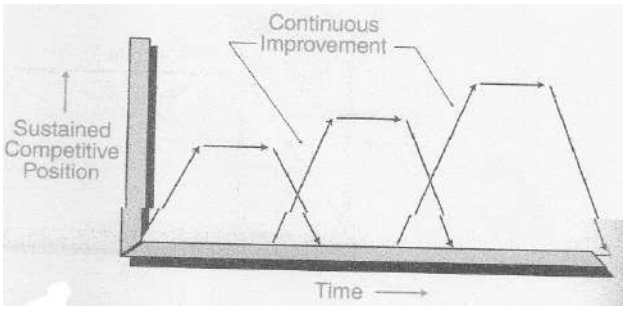

Fig. 6 : The Need for Continuous Improvement

CAPACITY PLANNING

The classical way that companies perform capacity planning is shown in Fig.7. The approach outlined in this figure holds true for both projects and non-project-driven organisations. The planning horizon line indicates the point in time for capacity planning. The proposal line indicates the manpower needed for approval in internal projects for all work expected through competitive bidding. The combination of this line and the manpower

requirements line when compared against the current staffing, provides us with an indication of capacity. This technique can be effective if performed early enough so that training time is allowed for building competence.

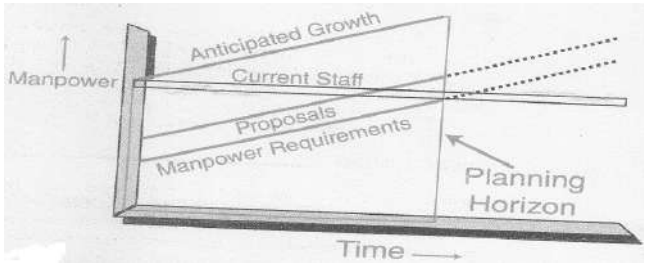

Fig. 7: Classical Capacity Planning

The limitation to this process for capacity planning is that only human resources are considered. A more realistic method would be to use the method shown in Figure 8, which can also be applied to both project-driven and non-project-driven organisations.

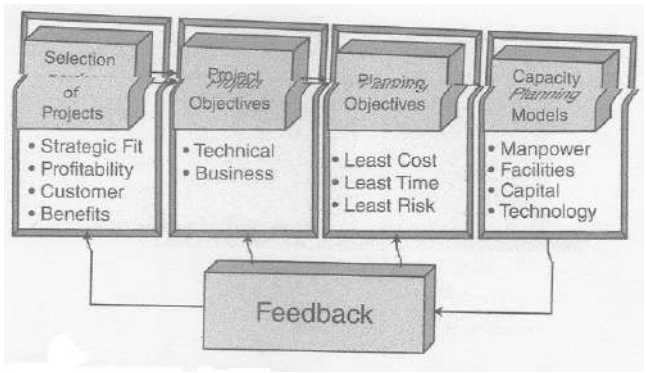

Fig. 8 : Improved Capacity Planning

COMPETENCY MODELS

The competency model is shown in Fig.9. Competency models focus on specialised skills in order to assist the project manager in making more efficient use of his time. Fig. 10 shows that with specialised competency training, project managers can increase their time efficiency.

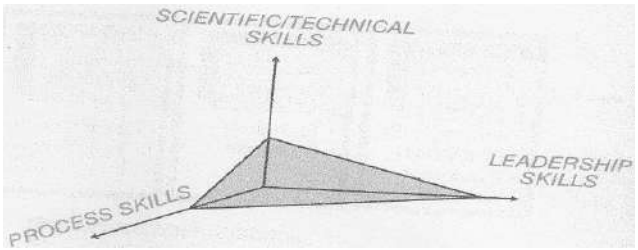

Fig. 9: Competency Model

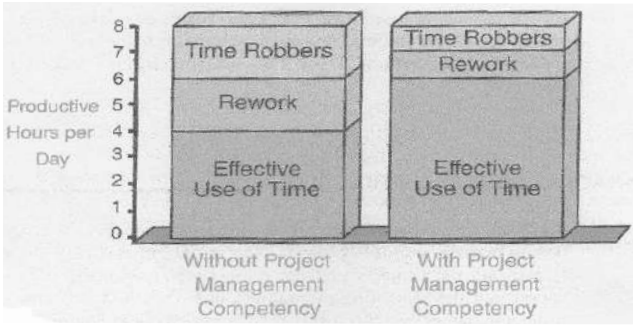

Fig. 10: Core Competency Analysis

Competency models make it easier for companies to develop a complete project management curriculum for imparting education and training rather than a singular course. This is shown in Fig. 11.

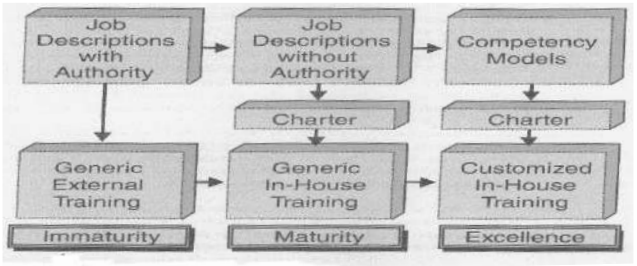

Fig. 11 : Competency Models and Training

UNDERSTANDING PROJECT HEALTH CHECKS

People trend to use audits and project health checks synonymously. Both are designed to ensure successful, repeatable project outcomes, and both must be performed on project that appear to be heading for a successful outcome as well as those that seem destined to fail. Lessons learned and best practices that can be discovered from both success and failures of project implementation. Also detailed analysis of a project that appears to be successful at the moment might bring to the surface issues that show that it is not so. One of the challenges facing companies is whether the project health checks should be conducted by internal personnel or by external consultants. The risk with using internal personnel is that they may have loyalties with people on the project team and therefore may not be totally honest in determining the true status of the project. External consultant is therefore a better choice.

Some of the critical areas that must be investigated are, Performance against base lines,

Ability to meet forecasts, Benefits and value analyses, Governance, Stakeholder involvement, Risk mitigation and Contingency planning.

SELECTING THE RECOVERY PROJECT MANAGER (RPM)

Companies often hire outside consultants to perform a health check on project. If the health check report indicates that an attempt should be made to recover the troubled project, perhaps a new competent project manager could be brought on board. Outside consultants normally do not take over the troubled project because they may not have a good grasp of the company's culture, business and project management processes, politics, and employee working relationships. Not all project managers possess the skills to be an effective recovery project manager. In addition to possessing project management knowledge, typical skills needed include: Strong political courage and political savvy, A willingness to be totally honest when attacking and reporting the critical issues, Tenacity to succeed even if it requires a change in resources, Understanding that effective recovery is based upon information, not emotions, Ability to deal with stress, personally and with the team.

In addition to having the right skills, some degree of luck is also required. Taking over a troubled project is not the same as starting up a new project. Recovery project managers must have a good understanding of what they are about to inherit, including high levels of stress. This includes: A burned-out team, An emotionally drained team, Poor morale, An exodus of the talented team members that are always in high demand elsewhere, A team that may have a lack of faith in the recovery process, Furious customers, Nervous management, Invisible sponsorship and governance and Either invisible or highly active stakeholders.

Project managers that do not understand what is involved in the recovery of a troubled project can make matters worse by hoping for a miracle and allowing the "death spiral" to continue to a point where recovery is no longer possible. The death spiral continues if we Force employees to work excessive hours unnecessarily, Create unnecessary additional work, Replace team members at an inappropriate time, Increase team stress and pressure without understanding the ramifications, Search for new miracle tools to solve some of the issues and Hire consultants that cannot help or make matters worse by taking too long to understand the issues.

Once all of the elements are placed on the grid in Fig. 12, the team will assist the RPM with trade-offs by answering the following questions. Where are the trade-offs?, What are the expected casualties?, What can and cannot be done?, What must be fixed first?, Can we stop the bleeding?, Have the priorities of the constraints changed?, Have the features changed? And What are the risks?

Once the trade-offs have been discovered the RPM and the team must prepare a presentation for the stakeholders. There are two primary questions that the RPM will need to discuss with the stakeholders.

- Is the project worth saving? If the project is not worth saving, then you must have the courage to say so. Unless a valid business reason exists for continuation, you must recommend cancellation.
- If the project is worth saving, can we expect a full or partial recovery and by when? There are also other factors that most likely are concerns of the stakeholders and must be addressed. These factors include: Changes in the political environment, Existing or potential lawsuits, Changes in the enterprise environmental factors, Changes in the organisational process assets, Changes in the business case, Changes in the assumptions and Changes in the expected benefits and final value.

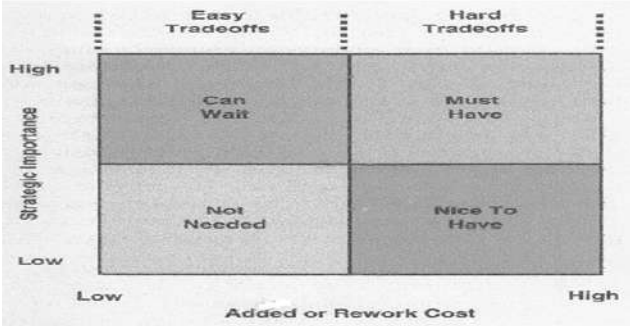

Fig. 12: Trade-Off Options

CONCLUSION

The future of project management may very well rest in the hands of the competent project management teams. The future of project management is quite good but all the same, it will always be a challenge. Complex projects have complex problems. All problems generally have solutions but not all solutions may be implementable or even practical. Also, the solution to problems need to be at optimum cost. Innovation in project management is generally regarded as a new way of doing something. The new way of doing something could be substantially different from the way it was done before, or may require small incremental changes consistent with continuous improvement. The ultimate goal of innovation is to create long – lasting additional value for the project, ensuring its successful implementation.

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