ISSN 2349-7467

IBC JOURNAL

Research & Review in Technology

Volume VI April 2022

Focus on Built Environment

IBC JOURNAL

Vol. VI

April 28-29, 2022

25th Annual Convention of IBC

INDIAN BUILDINGS CONGRESS

Kama Koti Marg, Sector VI,

R. K. Puram, New Delhi-110022

ISSN 2349-7467

Published By

H.P. Gupta
Honorary Secretary
Indian Buildings Congress
Kama Koti Marg, Sector VI, R. K. Puram,
New Delhi-110022
Phone: 011: 26169531, 26170197
Email: indianbldgscongress@gmail.com, info@ibc.org.in
Website: www. Ibc.org.in

Printed at

VIBA Press Pvt. Ltd.
C-66/3, Okhla Industrial Area
Phase - II, New Delhi - 110020
Ph. : 41611300, 9810049515
Email : info.vibappl@gmail.com

EDITORIAL BOARD

IBC Executive Committee

Chief Patron

Hardeep Singh Puri
Minister, Ministry of Housing & Urban Affairs; Petroleum & Natural Gas

Patrons

Kaushal Kishore
Minister of State, MoHUA

Manoj Joshi, IAS,
Secretary, Ministry of Housing & Urban Affairs

President	Immediate Past President	Founder President
Pradeep Mittal Consultant & Advisor, Prop. H.K. Consultants	**Dr. Anoop K. Mittal** Fmr. CMD, NBCC (I) Ltd.	**O. P. Goel** Fmr. D.G.,CPWD

Vice Presidents

P. K. Gupta CMD, NBCC (I) Ltd.	**Vijay Singh Verma** Fmr. E-in-C, M.P., PWD	**Anant Kumar** SDG, CPWD
R. N. Gupta CMD, Ramacivil India Const. Pvt. Ltd.		**Chinmay Debnath** Fmr. S. E. (Bldg.), Tripura, PWD

Honorary Secretary	Honorary Treasurer
Hitesh Paul Gupta Consultant Proprietor Hitech Engineering Consultants	**Pradeep Agrawal** Chief Engineer (R & D), New Delhi

Executive Members

Sanjeev Kumar Lohia Fmr. M. D. & CEO, IRSDCL	**V. R. Bansal** Fmr. C. E., North Delhi M.C	**Kashyap Kumar Gupta** Fmr. E-in-C., BCD, Patna
C. L. Verma Fmr. C. E. & Addl. Secy., Rajasthan, PWD	**S. K. Agrawal** Prop., S.K. Agrawal & Associates	**Hitendra Mehta** M. D., Mehta & Associates

From
President's Desk

In simple terms durability means the ability of buildings to last for a longer time without significant deterioration. Buildings and other structures have a certain useful life, which depends on the specifications adopted. In India, economic life of a normal RCC structure is considered to be 75 years. Carbonation, chloride ingress, leaching, sulphate attack, alkali-silica reaction and freezing thawing conditions mainly affect the durability of a structure. Deterioration in a structure leads to loss of its durability.

Distress once begins gets aggravated due to overloading and misuse of structures. There may be many causes of structural failure. In some structures, the cracks get generated within few years of completion of building which results in shortening of life and strength of structure. In case, the structures are not repaired, rehabilitated and retrofitted for structural deficiencies within the right time, they are to be reconstructed resulting into wastage of financial and natural resources.

At many places, particularly in coastal areas, structures have shown distress even in 15-20 years due to many adverse factors besides inappropriate type of reinforcement and cement being used. Hence, there is a need to incorporate appropriate type of reinforcing steel suitable for corrosion prone areas and cement for resisting salt action. Structures in which corrosion has started are to be structurally rehabilitated on priority as delay in rehabilitation accelerates the rate of corrosion particularly under adverse conditions.

The skills, knowledge, and experience required to repair damaged or deteriorated structures are decidedly different from those required to build new structures. Thus, we need to create a pool of skilled manpower for the purpose to address this problem.

It is hoped that the papers submitted by the galaxy of authors in this publication will be immensely useful to all the stake holders.

(Pradeep Mittal)
President, IBC

Portfolio

IBC Journal
April 2022
Focus on
REPAIRS, REHABILITATION AND RETROFITTING OF STRUCTURES

From
Editor-in-Chief's Desk

Rapid urbanisation in India is resulting in massive construction activities, rapid economic and social transformation, leading to increasing carbon footprints, climate change and at times disasters. Issues such as increasing pollution, transportation, energy and water consumption are additional causes of concern. Accordingly, appropriate construction technologies, integrated with proper repair, maintenance, rehabilitation and retrofitting need to be evolved and made operational, to make India global leader in safety and sustainable construction practices.

Due to large scale new construction taking place all across the country large number of new assets are being added annually. Yearly Construction creates approx. 3 to 3.5 lakh crores worth of Assets. There is a growing awareness of the need to manage the condition of the nation's building stock more efficiently. Paralleling these developments has been the increased application of new technology, permitting more efficient use of data and resources. Keeping in view the fact that Repairs and rehabilitation will constitute major chunk of Construction expenditure, we need to assign 8-10% of cost of construction for Asset Maintenance and upkeep of assets being added. There is need of training to develop skills to diagonise and rectify the defects is required.

Natural disasters can be predicted but cannot be controlled. Earthquakes, tsunamis, cyclones are among the most catastrophic natural disasters which affect the humankind. Disasters not only affect human life but also damage the infrastructure. We are also facing premature deterioration of the structures due to natural disasters besides normal wear and tear, use of sub-standard material and defective construction practices. Therefore, along with massive new construction there is a growing global concern about the premature deterioration of buildings/ structures.

Clay Bricks, Timber, Steel and Concrete are most widely used construction materials. Though all these construction materials are being used since long and are quite strong mechanically, yet these are susceptible to deterioration and thus get damaged & even fail ultimately, unless some measures to enhance the durability of structures are adopted to counter deterioration. The new technologies and new repair materials, which have been extensively used by the advanced countries, are also being tried in countries

like India. Repair/rehabilitation/retrofitting is the fastest growing segment of the construction industry.

The list of possible causes of distress and deterioration in structures is a long one. A rationale approach to any repair and rehabilitation work is to consider the source of the problem and the symptoms together. Therefore, one of the major problems is to analyse accurate damages in buildings. Success of any repair/rehabilitation program depends upon the correct detection of the distress and deterioration along with its cause and accurate estimation of damages in infrastructures which plays a critical role in finding out the area and the amount of work that needs to reconstruct. Thus, evaluation and selection of appropriate repair materials is receiving more and more attention among Civil Engineers in the recent past.

Rehabilitation is the act of restoring something to its original state i.e. returning a building / structure to a useful state by means of repair, modification, or alteration. It is related to the strength aspect of structures. Some of the examples of Rehabilitation are: filling the wide cracks using some suitable material, Injecting epoxy like material in to cracks in walls, columns and beams, etc.,replacing damaged portion of masonry with rich mortar mix and addition of reinforcing mesh on both sides of the wall.

Retrofitting is extended to strengthen and make the structures safe against the damage caused by natural disasters. Considering its numerous and distinct advantages, retrofitting also became handy to be used for strengthening existing structure to enhance its performance; restoring buildings to original health when structurally damaged by exposure to sun, rain, frost, water etc.; changing the use/typology of the structure from one purpose to another; improving the shear resistance and capacity of the structural members to resist seismic loads etc.

For our country, the Repairs, Rehabilitation and Retrofitting of structures is a very critical issue which needs attention. Our country is spread in large geographical area involving huge variation in geographical features, atmospheric parameters, disasters and cultures where no typical application can solve the issue. Geographical area specific solution need to be evolved. Therefore, experts in this field were requested to give their papers, to cover multiple types of distress in the structures. It is heartening to note that seven papers relevant to the topic have been received which are being published in this issue of IBC Journal. I thank all the authors for their valuable contributions.

(Krishna Kant)
Editor-in-Chief

Global and Local Retrofit Strategies

Usha Batra

Former SDG, CPWD

Prologue

Deterioration to concrete structures globally is occurring at an alarming rate. It has now been confirmed that even if the structural design abides by all the codal provisions like the quality of concrete, cover etc., there is still an acceptable high risk of deterioration of concrete and corrosion of reinforcement. Steel corrosion is found to be most severe cause of deterioration of reinforced concrete that can create cracks, spalls the concrete cover, reduce the effective cross section area of the reinforcement and lead to collapse. In USA about 40% of the highway bridges, about 3,00,000 have been rated as structurally deficient or functionally obsolete or both and need about US $100 billion as estimated expenditure to improve the service life and performance level. The situation in India is not better. The reliable figures for estimated expenditure are not available, but it is substantially very high.

Earthquakes on the other hand pose one of the greatest challenges to the buildings and other civil engineering structures. The potential for violent ground motion lasting not more than few minutes causes great destruction as has been noticed in recent events. Most of the Indian building stock is vulnerable to seismic action even if located in areas that have been considered of lower seismic hazard. It is therefore paramount to retrofit these buildings / structures as replacement is generally the last option due to many factors amongst cost and time for new construction along with problem of temporarily make shift arrangement.

-Editor-

Introduction

Nearly 5,00,000 earthquakes occur every year around world among which about 1,00,000 are felt and the rest occur regularly almost anywhere.

Large number of casualties takes place in buildings due to earthquake. Reasons may be, inadequate design, poor construction and maintenance, lack of resources, inadequate knowledge and awareness and inadequate safety implementation. Such events have clearly shown the vulnerability of the building stock in particular and of the built environment in general and hence it is very much essential to retrofit the vulnerable building to cope up for the next damaging earthquake. Replacement of damaged building or existing unsafe building by reconstruction is generally, avoided due to a number of reasons, the main ones among them is higher cost of repair and retrofitting.

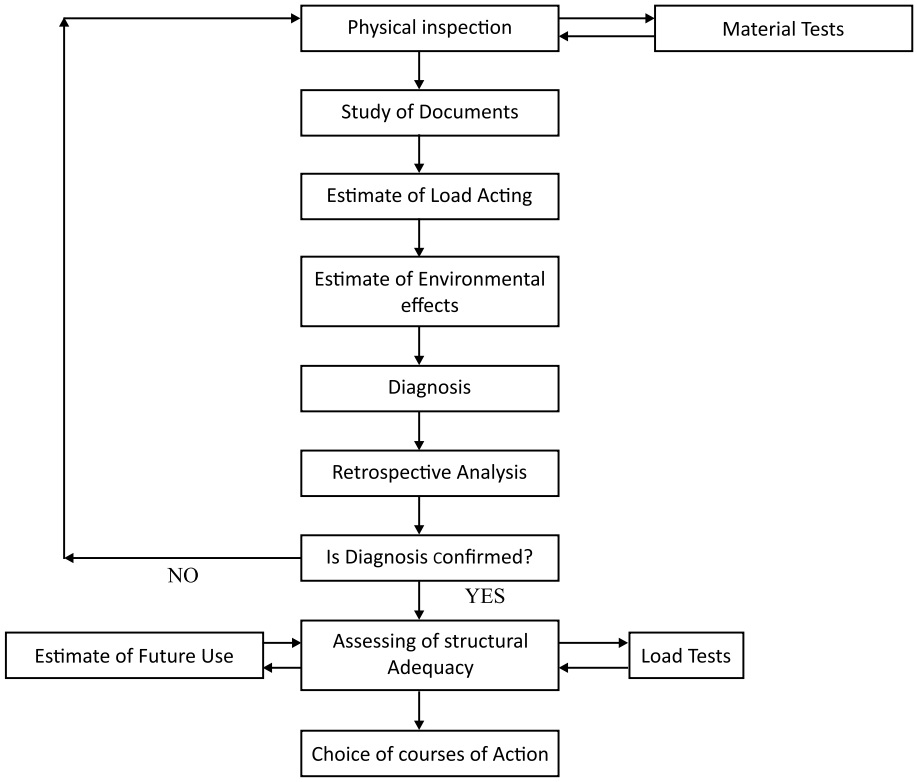
The earthquake at Bhuj, Gujarat, in 2001 had been a watershed event in the earthquake engineering practice in India. The code of practice for seismic analysis, IS 1893:2002 has been revised to reflect the increased seismic demand in many parts of the country. Many existing buildings lack the seismic strength and detailing requirements of IS 1893:2002, IS 4326:1993 and IS 13920: 1993, because they were built prior to the implementation of these codes.

Although list of possible causes of distress and deterioration in concrete is a long one, success of any repair program depends upon the correct detection of the distress and deterioration and cause that led to deterioration. A rationale approach to any repair and rehabilitation work is to consider the source of the problem and the symptoms together.

Road Map to Repair of Structures

The objective of any repair/rehabilitation or strengthening works is to enhance the performance of the structure, extend the service life or increase the load carrying capacity. Repair should be carried out only when it can extend the life of the structure for a desirable period.

A rational approach is to consider the source of the cause of the deterioration and symptoms together because treating only the symptoms without adequate understanding of the cause of the problems leads to defects camouflaged beneath the finishes.



This can be achieved only if the repair work is carried as per the following steps:

- Condition Evaluation
- Determination of the cause of the deterioration
- Selection of repair methods and materials
- Preparation of drawings and specifications
- Execution Process
- Appropriate quality control measures
- Maintenance after completion of the repair works

Depending upon the damage, it needs to be decided whether the building/structure needs to be repaired, rehabilitated or retrofitted.

- **Repair:** It means bringing back the structure to its previous condition so that it turn out to be capable of satisfying its scheduled function, whether or not in compliance to its original specifications, maintaining its architectural shape. It doesn't cover the strength aspect of the structures. Some examples of repair are - decoration of structure, painting, white washing, checking the wiring of building, replastering, repairing of damaged flooring, doors and windows, pipe line connections, gas line connections and plumbing serveries and relaying of disturbed roof tiles.

- **Rehabilitation:** It is the act of restoring something to its original state i.e. returning a building / structure to a useful state by means of repair, modification, or alteration. It is related to the strength aspect of structures. Some of the examples of rehabilitation are - filling the wide cracks using some suitable material, injecting epoxy like material in to cracks in walls, columns and beams, etc., replacing damaged portion of masonry with rich mortar mix and addition of reinforcing mesh on both sides of the wall.

- **Retrofitting:** It is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. Some examples of retrofitting are; increasing the lateral strength in one or both directions, by adding reinforcement or by increasing wall areas or the numbers of walls and columns; giving unity to the structure by providing a proper connection between resisting elements; eliminating features that are sources of weakness; asymmetrical plan distribution of resisting members; abrupt changes of stiffness from one floor to the other and avoiding the possibility of brittle modes of failure by proper reinforcement and connection of resisting members.

Major seismic deficiencies of RCC Building

- Inadequate depth and size of the footing
- Inadequate size of structural members
- Inadequate amount of reinforcement on structural member

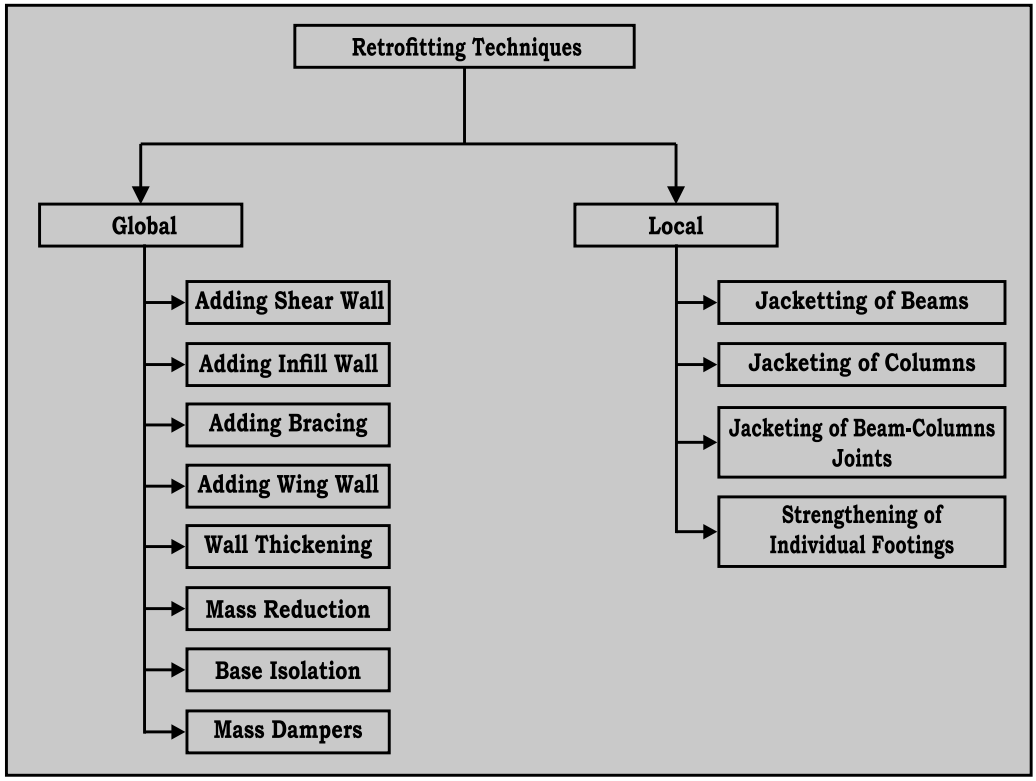
- Missing of bands on masonry walls
- Vulnerable parapet walls/staircase
- Soft/ weak storey

Retrofitting is the seismic strengthening carried out to upgrade the seismic resistance of a damaged building without hindering its elementary intent of use. It is of utmost importance for historic monuments, areas prone to severe earthquakes and tall or expensive structures. The retrofit techniques are also applicable for other natural hazards such as tropical cyclones, tornadoes, and severe winds from thunderstorms. Retrofitting proves to be a better solution taking into account the economic consideration and immediate shelter problem rather than replacement of building.

Retrofitting reduces the vulnerability of damage of an existing structure during a future earthquake. It aims to strengthen a structure to satisfy the requirements of the current codes for seismic design. In this respect, seismic retrofit is beyond conventional repair or even rehabilitation. The principles of seismic retrofit refer to the goals, objectives and steps. The steps encompass condition assessment of the structure, evaluation for seismic forces, selection of retrofit strategies and construction. The applications include different types of buildings, industrial structures, bridges, urban transport structures, marine structures and earth retaining structures. The benefits of retrofitting include the reduction in the loss of lives and damage of the essential facilities, and functional continuity of the life line structures. For an existing structure of good condition, the cost of retrofitting tends to be smaller than the replacement cost. Thus, the retrofitting of structures is an essential component of long term disaster mitigation.

Retrofit Strategies

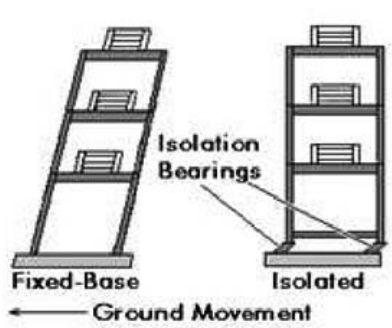
Retrofit strategies that are viable for the type of buildings considered, are grouped under local and global strategies. These groups need not be watertight and strategies falling in either group should be adopted.

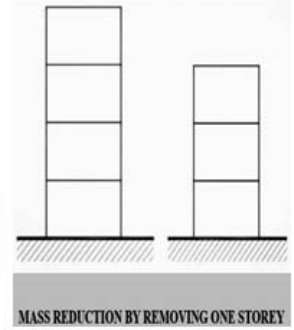


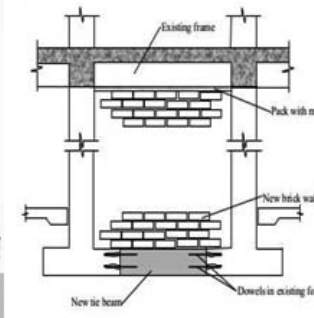
Global Retrofit Strategies: Global retrofit strategies aim to stiffen the building, by providing additional lateral load resisting elements, or to reduce the irregularities or mass.

Addition of Shear Walls: New shear walls can be added to control drift. Critical design issues involved in the addition of shear walls are as follows.

- Transfer of floor diaphragm shears into the new wall through dowels.
- Adding new collector and drag members to the diaphragm.
- Reactions of the new wall on existing foundations.







Infill wall

Addition of Infill Walls: The addition of masonry infill wall is a viable option for the buildings, with open ground storeys. Of course masonry infill walls increase strength and stiffness of the building, but do not enhance the ductility. Infill walls with reinforced concrete masonry units can act as shear walls. For cast-in-place RC infill walls, the significant parameter that defines the lateral strength of the frame is the presence of dowels between a wall and the bounding frame. The use of modular precast panels involves minimal on-site casting and modest handling equipment. Connections between the panels and the frame are critical. Use of infill steel panels is an alternative to the bracing system.

Addition of Steel Braces: A steel bracing system can be designed to provide stiffness, strength, ductility, energy dissipation, or any combination of these. Connection between the braces and the existing frame is the most important aspect in this strategy. The use of prestressed tendons and unbonded braces have been proposed by some investigators to avoid the problems associated with the failure of connections and buckling of the braces, respectively.

Reduction of Irregularities: Torsional irregularities can be corrected by addition of frames or shear walls. Eccentric masses can be relocated. Seismic joints

can be created to transform an irregular building into multiple regular structures. Partial demolition can also be an effective measure, although this may have significant impact on the utility of the building. Discontinuous components such as columns can be extended beyond the zone of discontinuity. As mentioned earlier, walls or braces can alleviate the deficiency of soft and weak storey.

Adding Wing Wall or Buttress: To increase lateral strength, ductility and stiffness of structure, wing wall are placed on the exterior side of an existing frame.

Wall Thickening Techniques: Increase the thickness by adding bricks, concrete and steel reinforcement can bear more vertical and horizontal loads and avoids sudden failure of the wall.

Mass Reduction: Reduction of mass results in reduction of the lateral force demand, and therefore, can be used in specific cases in lieu of structural strengthening.

Energy Dissipation Devices and Base Isolation: For the multi-storeyed buildings the use of energy dissipation and base isolation devices is not cost effective at present. However, it is the most powerful tool for passive structural vibration control techniques as it isolates building from ground motion lessening seismic loads and damage to the structure and hence inviting minimal repair to the structure. Building can remain serviceable throughout construction. It does not involve major intrusion upon existing superstructure.

Seismic Dampers : Seismic dampers are used in place of structural elements, like diagonal braces, for controlling damage in structures as it partly absorbs the seismic energy and reduces the motion of buildings. There are three types of mass dampers:

- Viscous dampers (energy is absorbed by silicon-based fluid passing between piston cylinder arrangement),
- Friction dampers (energy is absorbed by surfaces with friction between them rubbing against each other), and
- Yielding dampers (energy is absorbed by metallic components that yield).

Local Retrofit Strategies

Local retrofit strategies include local strengthening of beams, columns, slabs, beam-to-column or slab-to-column joints, walls and foundations. Local strengthening allows one or more under-strength elements or connections to resist the strength demands predicted by the analysis, without affecting the overall response of the structure. This scheme tends to be the most economical alternative when only a few of the building's elements are deficient. The local retrofit strategies are grouped according to the elements.

Column Strengthening: This technique includes concrete jacketing, steel jacketing and fibre reinforced polymer sheet wrapping.

Concrete Jacketing: This technique increases both strength and ductility of the columns. But, the composite deformation of the existing and the new concrete requires adequate dowelling to the existing column. Also, the additional longitudinal bars need to be anchored to the foundation and should be continuous through the slab. Frequently, these considerations are ignored.

Steel Jacketing: It involves encasing the column with steel plates and filling the gap with non-shrink grout. It is a very effective method to remedy deficiencies such as inadequate shear strength and inadequate splices of longitudinal bars at critical locations but, it may be costly and its fire resistance needs to be addressed.

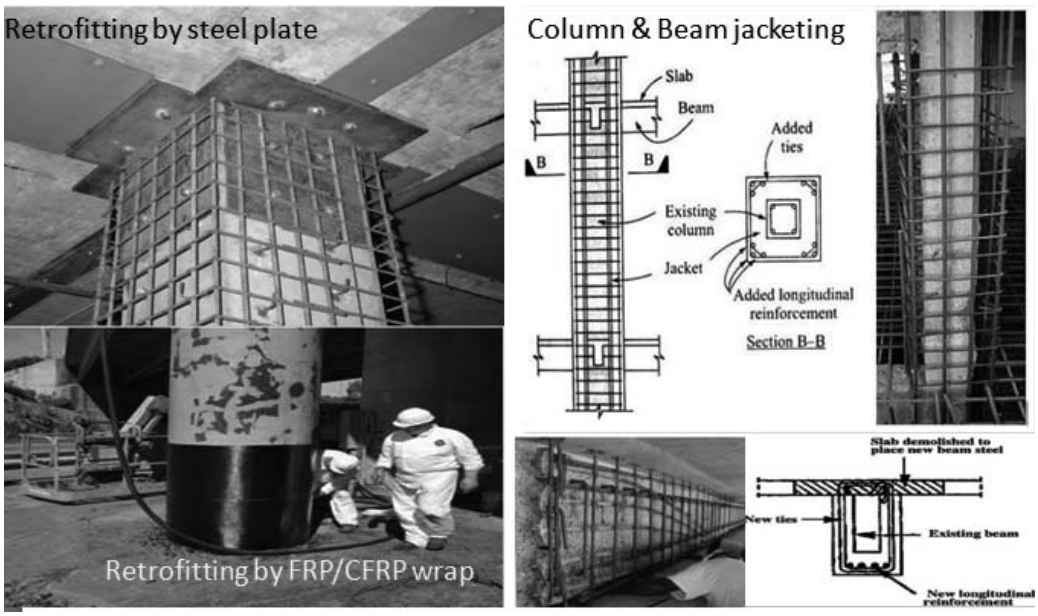
Fibre Reinforced Polymer Sheet Wrapping: The use of Fibre Reinforced Polymer (FRP) sheets is becoming popular in India. FRP sheets are thin, light and flexible enough to be inserted behind service ducts, thus facilitating installation. In retrofitting of a column there is no significant increase in the size. The main drawbacks of FRP are high cost, brittle behavior and fire resistance. Study indicates that column wrapped with two layers, four layers and six layers of GFRP shows 8%, 28% and 32% increase in the load carrying capacity respectively compared to the specimen without wrapping, whereas increase in ductility is 70% with 6 layers. The specimens jacketed with CFRP have an average of 98.3% increase in the strength capacity but increase in ductility of 2.7% only, compared to the specimen without CFRP wrapping.

Beam Strengthening: This technique includes addition of concrete, steel plating and FRP wrapping.

Addition of Concrete: This technique has some disadvantages like it increases the size and weight of the beam, the new concrete requires proper bonding to the existing concrete and lastly effects of drying shrinkage must be considered as it induces tensile stresses in the new concrete. Instead of regular concrete, fibre reinforced concrete can be used for retrofit.

Steel Plating: The addition of steel plate is simple and rapid to apply, does not reduce the storey clear height significantly and can be applied while the structure is in use. Gluing mild steel plates to beams is often used to improve the beam flexural and shear performances. Glued plates are of course prone to premature debonding.

FRP Wrapping: FRP laminates are attached to beams to increase their flexural and shear capacities. The amount of FRP attached to the soffit should be limited to retain the ductile flexural failure mode. FRP bars can be attached to the web of a beam for shear strengthening .FRP bars can also be used as tendons for external prestressing.



Beam–To-Column Joint Strengthening: Different methods used for strengthening are Concrete Jacketing, Steel Jacketing, Steel plating, FRP Jacketing.

Wall Strengthening: A concrete shear wall can be strengthened by adding new concrete with adequate boundary elements. For the composite action, dowels need to be provided between the existing and new concrete. Steel braces or strips, FRP or steel sheets, external prestressing or reinforced grouted core can be employed for strengthening unreinforced masonry walls.

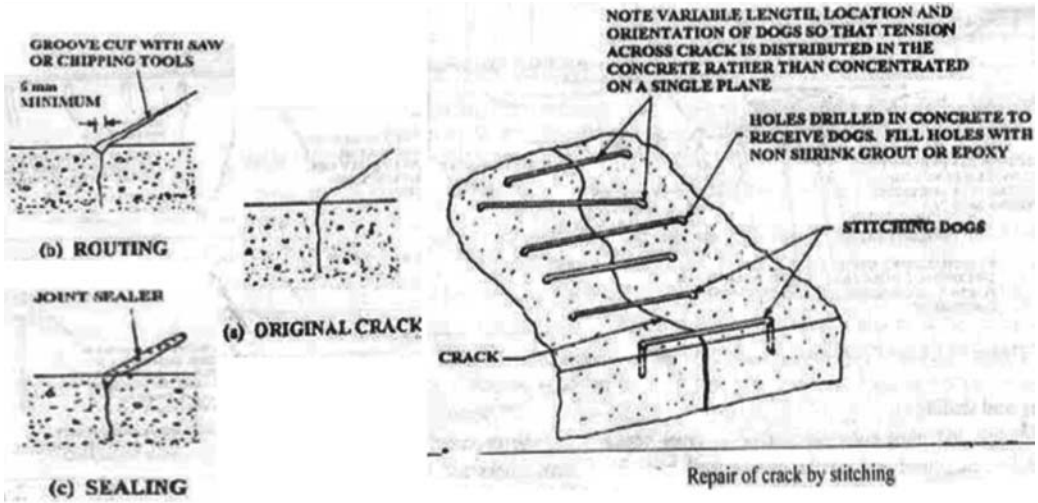
Foundation Strengthening: Foundation strengthening is done by strengthening the footing as well as the soil.

Causes of Damage in Masonry Building and Repairing Techniques

Causes of damage include heavy weight and very stiff buildings, attracting large seismic inertia forces, very low tensile strength particularly with poor mortars, low shear strength, brittle behavior in tension as well as in compression, weak connection between walls, weak connection between roof and wall, stress connection at corners of doors and windows and overall unsymmetry in plan and elevation of buildings.

Crack Repair Techniques

These techniques are Epoxy-injection Grouting, Routing and Sealing, Flexible Sealing, Stitching, Providing additional Reinforcement, Drilling and plugging, Prestressing steel, Grouting, Dry packing and Surface Coatings.



Repair of crack by stitching

Routing and sealing can be used to repair dormant cracks that are of no structural significance, and is used to seal the cracks against the ingress of moisture, chemicals and carbon dioxide. In Stitching the crack is bridged with U-shaped metal units stitching dogs before being repaired with a rigid resin material. This can establish restoration of the strength and integrity of cracked section; due care is to be given to make analysis check to ensure that this will perform well under applied loads. In Bonding, cracks are bonded by the injection of epoxy bonding compounds under pressure. A usual practice is to drill into cracks from face of the concrete at several locations. Water or a solvent is injected to flush out the defect. The surface is than allowed to dry. The epoxy is pressure injected into the drilled holes until it flows out through the other holes. In bandaging, flexible strip is fixed over the crack and only the edge of the strip is bonded. Where movement is not all in one plane and excessive movement is observed that can be accommodated by a recess of convenient size, or if there are factors which prohibit the cutting of a recess, a surface bandage can be used. In areas which are subject to traffic, the flexible bondage will be coated over with a wearing course.

Underwater Repairs

Many of the techniques available for above water repair can be used underwater with only minor modifications. The materials specified for use in air, however, are often completely unsuitable for underwater use. However, cost & difficulty of underwater working requires that operations to be carried out at the repair site be minimized & made as simple as possible and method of repair must be tailored to suit the available methods of access.

Preparation of the damaged area requires specially adapted techniques. Care must be taken to ensure that the area is not contaminated prior to application of the repair material. The material selected for the repair must be compatible with underwater use both during placing & curing. Many resin-based repair materials are not suitable for use underwater; cementitious systems are however, an ideal medium. Placement methods & formwork must be adopted that minimize mixing between repair material & water.

Checking during the repair operation and regular inspection on completion is difficult and costly to achieve underwater. The cost of underwater repair is far greater than for similar repairs carried out in the dry. The cost of

failed repairs is also therefore high. Hence it is important that laboratory trials on both repair methods and materials be carried out to identify possible problem areas and ensure smooth site operations.

The preparation of damaged area require removal of cracked concrete and cutting of corroded reinforcement. The damaged concrete can be removed by high pressure water jetting, wherein hydraulic expanding cylinder are inserted in to pre-drilled holes and pressurized until splitting of concrete occurs.

Conclusion

- Depending upon the damage, it needs to be decided whether the building / structure needs to be repaired, rehabilitated or retrofitted.
- Success of any repair program depends upon the correct detection of the distress and deterioration and cause that lead to deterioration.
- Seismic retrofitting is a suitable technology for protection of a variety of structures. It has matured in recent years but the expertise is required.
- Optimisation techniques are required to know the most efficient retrofit for a particular structure.
- The main challenge is to achieve a desired performance level at minimum cost, which can be achieved through a detailed nonlinear analysis.

References

1. Repair and Rehabilitation of Structures By Mrs. S.SHYAMALA GOWRI.

2. Seismic analysis and retrofit of existing multistoreyed buildings in India by Amlan K. Sengupta and others.

3. https://www.slideshare.net/aritrabanerjee1/seismic-retrofitting-techniques?next_slideshow=1.

4. https://www.slideshare.net/ankit_1610/chapter-4-repair-rehabilitation-retrofiiting.

****

Retrofitting for Sustainability of Buildings

Krishna Kant

Former UN Expert & M.D. Abhinav Consulting Engineers

Prologue

Due to large scale new construction activities taking place all across the country, there is a growing awareness of the need to manage the condition of the nation's building stock more efficiently. Magnitude of the issue can be appreciated by the fact that in our country assets worth 3 to 3.5 lakh crores of rupees are created yearly. These assets require not only regular maintenance and upkeep but retrofitting to keep them functional and useful for rendering to serve the objective for which these were created. It is a known fact that rehabilitation of existing assets is more viable a solution in most cases than creating new ones. Repairs and rehabilitation will therefore constitute major chunk of construction expenditure.

-Editor-

Introduction

Sustainable building is that which meets the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystem, both during and after its construction and specified service life. A sustainable building optimizes efficiencies in resource management and operational performance; and, minimizes risks to human health safety and the environment.

In order to make a larger impact, old and existing building stock needs to be brought under the purview of sustainability. Renovation, refurbishment or overhauling the whole structure is not a feasible option to achieve this, given the huge capital investment, collateral damage to adjacent buildings, massive waste generation and associated health hazards. The solution to this conundrum lies in retrofits.

Sustainable buildings have demonstrated reduction in energy and water consumption to less than half of the present consumption in conventional

buildings and complete elimination of the construction and operational waste through recycling. A sustainable building optimizes efficiencies in resource management and operational performance; and, minimizes risks to human health safety and the environment.

Retrofitting means 'providing something with a component or feature not fitted during construction or adding something that it did not have when first constructed'. It is often used in relation to the installation of new building systems, such as heating systems, but it might also refer to the fabric of a building, for example, retrofitting insulation or double glazing. Retrofitting has come to prominence in recent years as part of the drive to make buildings safe for seismic forces, more thermal efficient and sustainable. This can help cut carbon emissions, make it cheaper and easier to run buildings, and can contribute to overcoming poor ventilation and damp problems, therefore improving the health of occupants. It can also increase building adaptability, durability and resiliency.

Why Retrofitting

It is of paramount importance that the buildings constructed continue to serve the purpose for which these were constructed. As the time passes on account of normal wear and tear, and environmental effects, deterioration and usage the buildings start showing signs of distress and need retrofitting. Normal maintenance and upkeep is not enough to keep the buildings serviceable beyond a certain time and need intervention by way of a special effort such as retrofitting.

One of the most effective strategies for minimizing the environmental impacts of material usage is to reuse of existing buildings. Many of the buildings in India were not originally designed to resist seismic forces. In some cases codal provisions have undergone revision necessitating up gradation. Retrofitting is resorted to make these buildings earthquake resistant in order to make these buildings meet safety requirements for earthquake forces.

The other kind of buildings which are those showing signs of distress on account of ageing and an environmental effects. Buildings located in coastal areas and near industrial establishments are subjected to vagaries of weather and chemical emissions which harm the building and useful life of building gets reduced necessitating retrofitting of the buildings.

The third variety of buildings would be those which had been constructed with the technology that has now become outdated and building fabric as well as services need up gradation to be in line with the present times to save energy and provide more comfort and safety.

Before going out for any retrofitting of any structure it is essential that the cause for the deteoration of the building is first looked into. While deciding on the materials to be used for retrofitting and upgradation or restoration of the building to its original functional shape the causes which have caused the deteoration must be attended to. Special attention should be paid to the leakage and seepage in the buildings, drainage of areas causing damage to the structure, ventilation and lighting issues of the building and accessibility to service areas.

The approach to retrofitting in these cases cited above differs on case to case basis. In case of buildings which were designed without taking into consideration seismic forces of the area, planning and redesigning has to take into account existing building designs and make it fit for meeting the earthquake forces. Whereas in the buildings which have shown deterioration on account of weathering/ageing or neglected maintenance, retrofitting involves restoring the building to the original shape by resorting to methods which are economical and are in line with the original construction while ensuring that the materials used and processes adopted are eco-friendly and sustainable. Retrofitting for the third kind of buildings uses advancements in technology to provide more comfortable and economical living to the users.

Before finalization of design considerations of retrofitting measures evaluate hazards of the site and undertake site characterization and take into consideration Geo- technical Hazard's such as cracks, ground up heave, liquefaction, slopes stability and tsunami. It would be desirable to take into account weathering of materials waterproofing of structures, modern day requirements related to electric fittings and fixtures, ventilation air conditioning heating etc.

Durability is to be achieved with use of modern day technology, construction tools and procedures. Before making what may amount to a major investment in the retrofit of existing buildings for energy and sustainability improvements, it is important to determine if the investment is worthwhile in perspective with other building conditions.

Quality Control in Retrofitting

As the quantum of work involved in retrofitting is comparatively smaller, attention to quality gets neglected. If this be the case, sustainability of the work done and life of the retrofitted structure cannot be expected to last for a period for which it was planned while designing and carrying out retrofitting works. Quality plan needs to be prepared, implemented and well documented. The goal should be to create a high-performance building.

Checks before taking up Sustainable Retrofitting

- Whether building is structurally safe
- Can the work be done in phases without disturbing occupants
- Do the materials/paint etc. used in the structure need to be changed for better performance and sustainability
- Look for opportunities to reduce the cost of the work by recycling waste and demolition materials
- Develop a plan and follow a sequence of activities in order to determine the best options for energy and sustainability improvements
- Carry out an energy audit to determine if the existing systems are operating at optimum levels.
- Review utility bills from the last two years to determine if consumption (not cost) has risen
- Examine the building envelope, looking for leaky windows, gaps around vents and pipe penetrations, and moisture intrusion before deciding upon upgrading heating and air-conditioning systems

Sustainability through Retrofitting

As reconstructing huge buildings at scale isn't a sustainable strategy, retrofitting old buildings and making them more energy-efficient sounds like a better idea. Once retrofitting has been done in a proper way the building will be less costly to operate, will increase in value, last longer, and contribute to a better, healthier, more comfortable environment for occupants to live and work. Improving indoor environmental quality, decreasing moisture penetration, and reducing mold all will result in improved occupant health and productivity.

It is important to initiate energy conservation retrofits to reduce energy consumption and the cost of heating, cooling, and lighting of buildings. While designing major renovations and retrofits for existing buildings, at the same time consider upgrading the building for accessibility, safety and security with sustainability initiatives to reduce operation costs and environmental impacts, so as to increase building adaptability, durability, and resiliency and ensure better utility and service as well as safety to the users.

Other benefits that would accrue on account of smart retrofit of any old building would be attraction of more tenants, competitive positioning, superior environmental consciousness and lower energy bill, cost-effective operations and maintenance and state-of-the-art management of the building in addition to high performance, high efficiency, and low operating costs and low maintenance and easy service.

Holistic Approach for Retrofitting to Achieve Sustainability

Some of the most common problems facing retrofit include: under-ventilation, condensation, air leakage, rising damp, interstitial condensation and overheating. It is therefore very important that these and other risks are understood and managed in a way that is appropriate. It is advisable to have 'retrofit watch points' to help avoid such problems.

The process of retrofitting involves careful balancing of different elements and their effects on the overall performance of a building. A change in one part of a building can affect another, and sometimes this is apparent only after causing irreversible defects. By taking up retrofitting, following aspects need to be kept in mind for sustainable building performance:

- Take the opportunity afforded by the building renovation to incorporate sustainable operations and maintenance practices and switch to green cleaning products and methods.
- To ensure a newly renovated building continues to perform as designed, measure the performance of the building regularly.
- Plan on installing meters for electric, gas, water and other utilities. Smart meters and sub meters are preferable to monitor real-time consumption, control demand and increased tenant accountability.

- Building materials choices are important in sustainable design because of the extensive network of activities such as extraction, processing and transportation steps required for manufacturing a material, and activities involved thereafter till building construction and even thereafter.
- The use of rapidly renewable materials and recycled materials minimizes the adverse impact of natural resource consumption in the manufacture of new building materials. The use of local materials supports the local economy and reduces the negative impact of transportation.

HVAC System

As the air conditioning system account for nearly 50-60 percent of annual electricity bill for a conditioned building special attention needs to be given to planning, design and installation of HVAC system to achieve optimally size of the machinery for the cooling and heating equipment of the building. Sustainable development is aimed at enhancing occupant experiences, which has a direct bearing on their productivity, health and wellness. To that end, retrofitting exemplifies sustainability in the sense that an HVAC retrofit can not only conserve energy, but also deliver an optimal experience.

Electrical System

Efforts should be made to select electrical installations and systems which are energy efficient, while complying with the Indian Standards for the same which provide apart from efficiency, the various other important requirements including relating to performance and safety.

Lifts, Escalators and Travelators

To minimize the adverse environmental impact, the materials used for manufacture of lifts, escalators and travelators should be recyclable, shall not have a potential for depleting ozone layer, shall not be hazardous, and shall be easily disposable at the end of life cycle.

Conclusion

Before taking up new construction of any major project comparative study of alternate solutions should be considered whether the existing building

can be rehabilitated by resorting to retrofitting. While taking up the work of retrofitting existing design features of the building have to be taken into account in addition to the current and futuristic requirement of the users/owners and environmental factors. The opportunity should also be utilised for making the building more user-friendly and energy efficient by using locally available eco-friendly materials and minimising waste for its sustainability.

****

Rehabilitation/Retrofitting of Concrete Structures alongwith Case Study

Dr. J. Bhattacharjee

Consultant; Former Chief Engineer & Jt. Director General, (MES/MOD)

Prologue

The construction material mainly concrete is being used extensively for various types of construction projects. However, the deterioration of Reinforced Concrete structures is recognized as a major problem worldwide. Apart from requiring regular maintenance, many structures require extensive Repair/ Rehabilitation/Retrofitting. Over a period of time, as these structures become older, we find in them certain degradation or deterioration with resultant distress manifested in the form of cracking, splitting, delaminating, corrosion etc. Such deteriorated structures can be rehabilitated and retrofitted by using various types of admixtures & modern repair materials. There are many areas in structures where improvement is needed during its service life stage for sustainable development & also the method of carrying out Repair/Rehabilitation/ Retrofitting.

-Editor-

Introduction

There is a growing National/International concern about the premature deterioration of our buildings/structures, particularly concrete structures. Cement concrete is one of the most widely used construction material and has proved to be almost indispensable to the present-day civilization. Though concrete is quite strong mechanically, it is highly susceptible to deterioration and thus gets damaged & even fail ultimately, unless some measures are adopted to counter deterioration. Such measures would enhance the durability of structures. The maintenance of building is a lifelong continuous process. It has been observed that the minimum maintenance of concrete structures requires an integral approach which need the introduction of as much preventive measures as possible in accordance with the basic established concept– “Prevention is always better than cure”. Repair/rehabilitation/retrofitting is the fastest growing

segment of the concrete industry. Across the globe, billions of dollars are spent annually in repair and restoration of distressed concrete structures. Thus, selection and evaluation of repair materials and protective coatings is receiving more and more attention among Civil Engineers in the recent past. The new technologies and new repair materials, which have been extensively used by the advanced countries, are also being tried in developed country like India. This paper highlights the present state of maintenance especially in developing country like India and about the utilization of those new techniques/materials for repair/restoration of the buildings/structures, for long term sustainable development.

Present State of Maintenance/Repair

It is a matter of serious concern of us, the Civil Engineers, that in some countries, the repair activities of structure done today account for nearly half the total annual expenditure on construction activities. Such a state of affairs is of great concern mainly for two reasons. Firstly, concrete is, in essence a proven, durable & mostly maintenance free material. This is exemplified by a large number of structures constructed properly more than half a century back & is still in good stead today. Secondly, the know-how of making concrete, which does not need major repair/rehabilitation, is already well documented and is known to us. In spite of all these, the trend of early deterioration of concrete structure continues unabated.

At present there is neither any established existing procedure, mandatory or otherwise, for periodical inspection of buildings/ structures and recording the structural defects and symptoms, like cracks, spalling, corrosion, and deflection of structure, in a logical manner nor any record of structural repairs/ rehabilitations carried out, is maintained properly even for public buildings. We have barged into a repair activity without adequate preparation. Persons involved in repair/rehabilitation need to be better civil engineers. In fact, repair/ rehabilitation/retrofitting activity is a much more advanced application of science and technology involved in civil engineering, which is the most difficult challenge to engineers. We need to opt for new techniques and materials to resolve these difficulties. We have enough options to select from various construction chemicals, minerals, methods for repairs/rehabilitations, the economics etc. to set right the damage. These all are to be considered in totality before deciding

upon the repair/rehabilitation/retrofitting strategy and hence required enough background preparation.

Replacement of damaged materials is the trend for repair/rehabilitation. Mass scale replacements are convenient repair strategies, which were being followed mostly in developing country like India, as these offer fast turn-over & are more profitable. This is normally a cosmetic strategy, restricted to the facade and offers a sense of safety due to the impressive new looks. The really needed repairs i.e., Structural repairs to the actual load-bearing structural members are often missed. Rather structural distress is camouflaged and buried beneath finishes. Thereby damage syndrome recurs and continues unabated. The ordinary classical methods of repair/rehabilitation like re-plastering, re-concreting, jacketing and shotcreting etc are often seen not to offer satisfactory results. It is often found that in traditional repairs, the same problem may recur fast. Investigations have brought out that the repair measures in such cases failed basically due to two reasons for RCC buildings: -

- Corrosion of steel not being totally removed.
- Bonding between old and new concrete being inadequate.

For repair of any concrete structures, use of construction chemical is very common in advanced countries, for obtaining long term results, which in India is still very much lacking. It is difficult to match the response of the non-repaired and the repaired areas in rehabilitated structures. In India we are yet to opt for new technologies and materials on large scale to resolve the difficulty of attaining durable repaired structures on long term basis. In fact, normal periodical maintenance is often very much lacking & thereby requirement of rehabilitation is also increasing.

Principal Causes for Deterioration of Structures

Concrete normally provides excellent corrosion protection to embedded reinforcement. The high alkaline environment in concrete results in the formation of a protective oxide film on steel bars. However, unless concrete is well compacted and dense, it is susceptible to carbonation, losses its capacity to protect reinforcement. Some of the major causes for deterioration of concrete structures are brought out below:

The deterioration of typical concrete structure starts from the time it is exposed to the elements of nature, primarily under high humidity, high temperature conditions & variation in temperatures; thus, certain parts of structures including roofs and structural elements directly exposed to weather condition, are more susceptible to deterioration. The deterioration of materials such as concrete & reinforcement reduce the strength of the structural members. While elements such as temperature variations, pollution, wind, rains, floods etc. contribute towards deterioration; sometimes changes in environment after construction and changes in functional requirement also contribute towards premature deterioration.

Corrosion of embedded steel is the prime cause of damages to the reinforced concrete structures. It is like a “CANCER”, which progresses with slow deteriorating process and if neglected or not attended in time, may spread over a large area and cause extensive disintegration/deterioration of structural elements. It may even lead to catastrophic structural failure, in the absence of timely remedial measures. Various causes which create conducive conditions to accelerate/propagate rate of corrosion are as under:

- Inadequate cover to reinforcement.
- Use of inadequate grade of concrete for the purpose.
- Use of rusted steel.
- Poor workmanship/workability/compaction, thus leaving concrete porous.
- Poor Unsuitable ingredients (both coarse & fine aggregate).
- Use of high W/C ratio resulting in fine hairline cracks in concrete during drying.
- Use of water containing high incidence of salts/sulphates.
- Wave action (alternate wetting and drying processes).
- Presence of harmful gases in the air.
- Contact with acids/fumes.
- Exposures to relatively high humidity (>70%).

Apart from these, other main reasons for deterioration of any structure are:

- Foundation settlements.
- Lateral movements.
- Accidental overload.
- Poor maintenance during service life.

Method of Rehabilitation/Retrofitting for Concrete Structures

The techniques and materials used for repair/rehabilitation/retrofitting and maintenance depend upon the extent of deterioration. Construction chemicals/ Polymers entered the world of concrete during the late Sixties. Today one can say that they are an integral part of many concretes. Broadly, polymers are chemical compounds, which essentially consist of repeating structural units. Though polymers are in use in concrete for quite some time; they are known by the respective roles they play such as admixtures, bonding agents, sealants and so on. Some of the most commonly used polymer-modifiers in concrete & mortar are ethylene vinyl acetate co-polymer, styrene-butadiene co-polymer and acrylic resins. Polymer-concrete composites display several improvements in the mechanical properties, including substantial increase in the strength & modulus of elasticity. In India, though the use of polymers in the construction industry particularly in repair/rehabilitation & maintenance field is growing, we are yet to have our own set of Standards & Codes, which can guide both the specifier & the customer in their proper use. There are large number of products available in the market. As such there is a requirement of coming up with general guidelines and standard evaluation techniques, which should enable users to make the best use of products available. The construction industry as a whole will gain from such a standardisation.

Requirement & Method for Retrofitting/ Strengthening of Structures

Retrofitting/strengthening is a technical option for improving the strength and other attributes of resistance of building to seismic and other forces. The requirement of retrofitting of any structure arises mainly due to the fact that old buildings which were designed as per old Codal provision may not be having adequate strength as per requirement of latest Codal provisions. Moreover, in certain cases deterioration of concrete of foundation and other structural elements etc. takes place due to various reasons including settlement of soil strata etc. Foundations are a very important part of building. The strengthening

is also required, whenever we want to increase any additional floor of a building due to increase in FAR etc. Shoring and underpinning are important in repair/ retrofitting of any foundations. Shoring is the forms of temporary support given above the foundation to the existing building to avoid any damage due to collapse of the building during repair/retrofitting. Underpinning is the process of strengthening the foundation of an existing building by repair. The process of strengthening the foundation of an existing building is called underpinning. The main objective of underpinning is to transfer the foundation load to a lower stronger depth. The reason for underpinning can be due to any one of the followings:

- Larger than permissible settlement of the building
- Increase in loading
- Lowering the level of adjacent ground below the foundation of the building for some construction on the adjacent site.

There are various methods available for underpinning; one is Traditional Method, others are Needle and pile underpinning of walls, Angle piling and Underpinning of Column Foundations by Jack Pile Method. Further, there are methods available for improving foundations on expansive clays also. The Strengthening of RC Beams, Columns and Slabs can be carried out by Plate Bonding, RC Jacketing and by FRP systems. The Strengthening of Columns and Beams can also be done by RC Jacketing. RC jacketing is jacketing with additional layer of steel and concrete. It is one of the simple methods of strengthening of columns and beams. The RC slab Strengthening is carried out by Concrete Overlay. This is applied, where RC slab already constructed but found having structural deficiencies. In India, due to changes in codal provisions particularly for earthquake code, most of the existing old important buildings require retrofitting for structural safety against calamity like earthquake, tsunami and cyclone etc.

Latest Repair/Rehabilitation/Retrofitting Materials & Techniques

Polymer: High strength, resilient materials which have high resistance to attack from chlorides & sulphates are normally used for repair materials. The polymer modified concrete (PMC)/polymer modified mortar, which are commonly used as repair material has following properties:

- High compressive strength at early age.
- Increased flexural & tensile strength.
- Water tightness
- Adhesion
- Resilience, durability & im-permeability etc.

The polymer to be used is latex. SBR latex or another equivalent polymer should be used. It imparts the following properties to concrete.

High Strength:

- Resilience
- Im-permeability
- Resistance to carbonation & chloride ion penetration.

The polymer is mixed in water prior to addition in cement concrete. The PH value of polymer should be more than 7.5. The 28 days flexural strength should be at least 50 kg/cm^2. The minimum compressive strength is 150 kg/cm^2 at 3 days & 350 kg/cm^2 at 28 days. The split tensile strength should be at least 25 kg/cm^2 at 28 days.

Epoxy Mortar/Grouting: Epoxy mortars are used for repair of spalled concrete in underside of slab floor/roof slab & chajjas having damage less than 75mm. Epoxy grouting is used normally for filling of cracks. Epoxy grouting systems have high mechanical strength. They obtain strength only in a few hours and are resilient in nature. Epoxy systems are immune to sulphate & chloride attack and are impermeable. They have got high compressive & tensile strength also. Since epoxy grouting system can be injected into even hair line cracks, effective repairs can be carried out with them.

Polymer Coating: For enhancing the life of structure, coatings like IPN (Interpenetrating Net work) or other equivalent polymer should be applied on all the concrete surface of the structure. The coating prevents any future ingress of air & harmful chlorides, sulphates etc. into the structure. It thus protects the entire structure from corrosion & spalling. However, these coats are to be

applied periodically, normally with interval of 5 years or so, depending on type of product being used.

Methodology for Repair, Rehabilitation & Retrofitting

Common Guidelines: Presently number of companies are manufacturing various construction chemicals for repair/rehabilitation of civil engineering structures, in India. Various products manufactured by these companies cover all the repair materials available in India. However, their product range & utility varies. In case corrosion of steel has not started but carbonation of concrete has taken place unto reinforcement surface, coating of required thickness can be applied to prevent/retard the carbonation process. Depending upon the severity of carbonation, polymer or epoxy resins or polymer modified mortar concrete provide adequate protection. Such coating also stops penetration of chloride and other deleterious elements.

Whenever the process of corrosion has set in, the restoration techniques depend on the extent of damage to the concrete and or steel. But following guidelines are common:

- Remove all unsound concrete & expose reinforcing steel all round.
- De-rust the steel by appropriate methods viz sand blasting, brushing & applying rust removers etc.
- Restore reinforcement with anchorages i.e., shear connectors, wherever required.
- Apply tack/binding coat of polymers or Epoxy based materials.
- Use one of the several stitching techniques to restore concrete to the original surface level.
- Injection of cement slurry or polymer modified slurry or epoxy of suitable grade to fill up the pores, internal cracks or segregation.
- Apply suitable protective coating.

Case Study

The author has successfully used various admixtures for major rehabilitation of wharves along with other repair works of caissons, dry dock etc costing Rs.50 million (App.) at Bombay (Mumbai), India. The two wharves (Contiguous to each other) having width of 16.45 m and total length of 500 m, was constructed during 1957 and 1967 (one having length of 350 m and other of 150 m). The damages observed were excessive spalling of concrete, formation of wide cracks, excessive corrosion, falling of fenders and shearing off of piles etc. In general, it was observed that various structural elements after these have been exposed/chipped off showed much more deterioration than was observed at the time of the site survey.

The two wharves were composed of fender portals, bollard portals, curtain wall (on one side of wharf only), wailings (connecting piles at the bottom of the bracing level), Deck slab (37.5 cm thick) and wearing coat (17.5 cm thick) over deck slab. Apart from a visual and dimensional survey, various other tests were carried out to diagnose distresses. Cover meter test, half cell potential survey, ultrasonic pulse velocity test, petrography test, core test, water permeability test, chloride sulphate test and porosity test were carried out. In addition, analytical assessment of residual strength was also made. The structure being very old, design calculation/details were not available. Using a computer, a structural analysis was carried out that showed that all structural members were adequately designed based on earlier codal provisions. Because of the extent of deterioration repairs were required to wharf portals frames, curtain wall, wailings, deck slab, wearing coat and fenders. The repair methodology adopted for different types of defects are as follows:

- All cracks at various locations were filled with epoxy grouting under pressure. The stages involved in grouting are:

    - Cutting ‘V’ grooves with pneumatic cutter.
    - Drilling of holes, at intervals.
    - Fixing of entry ports.
    - Application of epoxy sealant.
    - Cleaning of grooves with compressed air.

- Injection of Epoxy under pressure
- Cutting of entry ports.
- Grinding of sealant.

➢ Spalling of concrete was repaired by various methods depending on locations. For soffit of slabs & fenders where the depth of deterioration was less than 75 mm, epoxy mortars were used. The sequences of activities involved were as follows:

- Square cutting the boundary of damaged concrete.
- Chipping the spalled surface by pneumatic chipper.
- Removing rust from existing reinforcement by wire brushing.
- Welding of additional reinforcement after carrying out anti-corrosive treatment and an epoxy coating.
- Removing dust from surface of concrete and reinforcement by compressed air, drying of the surface before applying coating of epoxy.
- Applying an epoxy coat within an interval of 15 to 30 mins after mixing of resin & hardener and quartz sand, in the proportion of 100, 50 & 800 by weight. Air curing, for 48 hrs.

For piles, beams, wailings, bracings and fenders/soffit of slabs (having a depth of deterioration greater than 75 mm), polymer modified concrete (PMC) were used. The stages involved in application of polymer modified concrete (PMC) is similar to that of epoxy mortar, except for mix of PMC and curing requirement. In PMC the materials used were cement, quartz sand, polymer & water in the proportion of 100, 400, 15 and 30 by weight, for the damaged portion of structural member having shallow depth up to 75 mm. However, where damaged portion is considerable and having thickness more than 75 mm, cement, quartz sand, polymer water & aggregate (20 mm & down grade) was used, in the proportion of 100, 200, 15, 35 & 400 by weight. Further, in case of PMC, water curing is also required. One pile which was sheared off (because of which the jetty was declared non-operational) was replaced by two piles after

cutting the deck slab, lifting the slab by jacks and casting two new piles under water by bored cast-in-situ method and thereby restoring the structure to its original position. In other locations only a wearing coat, bonding coat of epoxy resin needed to be applied to the concrete. For repairs to the curtain wall (which is not a very important element of the structure) guniting was used. For enhancing the life of structure, a special penetrating thermosetting polymer was applied over the entire concrete structure including fender, after cleaning the structure by sand blasting.

The repair/rehabilitation work of the two wharves costing approximately Rs.30 million carried out during 93-94, appears to have stopped the deterioration and no further deterioration has been observed (by visual inspection) after about more than 20 years since the repair/rehabilitation work was carried out. It is expected that this work will extend the service life of the facility for another 15 to 20 years, with normal periodical maintenance. The Author has planned and got executed repair/rehabilitation/retrofitting of various types of structures like residential accommodation, commercial accommodation, swimming pools and water tanks etc by similar procedure and found the procedure is very effective.

Precautions in the use of Polymers in Execution of Work

Presently in India we are not having any detailed codal provision for utilisation of various construction chemicals/polymers & utilisation is restricted to a select few privileged ones who are acquainted with the same. In the absence of proper detailed codal provision, a careful attention should be given to the instruction given by the manufacturer of the polymers. A polymer should be employed only after appropriate evaluation of its effects, preferably by use with the particulars materials & the condition of use intended. Such an evaluation is particularly important in our country, as the chemicals/polymers have mainly been developed in country having colder climate. They therefore require long term testing under tropical climate. Besides, such evaluation is also needed under the following situations: -

- Special types of cement are specified.
- More than one polymer to be used, together.
- Mixing & placing is done at temperatures well above or below the generally recommended concreting temperatures.

The repair work needs to be executed in accordance with project documents. The repair process, especially concrete removal and reinforcing repair, may alter the load distribution of the structure and the members being repaired. Proper shoring and bracing needs to be provided throughout the repair process. Quality control throughout the repair process is essential to any successful project. Appropriate inspection by the Engineers and periodical testing at site & in laboratory is to be performed and ensured on regular basis, for long lasting solution.

Conclusion

The repair/rehabilitation/Retrofitting of Concrete repair projects are very challenging, as is true with most repair and renovation projects. Repair/ Rehabilitation of concrete structure is comparatively a new subject in India. It is a real challenging task to carry out the repair/rehabilitation work, when structure has already undergone major structural damages/deterioration. As such, there is a requirement of periodical/timely assessment and maintenance with latest available techniques and materials as described in this paper. This will go a long way to arrest deterioration and extend the lease of life to the structure. As the time passes, many more concrete structures will come up for major rehabilitation. Time has come to have a structural auditing of all the old concrete buildings/structures, which were constructed during sixties and earlier. Depending on the severity of the environmental effect, the restorative measures can be selected. In poor country like India, we cannot afford to spend money on replacing the building, which is against implementation of green building concept also. As such selection & evaluation of right repair material and protective coatings will save enormous money & time by reducing the frequent repair costs of already repaired concrete buildings/structures.

To modify/improve the properties of concrete or mortar, a large number of polymers/admixtures have been tried and extensively used in other countries. World over polymers/admixtures have been in use for over 45-50 years and their long term behaviour patterns are known. The superiority of polymer modified mortars/concretes over normal mortars/concretes in repair/ rehabilitation field is established beyond doubt. In India, such effective polymers/ admixtures have only become available during last two decade mainly. Now a number of internationally known and time tested polymers/admixtures are available all over India. However, before using various new polymers/

construction chemicals available in the market, one must be familiar with the products and its limitations. Further, the repair/rehabilitation works should be undertaken only after ascertaining properly the cause of deterioration. It is imperative that the Engineer understands the reasons which led to damage and or deterioration prior to developing a repair programme. The underlying causes should be corrected, although it is a difficult process. The polymers/admixtures should form a permanent part of original construction and repair/rehabilitation/ retrofitting & maintenance of concrete structures in coming years, for long term sustainable development.

References

1. Bhattacharjee J (2015): “Need for repair/retrofitting of Concrete Structures using latest materials & Techniques”, in International Conference of NCB, in New Delhi on 01-04 Dec15, (PP 710-713)

2. Paul. H Jay, (2002): “Repair, Renovation & Strengthening of concrete structures” in Seminar on “Evaluation & Rehabilitation of concrete structures”, in Mexico City on 11-13 Sept, 2002, PP 1- 11.

3. Bhattacharjee, J.(1997): ‘Utilisation of Superplasticizers & other Chemical admixtures in Rehabilitation of Marine Structures along with a Case Study”, in Proceedings of International Conference organised by CANMET/ACI at Rome, Italy on 7-10 Oct.1997. PP 23-26.

4. Seminar Proceedings on “Admixtures for Concrete” (1996), Concrete for the 21st century Meeting the challenges”, ACI (Maharashtra India chapter), at Bombay on 02 May 96, PP 95-126.

****

Optimising Existing Structures through Retrofitting

Jit Kumar Gupta

Founder Director, College of Architecture, I.E.T., Bhaddal, Punjab

Prologue

History of construction is said to be history of human civilization. Globally, construction sector is valued for leveraging economies, promoting industry and generating employment. Construction sector accounted for 11% of India's GDP and 1/6th share (35 million) of the total employment generated in the country. India ranked fourth globally in the construction, after China, United States and Japan, with total output placed at 333 billion US dollars. In India, construction sector accounted for around 40 per cent of the development investment during the past 50 years and created assets worth over[1] 200 billion. Despite large scale construction of structures is taking place yet we can see around many poorly constructed/maintained structures showing distress due to various reasons. Considering ever increasing volume of building being/ yet to be constructed, it becomes critical that construction sector is made more effective, efficient, productive and sustainable. Accordingly, appropriate construction technologies, integrated with proper repair, maintenance and retrofitting, need to be evolved and made operational, to make India global leader in safety and sustainable construction practices.

When hit with disasters, majority of existing structures face extensive

damage, destruction and remain vulnerable due to improper design, poor quality of construction, lack of proper care and maintenance. This necessitates construction of new buildings, to compensate the buildings damaged and destroyed. In addition, number of existing buildings are also being demolished and replaced by new structures. Demolishing and destruction of existing buildings, causes colossal loss to the economy, environment, communities and nations. In order to minimize loss caused by the destruction/demolition, it will be essential that not only quality of built environment is appropriately ensured, but also effectively monitored and efficiently maintained by ensuring time bound repair and maintenance. In addition, mechanism of retrofitting also needs to be valued and adopted not only to restore existing structures to their original health but also to put good structures to alternate use.

-Editor-

Retrofitting

Retrofitting, as a concept and approach, had its genesis in the second world war when weapons technology was advancing at an intense pace and planes/ships were becoming outdated, even before their completion. Retrofitting was then found to be the option and applied to completed craft with the addition/ application of latest technology for making them appropriate for using them in the war. Retrofitting was later revived and made applicable to buildings, on a massive scale, during the energy crisis of the 1970s, when new features were added to millions of old houses to make them more energy-efficient. Later on, concept of retrofitting, was extended to strengthen and make the structures safe against the damage caused by natural disasters. Considering its

numerous and distinct advantages, retrofitting also became handy to be used for strengthening existing structure to enhance its performance; restoring buildings to original health when structurally damaged by exposure to sun, rain, frost, water etc.; changing the use/typology of the structure from one purpose to another; improving the shear resistance and capacity of the structural members to resist seismic loads; making addition of new technologies for improving the operational efficiency & reducing emissions and making structures safe against natural and man made disasters. Retrofitting is extensively used for restoration, repairing and rehabilitating the heritage buildings, for maintaining their old glory and minimizing damage caused, due to large number of people visiting them. Looking at the variety of damages caused and for making value additions to the structures, number of options are being used for retrofitting. Five different typologies of retrofitting are generally used for restoring the existing structures.

Typologies of Retrofitting

Energy Retrofit: Essentially includes and involves process of reducing the energy consumption to maintain the ambient temperature; making existing buildings energy efficient and least consumers of energy, as compared to conventional buildings.

Disaster/Seismic Retrofit: Includes the strengthening of the existing buildings to make them safe and resistant to disasters, both natural and manmade, involving earthquake/ cyclone/tsunamis/fire etc. Seismic retrofit is carried out primarily to protect; human lives and structures from total failure.

Use Retrofit: Process includes and involves, redefining the use and purpose of older buildings and to put them in new role/order/use to meet the changed needs.

Cultural Retrofit: Process followed involves retaining/ restoring/enhancing the old glory and making value addition to historical /heritage buildings.

Storm Water Retrofit: Process used for sites with extensive impervious surfaces to manage storm water runoff during rainstorms, to avoid flooding and polluting water bodies. Storm water retrofit includes creating/rain gardens, permeable paving and green roofs.

Advantages

Retrofitting is known for its distinct advantage to the owners, economy and communities, because it saves existing buildings from becoming obsolete, outdated and possible damage and destructions. Retrofitting as a process and mechanism, offers enormous advantages and makes value addition besides providing longevity to structures in terms of;

- Valuing existing structures by avoiding demolition. Retrofitting the existing building invariably remains cost-effective and time-efficient when compared with undertaking construction of new building.

- Making buildings sustainable by minimizing the carbon footprints and making optimum use of available construction material, by redefining, reusing and remodeling the existing building.

- Making buildings energy efficient by bringing number of benefits to owners, tenants and occupants in terms of reduced life-cycle operational cost.

- Increasing the market value of a building.

- Offering most economical and cost-effective option to increase the life span of existing structures while preparing the buildings to face adverse climatic conditions.

- Strengthening the existing structure and saves on the capital expenditure while benefiting from new technologies.

- Making buildings economical owner/user-friendly, by reduced maintenance and increased reliability.

Disadvantages of Retrofitting

Despite distinct advantages, retrofitting as a process is also known for its limitations and disadvantages and accordingly needs to be used with care and caution. Retrofitting remains highly professional and scientific process and accordingly needs detailed study and analysis of the structure for assessing the

typology /option of the retrofitting required for achieving the objective. In addition, retrofitting requires trained manpower to undertake the repair/remodeling and avoid any structural damage caused to the structure. The possible limitations of the retrofitting include:

- Retrofitting remains a time - intensive exercise, due to the need of detailed, in-depth, objective, critical and expert analysis for deciding about the extent of damage and options to be used for retrofitting.

- Retrofitting needs high degree of precision and workmanship while undertaking repair. Minor mistake/irresponsibility in execution can even cause damage to the structure.

- Retrofitting Heritage sites remains a highly demanding /high risk time- consuming, cost-intensive and precision oriented process and accordingly needs trained manpower, appropriate expertise and thorough understanding of the basic fabric of the structure, materials and construction used in the building construction, for avoiding any disfiguring/damage to Heritage Site.

Analysis of Retrofitting

Before retrofitting any structure, it will be important to understand, consider, analyze and evaluate, critically and objectively, the status of existing structure in terms of its problems, deficiencies, damage and inadequacies, causes of the deterioration along with the symptoms which needs to be addressed to make building safe and usable. Only treating the symptoms, without proper understanding the underlying cause of the problems, will invariably lead to camouflaging defects identification beneath the finished work. Analyzing existing status of structure will require very specialized assessment and comprehension of the conduct of the building, which is being fixed. Based on these studies and analysis, detailed strategy needs to be evolved in terms of process, materials and method to be used for retrofitting. The choice to retrofit a construction or its segments, needs to be made after carrying out detailed cost-benefit analysis, based on financial implications and availability of appropriate options for retrofitting. Steps involved in retrofitting should include; preparation of drawings and specifications of the building under retrofit;

documenting condition, evaluation; determination of the main cause behind the deterioration; selection of materials and methods of repair; execution process; maintenance after completion of the retrofitting work and checks and balance to monitor quality control during retrofitting.

Prevailing Techniques for Retrofitting/Strengthening

Primary focus of retrofitting an existing structure is to increase its load bearing capacity with respect to its previous condition; improve the structural stability; eliminate vulnerability of structure to any unforeseen disasters/shocks; improving its operational efficiency and changing the existing use/ operational framework of the structure. Established techniques which have been used successfully for number of years have been recognized as; Over Slabbing; Sprayed Concrete with Additional Reinforcement; Steel Plate bonding and External Pre-stressing. Retrofitting has also been divided into two broad and distinct categories i.e. Local and Global retrofitting.

Local Retrofitting : Local Retrofitting involves jacketing of beams**;** jacketing of beam-column joints**;** strengthening individual footings and jacketing of columns.

Global Retrofitting : Global Retrofitting includes making addition of shear wall**;** adding infill wall**;** mass reduction and wall thickening. However, additional/ separate strategies will also be needed while changing the existing use of building for making it green or to meet the additional requirement of services and space. Options to be used for retrofitting will have to be based on the study and analysis carried out for the inadequacies and structural deficiencies existing in the building/structure to be retrofitted and appropriateness and suitability of the options selected. All the processes defined have their limitations, positivities, negativities, advantages and disadvantages and accordingly choice has to be based on professional /detailed study and analysis.

Way Forward

Retrofitting remains one of the best options to restore the existing derelict buildings to their original health and make buildings operationally efficient and usable for all human operations. Retrofitting should not remain confined only to meet the structural inadequacies or needs of repair and restoration. It needs to be extended and taken forward by making use of its enormous capacity it provides to make buildings energy efficient and more livable. Retrofitting can help in reshaping, reframing and putting to new use/options the existing structure, without resorting to demolition and destruction. Potential of retrofitting has not been properly studied, understood, appreciated and exploited in the context of building industry to make existing buildings more livable, cost-effective, operationally efficient, having larger/ extended life-span and reducing their adverse impact on the environment and ecology. It needs to be done on priority to make building industry more sustainable and least consumer of energy and resources besides generators of minimum waste. Few of the options which can be leveraged to make buildings sustainable will include;

- **Achieving Sustainable Development Goal 11 :** UN has mandated that in order to promote global sustainability, cities will have to be made sustainable, safe, resilient and inclusive. Accordingly, a dedicated goal 11 has been made part of 17 SDGs to achieve the objective. Under the said goal, indicator 11-C has been included to make buildings Green, as part of making cities sustainable. Further it has been mandated that by 2030, all nations will ensure to make new construction to be net-zero and by 2050, all existing buildings will also be retrofitted to make zero- energy. Prime Minister of India has already committed in COP 26, to make India Net Zero by the year 2070. Achieving the said objective will be both difficult & impossible, without making buildings green and zero-energy. Retrofitting offers best option to achieve the target given by the Hon PM. Accordingly, it will be important for the professionals and professional institutes like IBC, IE, IIA to find out simple, cost-effective and

time-efficient retrofit techniques to promote a culture of green buildings, both in new and old categories of buildings.

- **Retrofitting Existing Buildings to make them Sustainable :** Buildings are known to be major consumers of energy and resources besides generators of the waste. Buildings also are known to be major determinant of global sustainability. Statistically, there exists more old buildings than new buildings. Majority of existing buildings remain highly energy inefficient. In order to promote energy efficiency; reduce carbon footprints and minimize energy demand in the existing built environment, it will be essential that in addition to making buildings structurally safe, it will also be critical that concerted efforts should focus on making these buildings energy/resource efficient and carbon neutral. Accordingly, energy efficient process/mechanisms of retrofitting buildings needs to be leveraged on large scale.

  Despite distinct and far reaching advantages offered, retrofitting has been used on a very small/limited scale to make the existing buildings green and sustainable. Understanding the potential of retrofitting in making cities/ buildings carbon-neutral; Singapore has drawn a master plan to make all the existing buildings green through a collaborative policy framework involving residents, property owners and the government. The policy involves and includes, adopting retrofitting as the process to achieve the defined objectives. Detailed retrofitting guidelines have been framed and norms defined, for the existing buildings to make them sustainable.

  In addition, in USA process of retrofitting has also been leveraged to reduce the energy consumption of high rise buildings; minimize their carbon footprints and reducing their heat island impact on the city and surrounding buildings. Retrofitting of Empire State Building of New York (one of the tallest structure globally) under the said initiative of the city, was led by replacing more than 6000 windows with double glass, generating solar energy; improving operational efficiency of chillers and rationalizing the requirement of air-conditioning, light and ventilation through artificial intelligence, which resulted in achieving reduction of electricity load of the building to the tune of 3.5 MW and lowering greenhouse gas emissions by 1,00,000 tons over a 15 year period. The payback/recovery of the $13.1 million spent on retrofitting of building, has already been achieved in 3.5 years, due to lower connected electric load, saving on energy, lighting, air conditioning etc.

In view of the above, Retrofitting needs to be promoted and made mandatory to make existing buildings green, sustainable and least consumers of energy and resources. Considering the large constructed buildings and 700-9000 million sqm of new built space to be added annually in the urban India, local/state authorities need to prepare a roadmap for each city and define the detailed agenda and guidelines to make both existing/new buildings, green and energy efficient, using the process of retrofitting.

- **Making retrofitting integral part of Study Curricula:** Retrofitting, as an option to improve the operational efficiency and making built environment sustainable does not find much favour with academic institutions involved in teaching-learning of designing, construction and management of built environment and accordingly remains marginalized. This leads to professionals graduating, having low competency and understanding of the process and advantages of retrofitting. Considering the important role of the technology, it will be important that retrofitting must be made and taught as integral part of the curricula as a separate and dedicated subject of study of the profession for promoting deeper understanding of the process and technique.

- **Skilling Manpower in Retrofitting:** Major roadblock in promoting retrofitting as a methodology and a construction practice, is the non-availability of adequate number of professionally skilled manpower in the construction sector. Accordingly, it will be vital, that adequate opportunities for training and skilling the manpower in the art and science of retrofitting are created at the state/regional/local levels in order to produce large number of professionally trained competent manpower required for retrofitting, keeping in view immense potential and large demand generated by making existing buildings energy efficient and sustainable.

- **Promoting Research:** Considering the numerous advantages retrofitting holds an opportunity and employment it can generate, by making value addition to the construction sector. It will be prudent on the part of all academic institutions engaged in imparting education in Architecture, Engineering, Construction, Management; Development Authorities, Housing Boards, Improvement Trusts; Associations of Developers, Promoters and Builders, NARDCO; Parastatal agencies and Urban Local Bodies to come forward, provide resources and create facilities and

promote research in the area of retrofitting of constructed buildings, in order to make buildings safe and sustainable. Even when the nation has launched Housing for All, as the goal to provide pucca house to all Indian nationals having no permanent shelter, it will be prudent on the part of the government to include retrofitting as integral part of the PMAY, so that buildings constructed remain relevant and do not become obsolete in the fast changing physical and economic scenario.

Consultancy in Retrofitting also needs to be promoted to aid, advise, assist and guide the stakeholders in making buildings safe and to make value addition to existing buildings besides changing their usage. A dedicated fund needs to be created for focusing on R&D 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.

- **Redefining Construction Practices :** For construction sector to be really effective and efficient, its scope must not be limited to structural integrity and stability of buildings but should also include functional efficiency and 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, it will be rational to evolve a detailed mechanism of checks and balances for promoting best construction practices and adherence to process improvements.

  Learning from the collapse of Hotel New World, Singapore in March 1986, passed a legislation in the year 1989, which mandated all construction projects to undergo mandatory checks at the stages of design, construction and completion of buildings. It also 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, occupation and use of buildings; 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 the building. If periodic certification of buildings are conducted

based on highest professional standards at the design, construction and post construction phases, then any subsequent rectification work becomes minimal. Periodic post- construction checks are also known to help in making buildings more cost- effective over its entire life span because of low cost of maintenance involved 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 on priority, to ensure that construction and maintenance of buildings is carried out in a most professional manner and built environment is made safe, qualitative, productive, inclusive and sustainable.

References

1. The Future of Construction Sector in India, Build Tech Magazine India - September 9, 2016

2. McKinsey Global Institute: “India’s Urban Awakening: Building Inclusive Cities, Sustaining Economic Growth”, April 2010

3. World Green Building Council; https://www.worldgbc.org/what-green-building

4. Wikipedia; Green Buildings; sustainable construction principles

5. Wikipedia; Retrofitting; en.wikipedia.org/wiki/Retrofitting

****

Rehabilitation and Seismic Retrofitting

Dr. K. M. Soni

Former Additional Director General, CPWD

Prologue

Repair, rehabilitation and retrofitting are part of maintenance works taken up in an existing structure. All such maintenance works are essential for safety and durability of a structure. In case, maintenance of earlier stage is ignored, it leads to deterioration of structure and higher cost hence timely appropriate maintenance is essential for durability of a structure.

-Editor-

Introduction

Distressed structures need immediate rehabilitation as delay in rehabilitation accelerates the rate of corrosion in steel/reinforcement particularly under adverse conditions. Rehabilitation carried out along with repair and seismic retrofitting proves to be economical.

Seismic retrofitting is carried out in existing buildings, deficient from seismic design as per the latest codes. RCC structures are retrofitted with methods like jacketing, plate bonding and wrapping by FRP sheets or carbon fibre sheets. In load bearing structures, horizontal and vertical seismic belts at various locations are provided.

Durability of Structures

Durability of concrete structures in simple terms means the ability of concrete to last for a longer time without significant deterioration. Certain degree of deterioration is built in the design but the materials, process, placement and maintenance have to conform to the design requirements.

Some of the factors affecting durability are (Soni, 2018);

- Poor quality of concrete leading to porosity and ingress of water/

moisture leading to corrosion.

- Insufficient cover to the reinforcement.
- Excessive water/cement ratio used in concrete mix producing porous concrete.
- Plaster/cladding works started when concrete is green preventing liberation of heat without adequate curing leading to cracks.
- In cold climates, non provision of air entrained materials in concrete subject to freezing and thawing.
- Providing corroded steel lying in stock in original work.
- Alternate wetting and drying of concrete surface continuously widening micro cracks.
- Poor or inadequate maintenance leading to exposure of RCC surface.
- Poor compaction of concrete leading to porosity.
- Damaging protection layer of RCC members for installation of utilities and services like ACs, coolers, dish TV antenna etc.
- Leakage and seepage

Poor quality work during original construction cannot be maintained properly and will certainly lead to deterioration of structure before prescribed life as there is no substitute of standard quality work. Hence, quality has to be given high importance both during construction and maintenance stage for durability. Adequate, timely, and proper maintenance is also to be given equal importance.

Repair and Maintenance

Repair and maintenance are essential during life period of a structure. There is a periodicity of maintenance prescribed by many manuals, books and

codes. In case, maintenance is required before the prescribed periodicity, it indicates poor quality of work during its original construction or poor quality of maintenance works taken up earlier. Sometimes, wrong selection of materials during original construction also leads to early deterioration of structure or frequent maintenance.

In general, routine and regular maintenance of civil structures is not given due importance in the country. Maintenance cost of industrial and IT equipments may vary from 5 to 10% of its original or replacement cost whichever is higher still their maintenance is given due importance but same concept is lacking in civil structures, be public or private buildings, roads or irrigation structures even if maintenance cost may be 2-3% of replacement cost. Such a mindset leads to early deterioration of structures.

Rehabilitation and Seismic Retrofitting

Once a structure has shown the distress, it has to be rehabilitated. Rehabilitation means bringing the structure in its original condition and may include rehabilitation of structural and non structural components and as such is part of special repair. Rehabilitation requires major repair works hence is a costly affair. Normally, other types of repair works are also taken up with rehabilitation. If required, seismic retrofitting/strengthening works should also be taken up with such repair. Seismic retrofitting is structural strengthening of the existing structures from earthquake considerations as per the latest codes to achieve intended performance level.

In case seismic retrofitting is to be carried out after damage due to earthquake, a judicious decision is to be taken based on structural evaluation and financial implications on repair, rehabilitation and retrofitting works compared to new construction except in case of monumental, heritage and buildings of high importance which are to be preserved. NBC has laid down the criterion of taking up repair, rehabilitation and retrofitting works in case not exceeding 50% cost of reconstruction.

In case of structures deficient from seismic provisions as per latest codes or damage observed after earthquake occurrence, structural evaluation is to be carried out through condition survey and non destructive testing. Condition survey is carried out in four stages i.e. preliminary inspection, planning, detailed

visual inspection, and field and laboratory testing. Non destructive testing includes tests for in situ compressive strength like rebound hammer test, ultrasonic pulse velocity test, windsor probe test, pull out test, core tests and load tests. Tests due to chemical attack include carbonation tests, chloride test and sulphate test. Corrosion potential assessment can be made from cover meter/profo meter, half cell method, and resistivity meter. Normally a series of tests or a combination of tests are carried out based on condition assessment and importance of the structure.

Rehabilitation works may involve repair of structural components. Rehabilitation of slab, beams and columns pose major problems due to corrosion of reinforcement and damage of concrete which may be due to porosity, leakage and poor quality of original work. Rehabilitation works by way of additional reinforcement, concreting, guniting etc should not be carried out without removal of corrosion on the existing reinforcement, and application of anti corrosive coat on reinforcement and bonding coat on existing concrete surface. Also, it should be ensured that additional reinforcement provided in deteriorated structural members is properly bonded/anchored with existing reinforcement for integral monolithic action else wide cracks may appear in short period of rehabilitation i.e. within one to two years. Also, in case only rehabilitation works are being carried out, thickness of structural members should not be increased without evaluation and strengthening of foundation. In rehabilitation works, some members like columns and beams may require retrofitting and even some may be casted afresh depending upon site conditions.

Seismic retrofitting in RCC members can be done by the following methods;

- RCC jacketing
- Plate bonding
- Fibre wrapping

Jacketing of columns and beams is like wearing jacket over the shirt in a human body. As the jacket should be such avoiding cold air entering into the gap between jacket and shirt else it will defeat the purpose. Therefore, shirt and jacket should act like one entity. Similarly in case of RCC columns or beams,

jacketing should be such that it acts as a monolithic component of the existing member. To make it monolithic, shear keys are provided as shown in Fig. 1 or through welding reinforcement of jacketing to the existing one as shown in Fig. 2. Since RCC jacketing increases column/beam section, strengthening of foundation should also be taken up if not found suitable to take additional loads.

Fig. 1 RCC Jacketing with Shear Keys

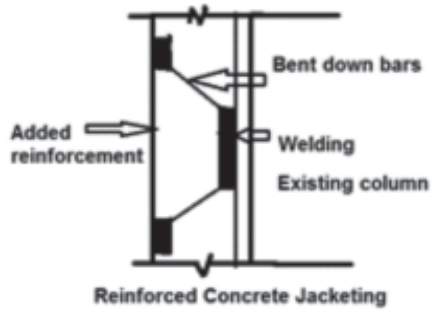


Fig. 2 RCC Jacketing with Welding

In case existing column is showing distress, rehabilitation should be taken up before seismic retrofitting by way of opening existing reinforcement i.e. removing cover, removing corrosion through sand blasting or any other method, anti rusting coat applied, extra reinforcement added as required for rehabilitation, bonding coat applied and then adding additional reinforcement and concreting. If the section used for jacketing is not enough for casting of conventional concrete, micro concrete may be used. Epoxy mortar/concrete, grouts, polymers and admixtures can also be used as per the requirements. Self compacting concrete (SCC) does not require compaction and as such SCC can be used for durability as compaction becomes difficult due to thin section being added to the members.

Plate boding is done normally by MS plate which is fixed on existing member to be retrofitted (Fig.3) and welding adopted for joining different pieces/ plates simultaneously anchoring with existing members. Nowadays, MS plate is not much used for retrofitting due to fibre wrapping materials available which have advantage of being light weight and easy in installation.

Fibre wrapping can be adopted without strengthening of foundation as the load of fibre sheets is not substantial. Wrapping works on the principle of

confining. Fibre sheets are wrapped around the columns/beams after applying adhesives (Fig. 4 & 5). Fibres may be of glass/plastic, or carbon. Carbon fibres have high strength. Paintings can be applied over the wrapped surface and advantage is that wrapping does not increase section due to thickness of fibre sheets being very less, thus saving the space inside building compared to jacketing.

Fig.3 Plate Bonding

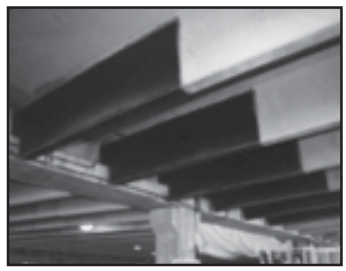


Fig. 4 FRP Wrapping

Fig. 5 Carbon Fibre Wrapping

Load bearing structures are retrofitted through fibre wrapping techniques or wire fabric anchored with wall thereafter covered with micro concrete. In place of lintel band, roof band, and plinth band, horizontal seismic belts, and for corner reinforcement, and around openings, vertical seismic belts are provided on both faces of walls. The wire fabric has to be necessarily anchored to existing structure. Thus the measures adopted in load bearing structures include seismic belt around door/window openings, horizontal seismic belts at plinth, lintel, and roof level, vertical seismic belts at external corners, vertical reinforcement at interior corners, inter connections of segmental arches if any, and strengthening of foundation, if required.

Horizontal seismic belts are provided on all walls on both the faces just above lintels of door and window openings and below roof (Fig. 6). Jack arches are tied together by welding MS flats/rods. Vertical seismic belts are provided at the external corners of the building and junctions of walls while rebar is provided in inside corners (Fig. 7) starting from 750 mm below the ground floor going up to the roof slab anchored to the wall. Plaster/micro-concrete is applied over the wire mesh/reinforcement.

Anchoring of welded steel wire fabric/reinforcement is essential to make it a monolithic part of the structure. In brick masonry, chemical anchoring is used. Retrofitting with wire fabric and micro concreting leads to creation of band

Fig. 6 Seismic Belt around Window Openings

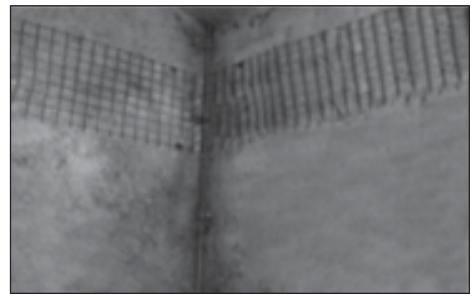


Fig.7 Rebar in Internal Corner

due to their thickness while wrapping with fibre sheets has advantage of not increasing thickness substantially and easy installation though it is costly.

There are very few contractors having expertise in carrying out rehabilitation and retrofitting works hence a special category of such contractors needs to be created. Further, a subject of rehabilitation and retrofitting should also be included at undergraduate level. Till then, capacity building should be carried out through training, conferences, seminars and articles.

Conclusion

In the country, large numbers of structures require rehabilitation and retrofitting due to non engineering construction, delayed maintenance and adverse weathering conditions resulting into distress of the structures. Rehabilitation and seismic retrofitting is required to be taken up to make the structures durable and safe during earthquakes. Material and methods of rehabilitation are to be selected based on type of structure, durability, cost of the rehabilitation, budget availability, and importance of structure.

Analysis, design, specifications of materials and methods of installation for rehabilitation and seismic retrofitting are required to be included in the codes and manuals/guidelines for engineers, architects and designers. Since rehabilitation and seismic retrofitting require highly technical skill and knowledge, an exclusive subject is required to be included at undergraduate level. Further, there should be a pool of specialised agencies having the knowledge of carrying out such works for the benefit of the public.

References

1. IS 13935-2009. Guidelines for repair, restoration, condition assessment and seismic strengthening of masonry buildings, Bureau of Indian Standards, New Delhi.

2. Rai, D C (2005), Draft code with commentary on seismic evaluation and strengthening of existing buildings, IIT Kanpur.

3. National Building Code 2016, Bureau of Indian Standards, New Delhi.

4. Soni, K.M. & Khatri, N.K. (2006), "Retrofitting of a Brick Masonry Bungalow in Lutyen's zone". New Building Materials & Construction World, Vol. 12, Issue 4,140-148.

5. Soni, K M (2007), "Retrofitting of a Brick Masonry Structure in Lutyen's Delhi". Civil Engineering & Construction Review, Dec issue, 64-71.

6. Soni, K M (2014), "Concrete and its Durability". Souvenir, 2nd International Congress on Durability of Concrete, New Delhi, 22-28.

7. Soni, K.M. (2015), "Rehabilitation and Retrofitting of Buildings". Civil Engineering & Construction Review, Vol. 28 No. 5, May issue, 46-51.

8. Soni, K M (2018), "Repair, Rehabilitation and Retrofitting", IBC Journal, Vol. IV, 36-46.

9. http://www.materialsperformance.com/articles/material-selection-design/2016/07/gas-plant-uses-carbon-fiber-reinforced-polymer-wrap-to-strengthen-concrete-columns

10. https://www.structuremag.org/?p=8643

11. https://www.indiamart.com/proddetail/carbon-fibre-wrapping-3361243588.html

12. https://www.horseen.com/steel-plate-bonding-system/perfusion-steel-plate-bonding

13. https://theconstructor.org/practical-guide/jacketing-collars-concrete-column-beams-repair-strengthening/5829/

****

Repair, Rehabilitation and Retrofitting of Cities

A.K. Jain

Former Commissioner (Planning), DDA

Prologue

According to the 6th Report of the IPCC (2021), in the next 20 years the global temperature rise will cross the 1.5° Celsius limit. This will increase the intensity of heavy rain events, concentration of carbon dioxide, sea level rise and warming of the built environment affecting the health and productivity.

In India, construction contributes 8.2% of the GDP and 11.52% of jobs. According to Inter-governmental Panel on Climate Change, urban areas account for 67% to 76% of global energy use and 71% to 76% CO_2 emissions. The buildings in India account for 40% of energy use, 30% of raw material use, 20% of water use and 20% of land. They generate 30% of solid waste, 29% of liquid waste and 24% of CO_2 emissions, contributing to climate change and poor air quality. Therefore we need to rethink the approaches of development, construction and repair which is based upon the concept of renewal, recycling and re-engineering and aim at net zero water & energy consumption.

-Editor-

Introduction

With the emerging issues of sustainability, climate change, air and water pollution, disasters, pandemics and shortages of infrastructure services, etc., it is necessary to rethink the approaches of development and construction. Not only the buildings but cities need to be based on circular concepts of renewal, recycling and reengineering and aim at net zero water, energy and land consumption. This involves environment sensitive recycling of land and buildings, readjustment, rezoning and repurposing of old, dilapidated structures.

The lexicon of urban development must be replete with a series of Rs, as given below:

- Restructuring and Urban Renewal
- Recycling, Readjustment, Rezoning and Repurposing
- Rehabilitation of Slums and Regularisation of Unauthorised Colonies
- Rejuvenation of Water Resources
- Re-engineering of Urban Services
- 5 Rs Strategy of Waste Management
- Recovery of Air Quality
- Removing Roadblocks and Grid locks
- Renewable Energy
- Resilient and Green Buildings
- Reforms for Gender Equity and Lifestyles

Restructuring, Redevelopment and Urban Renewal

Often a question is raised, whether to go for greenfield development or renewal of existing cities. This needs to be seen in the context of potential of jobs, land, economics, ecological and social aspects. New cities take a long time and heavy investments to become livable. Naya Raipur started 20 years ago is still a ghost town. Amravati, the new capital of Andhra Pradesh, is facing various hurdles in its development. Broad differences between greenfield development and brownfield redevelopment are shown in Table below:

Table: Comparison between Greenfield and Brownfield Redevelopment

Greenfield Development	Brownfield Redevelopment
• Costly and time-consuming land acquisition	• No land acquisition involved
• Huge footprint of buildings	• Minimum footprint added
• Freedom to plan and design	• Compromise with planning norms and regularization of unplanned development
• Services to be laid de-novo	• Services upgradation

• Disruption of community, jobs and economy	• Minimum dislocation of people and jobs, social, community and cultural relationships continue
• Financial investments	• Less expensive, private and community investments, self-financing
• Provision of open spaces, parking and roads	• Lack of open spaces, parking and wider roads
• Usually PPP, no community engagement	• Redevelopment with community participation and engagement
• White elephant and ghost town syndrome	• Lively and vibrant.

In Delhi, following is the rough estimate of the extent of built-up residential areas:

- 36000 acres – planned residential area
- 12000 acres – unauthorized / regularized colonies
- 1000 acres – government land available for social housing
- 2390 acres – slums & JJ clusters
- 6000 acres – resettlement colonies
- 30,000 acres under Transit Oriented Development (500m distance from metro stations)

These offer scope for redevelopment and densification of built-up areas and amalgamation of fragmented plots for composite Group Housing with common greens and parking. This involves upgradation of infrastructure services, facilities and open spaces.

The densification and urban restructuring can lead to travel reduction, economy of services and conservation of agricultural areas. The densities of Indian cities can be selectively doubled along public transit corridors, excluding

the archaeological, heritage and conservation zones. The focus has to be on redevelopment of the brownfields, infrastructure services, transportation, public greens and facilities (Fig. 1, 2 & 3).

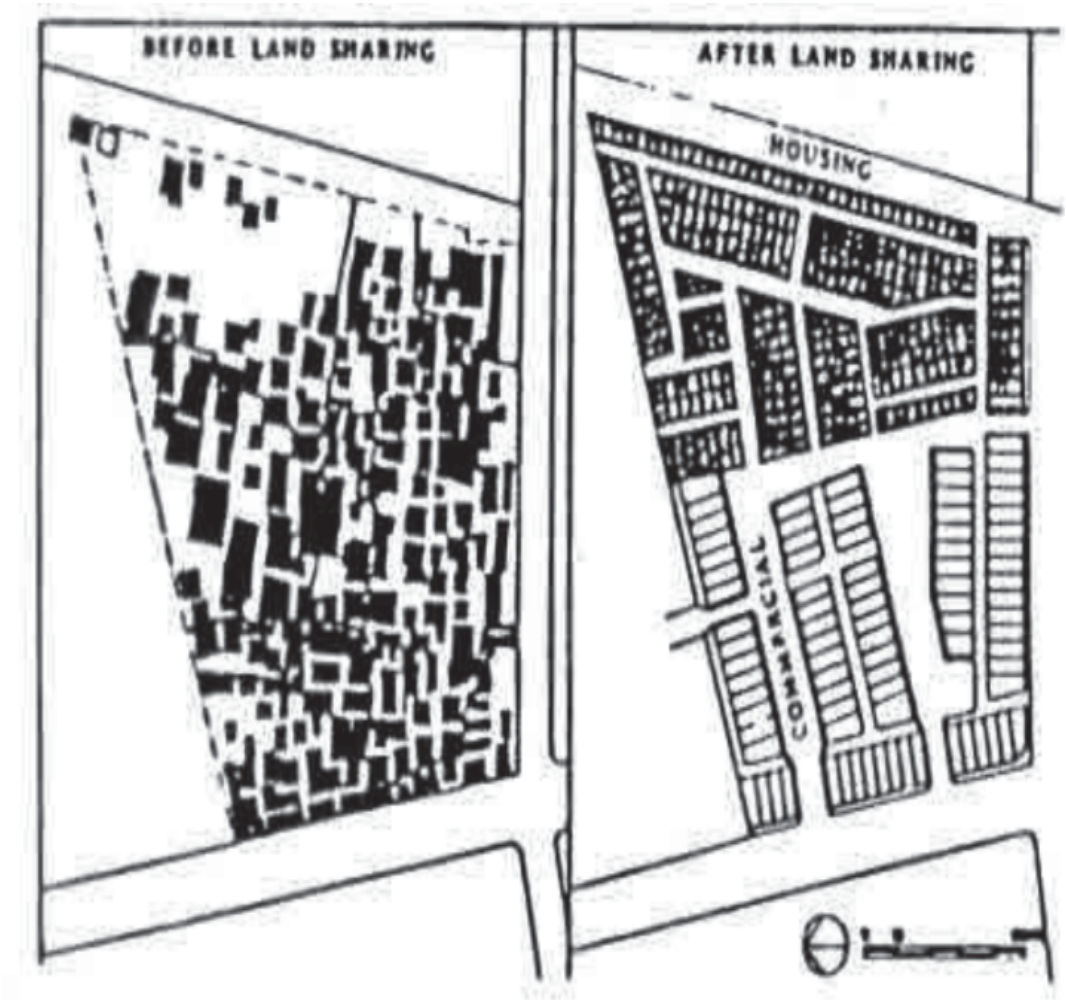


Fig. 1 Land Recycling and Resharing

Source: Jain A.K. (2021) Housing and Community Planning, Discovery Publishing House, New Delhi

Fig. 2 Redevelopment of Kidwai Nagar, New Delhi

Source: NBCC

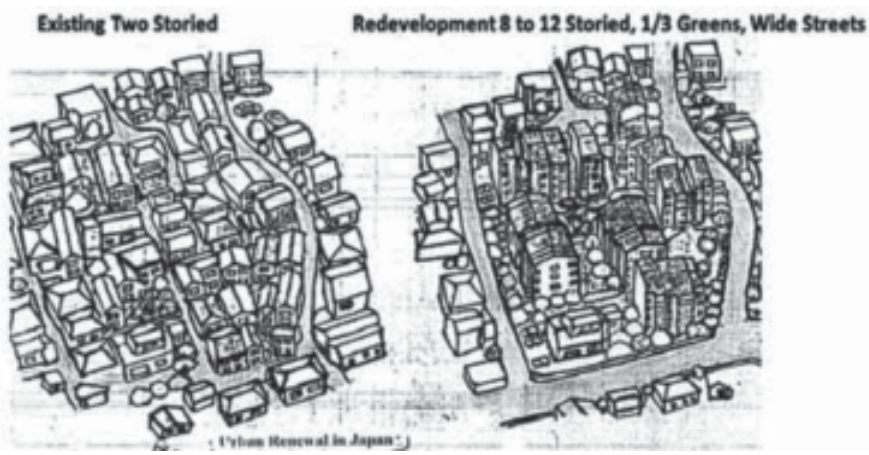


Fig 3: Redevelopment and Redensification of Dilapidated and Congested Areas

Source: Jain A.K. (2021) Housing and Community Planning, Discovery Publishing House, New Delhi

Recycling, Readjustment, Rezoning and Repurposing

Lands under agricultural use are being increasingly getting converted and annexed for uses like expansion of highways, airports and habitation. The rate of conversion shows that an additional 2 to 3 million hectares would be required for human settlements during next 10 years. Sacrificing agricultural land for habitation implies reduction of land for producing food for the ever-growing population. Agricultural land sustains biodiversity, water quality and groundwater recharge, fragile areas, sensitive areas, coastal zones, etc. which need protection and conservation. Land needs to be judiciously utilized according tothe inherent sustainability and its suitability for the particular land use. The development of greenways along natural water drainage corridors and harvesting of rainwater in balancing lakes and ponds can be a new frontier in urban development. The water bodies, greenery and open space in windward direction and cooler surface materials (roads, parking, buildings, roofs, etc.) can help in mitigating the effects of urban heat island.

Remote Sensing and Digital Planning

Lack of digital Land Information System is a major hurdle in planning and implementation. There is a need to adopt information communication technologies (ICT) based digital ledgers for data management, Land Admin Domain Model (LADM), geographic information system (GIS), electronic data capture, web-based applications, satellite/Total Station/Drone surveys, national spatial data infrastructure (NSDI) and e-governance.

For efficient and sustainable urbanism intelligent and smart systems viz, Big Data Analytics, Supervising Control Data Acquisition Systems (SCADA), ERP solutions, GIS, Integrated Digital Control/Command Centres and Satellite Surveillance need to be used for planning and development. The technological solutions have to be based on public engagement and collaborative partnerships. The adoption of Remote Sensing in real time for pollution control, water supply, energy, construction and land management can be a better tool.

A digital ledger is a geographically distributed database that is shared and synchronized across a network of the participants. It has a block chain structure where the data is stored in blocks, linked and secured by cryptography for handling identities, contracts and assets. The block chain is an

electronic transactions system. It is based on a hash algorithm that converts data into a block. Digital Block chain system for land registration is indispensable for land management in order to expedite property transactions and curb the frauds and power of attorney transactions.

Rehabilitation of Slums and Regularisation of Unauthorised Colonies

About half of the urban population lives in the slums and informal settlements, jhuggi jhompri clusters, unauthorised colonies, villages and unplanned settlements. For regularisation and grant of in-situ ownership rights in the illegal colonies, the MOHUA vide its notification dated 29th October 2019 has enacted the NCT of Delhi (Recognition of Property Rights of Residents in Unauthorised Colonies) Regulations, 2019. Their regularisation and upgradation aim at improving the quality of life of the residents by participatory planning, better facilities, safe structures, accessible roads and services.

The Master Plan of Delhi (MPD 2021) provides a framework for redevelopment of unplanned areas by allowing the amalgamation of the plots to a minimum combined area of 1670 sqm with an FAR up to 1.5 times of entitlement or 400 and a minimum street width of 7.5 m. Additional floor area ratio (FAR) would mobilise the owners/tenants to form a small cooperative for a composite redevelopment, along with widening of roads, parking spaces and the structures conforming to fire and structural safety standards. As such, by amalgamation of fragmented, small plots, it would be possible to create better streets, open spaces and facilities, together with safe structures.

Instead of promoting a single development model for improving housing and living conditions, a range of options can be assessed and considered:

- **Repairs, Rehabilitation and Retrofitting:** Repairs, Rehabilitation and Retrofitting of the housing is a way of upgrading the physical environment and basic services in existing communities. Besides improving the physical conditions and quality of life, the physical improvements can act as a spring board for income generation, social welfare, etc.

- **Relocation:** The advantage of the relocation strategy is that it usually comes with housing security through land use rights,

outright ownership of some kind of long-term land lease. But relocation sites are often far from existing communities, job opportunities, support structures and schools. Community members who want to keep their old jobs or attend the same schools must bear the burden of additional traveling time and expense and must adapt themselves to a new environment. In cases of relocation, communities face the cost of reconstructing their houses at the new site and their social network are severed. However, tenure security and new buildings tend to be big incentives to invest in relocation projects.

- **Resharing of Land:** Land sharing is a Slum/JJ clusters improvement strategy which mutually benefits both the land-owner and the community living on that land. By land resharing, the community gets secure tenure via long term leasehold, and the people can design and develop/redevelop construct their housing, services and facilities.

- **Reconstruction:** In this strategy, existing Slum/JJ communities are rebuilt on the same land, or nearby. The security of land tenure provides the community an incentive to invest in their housing. Although the reconstruction option involves making considerable physical changes and adaptations, the strategy allows people to continue living in the same area and to remain close to their places of work, which is a crucial compensation.

- **Reblocking:** Reblocking is a systematic way of improving the infrastructure and physical conditions in existing communities by making adjustments to install sewers, drains, walkways, parking and roads in such a way that ensures the continuity of the community. Communities can develop their housing gradually at their own pace. When communities opt for reblocking, some houses may have to be moved and partially or entirely reconstructed to improve access or some lanes may have to be widened and realigned to enable power, drainage lines, water supply systems or sewers to be laid. Reblocking can bring illegal colonies into formal planning framework for composite development, together with land tenure security.

Reengineering of Urban Services

Surveys of Indian cities reveal that approximately 60% of the population is not covered by sewerage system, the treatment facilities are inadequate. Various alternative technologies, based on decentralized services, like Extended Aeration Technique, Bio-gas production, Bubble Diffusion Process, Flotation, Anaerobic reactors, etc. can be explored for urban sanitation.

Common utility ducts or tunnels carrying electricity, water, waste, cable television and internet network minimize damage from traffic, road repairs, rains, etc.. A series of low carbon zones across the city with co-located tri-generation energy systems (combining power, cooling and heating), dual piping for recycled water and automated, segregated waste collection and recycling can lead to bundling 'green infrastructure' together.

Engineering role ought to change given technological advances in building and urban services, materials, construction systems and operations that help mitigate climate change. For sustainability, the stress should be on least consumption of resources, following the dictum of doing more with less (Fig. 4, 5, 6 & 7).

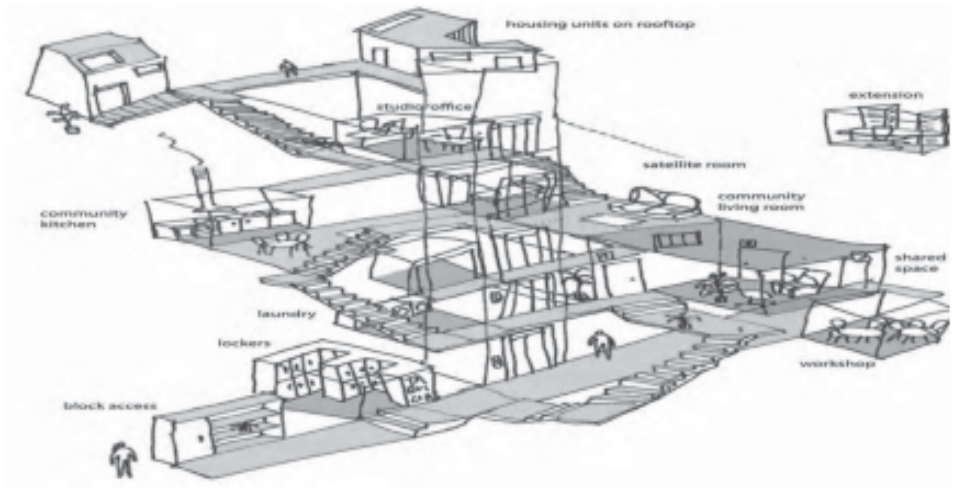


Fig. 4 Rezoning and Repurposing by Mixed Land Use

Source: www.npr.org/Jain A.K. (2021) Environment, Urbanisation and Development, Discovery Publishing House, New Delhi

Fig. 5 Repair, Rehabilitation and Retrofitting

Source: Aga Khan Trust for Culture

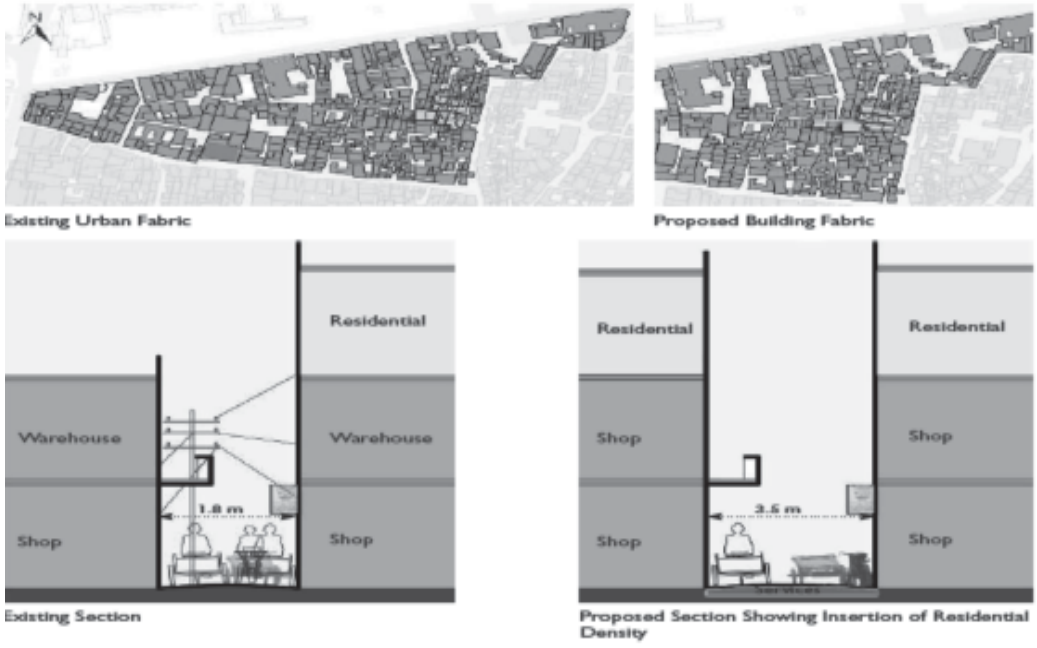


Fig. 6 Proposed Redevelopment of Kashmere Gate

Source: DUAC/ Ashok B. Lal

Fig. 7 Slum Resettlement under Mumbai Urban Transport Project

Source: World Bank/MUTP

Rejuvenation of Water Resources

Several cities in India have become water stressed. Only 18% of the renewable water resource is being used. India, though endowed with a good monsoon and ample rainfall, uses only 10% of the annual rainfall. The parameters of concern are increasing coliform levels and Bio-chemical Oxygen demand (BOD) in surface waters and increased concentration of nitrates in the groundwater. To overcome the health problems, water sources need to be protected by interception, recycling and treatment of waste water. Water resources can be augmented through recharging of groundwater resources, rainwater harvesting, conservation of rivers and water bodies, dual plumbing and recycling of waste water.

5 Rs Strategy of Waste Management

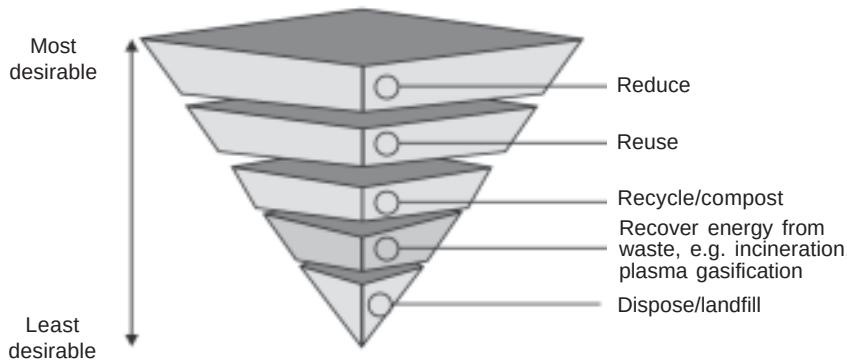


Fig. 8 Strategy of 5 Rs for Waste Management

Source: Ottawa.ca

The strategy of the waste management begins with the simple, workable actions, as given below**:**

- **Refuse:** Whenever and wherever possible, choose items that are not packaged in plastic and carry your own bag, container and utensil. Heavy tax and penalty on plastic carry bags, styrofoam, single use plastics, bottles and straws can diminish their use. Plastics can be replaced by more sustainable options like reusable steel, glass bottles and non-disposable utensils. Disposable sanitary napkins can be replaced by menstrual cups and cloth pads.

- **Reuse:** Choose glass, paper, stainless steel, wood, ceramic and bamboo over plastic and non-toxic straws, utensils, to-go containers, bottles, bags, etc. which can be reused.

- **Reduce:** Reduce waste by half by cutting down the consumption of goods that contain excessive packaging. The Ministry of Drinking Water and Sanitation, Government of India has requested various Government departments to avoid the use of plastic bottles for drinking water during meetings. The States of Maharashtra, Uttar

Pradesh, Bihar and Sikkim have banned the plastic carry bags and have restricted the usage of plastic water bottles in Government functions and meetings. The 2015 National Games of India (Thiruvananthapuram) aimed at "zero-waste" venues to make the event "disposable-free" and banned the usage of disposable water bottles, plastic tableware and tumblers.

- **Recycle:** Waste can be recycled keeping in view the entire life-cycle of items, from source to manufacturing, distribution and disposal. Waste plastic (HDPE) can be recycled into plastic timber, pallets, tiles, waste containers, liners, railway sleepers and construction materials. Recycled plastic can also be used for road surfacing which can help to reduce the pollution. It is necessary to adopt ecosystem-based adaptive management for solid wastes. Construction and demolition waste can be recycled into structural members, steel girders, beams, joists, aluminium framing, bricks, roofing tiles, concrete blocks, paving blocks, windows and door panels, etc,

- **Recovery:** The waste has potential to yield energy, fuels and raw materials for industry, buildings, roads, etc. As the organic matter decays, it produces biogas, known as landfill gas (LFG), which can be used as useful energy. Indian municipal waste has a potential to generate 150-250 cum of biogas/LFG per ton depending upon the quality of wastes. By employing a set of generator and transformer, bio-gas can be converted in electrical energy.

Recovery of Air Quality

According to the surveys conducted by the CPCB ambient air quality in Delhi and various other cities has reached a very critical situation. Relatively high frequency of suspended particulate matter, dust, SPM, SO_2, NO_2, CO_2 and heavy metals, including lead content in the exhaust of automobiles and scooters have been observed. The recent changes in the fuel like electric and hydrogen vehicles, adoption of clean technologies, new emission norms, shared taxis, Non Motorised Traffic (NMTs) and development of mass rapid transport systems can reduce the pollution levels due to vehicular emissions.

Removing Road Blocks and Grid Locks

Urban transport contributes nearly two-thirds of the total suspended particulate matter and 18 per cent of carbon emissions. Prime Minister Narendra Modi, while inaugurating the Global Mobility Summit in September 2018, encapsulated 7 Cs of mobility-common, connected, convenient, congestion free, charged, clean and cutting-edge. He underlined the need to use clean energy for transport as a powerful weapon against climate change, along with a pollution free, clean idea of clean kilometres through bio-fuels and hybrid electric vehicles. The MOHUA has issued Metro Rail Policy (2017) and Transit Oriented Development Policy (2017), which provide guidelines for preparing comprehensive proposals for promoting urban public transit.

It is time to think of sustainable modes of transit and provide Integrated Transit Corridors (ITC) integrating BRT, Metro and trains linked with pedestrian and cycle lanes. These can be flanked by public, semi-public, high-density, high-rise development. Metro, trains, sub-way and primary roads can run underground for easy bike and pedestrian traffic on the grade. Besides controlling growth of private vehicles, it is necessary to explore parking space in stilts, multi-level puzzle/skeleton structures, on roofs and in underground spaces. Seamless multimodal public transport system comprising bus rapid transit, rail-based mass transport system would work only by adoption of single ticketing and restructuring of land uses by transit-oriented development. Subterranean garages near commuter destination reduce the need for ground parking. Digital parking meters tell mobile phone when a space opens up, reducing traffic caused by drivers trolling for space.

The concept of walk to work, transit-oriented development, travel demand management, smart growth, corridor pricing, promoting NMTs, hybrid electric vehicles, multi-modal integration, last mile connectivity and the establishment of a Unified Transport Authority are the pillars of sustainable urban mobility.

Renewable Energy

Energy scenario in India is characterised by increasing demand for energy growing at the rate of about three times the rate of population growth in the last two decades. At the United Nations Conference of the Parties (COP 26) in Glasgow (November 2021) Indian delegation led by PM Narendra Modi put

forward the need to scale up clean technologies and formation of the International Solar Alliance (ISA). The One Sun, One World One Grid envisions an interconnected trans-national solar energy grid. The COP 26 agreed to reduce the use of fossil fuels and coal by new sources, such as green hydrogen, green metals, carbon capture, solid state batteries, electric fuels, heat pumps and next generation solar PV. PM Modi informed that India's non-fossil fuel energy will be raised to 500 GW by 2030 and 50% of the power requirement will be met by renewable energy. India will achieve net zero emissions by 2070 by clean technologies, like electric transport, ethanol blending in gasoline, solar photovoltaic and batteries.

Low carbon energy can be derived from renewable sources, such as biofuels, wind, tidal and solar power. The concept of energy efficiency, renewable energy and Zero-fossil Energy Development (ZED) can reduce the level of energy demand and slow down the rate at which resources are depleted. The renewable energy not only helps in energy generation, but also in a pollution-free environment.

The energy guzzling air-conditioning can be avoided by innovative methods like Net Zero Energy Design, variable refrigerant volume (VRV) system, earth air tunnel (EAT) and thermal storage. By HVAC and EAT systems inside temperature of building can be maintained within 27 degree Celsius during summer and 19 to 24 degree Celsius during winter. Green roof, light coloured finishes and insulation can help to reduce energy demand.

Resilient and Green Buildings

Resilient and low carbon building limits the use of fresh resources by resorting to recycling and reuse. An energy efficient building is closely linked to conserving fossil fuel usage. The heating, lighting, cooling, ventilation and powering of buildings are responsible for approximately 40% of the total energy use. Incorporating energy storage into them will increase the resilience of the total energy distribution network and enable widespread use of renewable energy.

The use of energy can be reduced by day lighting design, courtyards, green roof, ventilation, and integration of renewable energy sources. By passive design the building can be more climatically comfortable. It is also necessary to

specify building materials which are locally sourced and recycled from reclaimed construction and demolition wastes, that have low embodied energy and require less energy for transportation to the site.

Building Information Modelling (BIM) can simulate the entire construction sequence beforehand, addressing sustainability issues and reducing carbon emissions. Automated procedures can be adopted for dust free, speedy and more precise building construction. Computer-Aided Manufacturing (CAM) and Computer Integrated Manufacturing (CIM) for prefabricated components, viz. ceilings, walls, roofs, etc. are useful in reducing emissions, dust and greenhouse gases.

Reforms for Gender Equity and Lifestyle

The repair, rehabilitation and retrofitting strategies cannot succeed without involving the women, who comprise nearly half of the population. A sustainable and resilient city has to be gender sensitive with adequate, safe and affordable spaces for living, working and vending by the women.

Reforming the lifestyle requires a change in social norms and rethinking the ways of living based on the principles of organicity, non-accumulation (aparigraha), minimalism and slowing down. It is also about caring, sharing, recycling and living, working and moving in balance with the natural environment.

Conclusion

Urban India is passing through massive construction of mega projects, rapid economic and social transformation, leading to increasing carbon footprints, climate change and disasters. It is faced with increasing pollution, transport, energy and water consumption. It is necessary to relook the repertoire and processes of urban development which should shift to circular concepts of urban renewal, recycling and conservation of natural resource, leapfrogging in the areas of new technologies and fourth industrial revolution.

References

1. CPCB, Status of Water & Wastewater Generation, Collection, Treatment & Disposal in Class I Cities, New Delhi

2. CPHEEO (2014) Water Supply and Sanitation, New Delhi.

3. DDA (2004) Report of Committee on Making Delhi Slum Free (Madhukar Gupta Committee), Unpublished, New Delhi

4. Delhi Pollution Control Committee (DPCC) Real Time Ambient Air Quality Data of Delhi, India: http://www.dpccairdata.com/dpccairdata/display/index.php.

5. Ehrlich Paul R, (1968) the Population Bomb, Sierra Club/ýBallantine Books, New York

6. IEA, (2008) India Energy Efficiency Policies and Measures: Energy Conservation Building Code, http:// www.iea.org/textbase/pm?mode=pm&id=4162&action=detail.

7. ICLEI (2007) Preparing for Climate Change: A Guidebook for Local, Regional and State Government, Washington.

8. Indian *Network for Climate Change Assessment* (2011) 'Ministry of Environment and Forests, Lodhi Road, New Delhi,

9. IPCC (2021) Climate Change Working Group, Impacts Adaptation and Vulnerability, IPCC, Cambridge University Press, UK and New York.

10. IPCC (2014) Climate Change Working Group, 6th Assessment Report, Cambridge University Press, UK and New York

11. Jain A.K. (2021) Environment, Urbanisation and Development, Discovery Publishing House, New Delhi

12. Jain A.K. (2021) Housing and Community Planning, Discovery Publishing House, New Delhi

13. Jain A.K. (2017) Urban Transformation, Discovery Publishing House, New Delhi

14. Jain A.K. (2018) City Planning for a Changing India, Bookwell Publishers, New Delhi

15. Jain, A.K, (2009) Low Carbon Cities-Policies, Planning and Practice, Discovery Publishing House, New Delhi.

16. Jain, A.K. (2015) Smart Cities: Vision and Action, Discovery Publishing House, New Delhi,

17. Jain, A.K. (2015) River Regeneration and Water Resources. Discovery Publishing House, New Delhi

18. MOHUA (2015) Urban and Regional Development Plan Formulation and Implementation Guidelines, New Delhi

19. Narain, Sunita (2002) The Flush Toilet is Ecologically Mindless, *Down To Earth,* New Delhi, Feb.

20. Satterthwaite, D. (2008) Cities' contribution to global warming: Notes on the allocation of greenhouse gas emissions. Environment and Urbanization, 20 (2).

21. UNFCCC (2010) United Nations Conference on Climate Change, Proceedings, Mexico

22. UN-Habitat (2011) Cities and Climate Change, Global Report on Human Settlements, Earthscan, UK/USA/Nairobi.

23. United Nations General Assembly (2015) Sustainable Development Goals-2030, United Nations, New York

24. WRI, C40 and ICLEI (2015) Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, Washington

25. United Nations COP 26 (2021) Proceedings (Web site) Glasgow

****

Post-Disaster Building Damage Assessment Using Remote Sensing Techniques

Dr. Saurabh Gupta

Ph.D. Scholar, Indian Institute of Technology

Prologue

Natural disasters can be predicted but cannot be controlled. Earthquakes, tsunamis, cyclones are among the most catastrophic natural disaster which affects the humankind. Disasters not only affect human life but also damage the infrastructure. The estimation of damages in infrastructures plays a critical role in finding out the area and the amount of work, that needs to reconstruct. One of the major problems is to analyse accurate damages in buildings rapidly. The accurate analysis of destruction helps engineers and planners to provide a plan for rehabilitation in the affected area. The different remote sensing techniques used in building damage detection are helpful in this regard.

-Editor-

Introduction

The first important task after the occurrence of natural disaster is to make immediate assessment of damages. This data will support various organization to respond quickly, and that may reduce the number of casualties. For the same Naito et al., 2020 has developed a real-time damage assessment system to estimate the damages in building within 15 minutes after an earthquake occurs using satellite data. The real-time damage assessment and detection system is the primary sources during the period initial disaster response. The planning and assessment help in short-term and long-term recovery. Sometimes, damage detection and estimation are not so accurate, and shows variation from ground reality, this uncertainty is due to different data collection and data interpretation techniques. Thus, study of various data collection techniques and data interpretation techniques is necessary.

In this article a literature analysis is presented for the various remote

sensing techniques and presented a framework. In addition this article also discusses about different methods for data interpretation.

Literature Survey

The use of remote sensing for building damage detection is not novel. In the last two decades, many researchers used various remote sensing techniques to estimate damages in buildings. Satellites have different types of visual and non-visual wavelength bands, such as SAR (Synthetic Aperture Radar), high-resolution imagery, multi-spectral, and hyper-spectral shows capability of observing earth to collect various valuable information. On the other hand, data can also be collected from MAV (Manual Aerial Vehicle) and UAV (Unmanned Aerial Vehicles) using high-resolution cameras and LiDAR (Light Detection And Ranging). The literature from the last two decades is discussed in Table 1.

Table 1 Summary of Remote Sensing Methodologies used in Building Damage Detection

S.no.	Author	Disaster	Year	Methodology
1.	(Turker and Sumer, 2008)	Izmit, earthquake, Turkey	1999	Post-earthquake aerial images collected and further processed using image enhancement and edge detection. Polygons are created over different buildings, and using a watershed segmentation method, the damage is assessed.
2.	(Sui *et al.*, 2014)	Beichuan earthquake, China	2006	Aerial images are captured using camera mounted UAV. DSM (Digital Surface Model) is created for pre-disaster data and post-disaster data and compared to check the damage in buildings. The data is segmented, and shape and texture-based data is extracted and compared for pre and post-disaster events to estimate damage in buildings.
3.	(Pham *et al.*, 2014)	Haiti earthquake	2010	Both LiDAR data and images captured using an aerial survey. DEM (Digital Elevation Model) and, DSM obtained from LiDAR data. The image data is then

				georeferenced and orthorectified with LiDAR data. Image segmentation and classification using e-Congition software. The result then evaluated with the help of ArcGIS software having an accuracy between 70-79%.
4.	(Janalipour and Mohamma dzadeh, 2016)	BAM earthquake, Iran	2004	Pre and post-event image data collected and merged with the old vector map. Then the image is georeferenced to create a building polygon map. The image is then classified and labelled, and geometric features extracted, to determine damage in building, the sensitivity analysis is performed using ANFIS. The overall accuracy of 76.36% and a kappa coefficient of 0.63.
5.	(Anghel *et al.*, 2016)	Chastel landslide	2012	The methodology based on combining SAR data with LiDAR point cloud data. The point cloud data is comprising of GPS (Global Positioning System) and topographic data.
6.	(Ye *et al.*, 2017)	Yushu earthquake	2010	Satellite high-resolution images is used along with the building polygon. The building is analysed for roof edge and roof interior, which improves accuracy. Colour coded buildings based on the damage. Overall accuracy 84.10%.
7.	(Nex *et al.*, 2019)	Indonesia, 2016; Nepal, 2015; Italy,2009; Haiti, 2010; Nepal,2015; Taiwan, 2016.	2010 - 2016	Satellite data, Airborne data, UAV data, sets collected, and analysed. Trained and tested using CNN (Convolution Neural Network).
8.	(Li *et al.*, 2019)	Hurricane Sandy,US	2012	UAV mounted camera is used along with machine learning.
9.	(Xu *et al.*, 2019)	Haiti earthquake	2010	Comparison between pre and post-earthquake satellite data using CNN.
10.	(Erdogan and Yilmaz, 2019)	Van City earthquake,	2011	Aerial camera used to capture images and comparison between pre and post-

				earthquake DSM models based on geometric properties such as area, the perimeter is extracted.
11.	(Merlin and Jiji, 2019)	Nagapattinam, Tsunami, India,	2004	Comparison of pre and post Tsunami high resolution imagery satellite data, using image analysis.
12.	(Naito *et al.*, 2020)	Kumamoto earthquake	2016	Fixed-wing UAV is used to capture images, and two machine learning methods bag-of-visual-words model and a CNN model were used for determining damages in 4 different levels based on the damage.

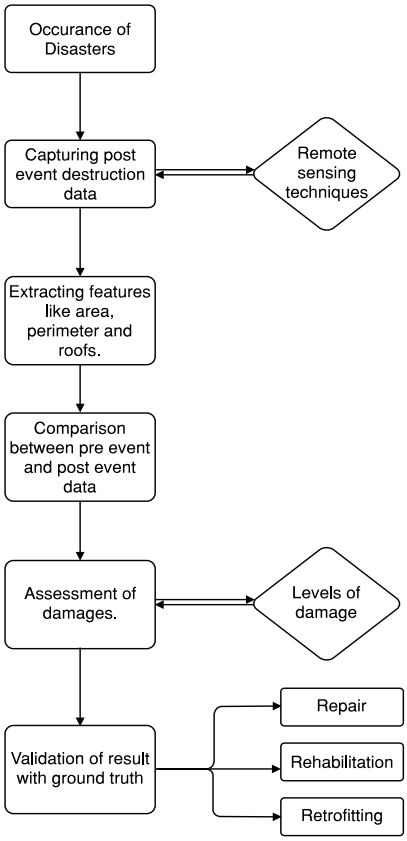


Fig. 1 Basic Framework for Building Damage Detection

In Table 1, the literature of various remote sensing techniques is briefly discussed. The interpretation techniques show the promising result with an accuracy between 80-90%. From the table, we can conclude that various methods, follow a common approach. The framework for the same is illustrated in the flow chart in Fig 1.

As explained in the flow chart, as soon as the disaster occur, we need to decide at the present situation which one of the remote sensing techniques will be appropriate and accurate. That depends on the funds, availability and expertise (Dong and Shan, 2013). Once the techniques is finalized, the data is captured and further processed. Features like polygon, area, perimeter, roofs are extracted. These features are then compared with the pre-event data. This gives a certain estimate of damages that can be evaluated with the ground reality to find the accuracy of developed methodology.

The output gives a guideline to the administration for the structure that require repair or rehabilitation or retrofitting.

Table 2. Remote Sensing Techniques, and Interpretation Techniques for Building Damage Assessment

Adopted remote sensing techniques	Adopted data interpretation methods
• Satellite Imagery • LiDAR • High-resolution camera with MAV • Camera with UAV	• Image processing • Machine learning (ML) • Deep Learning (DL) • Computer vision • Surface models (DEM, DSM) • Bundled software.

Mainly SAR data is used in Satellite Imagery; besides radar, remote sensing's for the weather, it can also collect data for urban mapping. The sensitivity is enough to capture heights of building in pre and post-event data. The resolution can be up to 1m for the latest generation of VHR spaceborne SAR sensors like TerraSAR-X and COSMO-SkyMed useful for urban area analysis at the building level.

Airborne LiDAR systems allow fast and extensive acquisition of precise height data, which can be used for detecting some specific damage types (e.g., pancake collapses) that cannot be identified from 2D images. Since LiDAR is a relatively new technology, and many places do not have LiDAR coverage, little research using real pre-event and post-event LiDAR data for building damage detection has been conducted.

MAV has the benefit of capturing data of the very large area with single scan and can carry a load lot more than UAV while UAV is readily available and requires less flight planning. In disaster like a cyclone, hurricanes, UAV is more suitable than MAV to collect data. UAV is also cost effective for data collection.

Similarly, many data interpretation techniques are discussed in Table 2. Image processing is the oldest method and is the backbone for all other processes. Machine learning and Deep learning are based on learning algorithms, and researchers used supervised learning to train the classifiers and tested on actual data.

Conclusion

The in-depth analysis of building damage detection methods has demonstrated, that these were designed as per the characteristics of the applied data, and the affected area is almost all types of natural disasters. Thus, a quantitative comparative evaluation of all these methods is challenging because they cannot be tested with one or more sets of experimental data. Nonetheless, some conclusive remarks common to the recent developments and findings of most studies can be drawn from the above review.

Diverse remote sensing techniques and related GIS (Geographic Information System) data are utilized in building damage detection. The remote sensors vary from airborne to spaceborne. The data types include optical, SAR, LiDAR, and vector maps. The resolution also varies from 10 to 0.3m. The advantages of various data have made them useful for different scenarios and purposes.

References

1. Anghel, A. *et al.* (2016) 'Combining spaceborne SAR images with 3D point clouds for infrastructure monitoring applications', *ISPRS Journal of Photogrammetry and Remote Sensing*. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS), 111, pp. 45–61. doi: 10.1016/j.isprsjprs.2015.11.008.

2. Dong, L. and Shan, J. (2013) 'A comprehensive review of earthquake-induced building damage detection with remote sensing techniques', *ISPRS Journal of Photogrammetry and Remote Sensing*. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS), 84, pp. 85–99. doi: 10.1016/j.isprsjprs.2013.06.011.

3. Erdogan, M. and Yilmaz, A. (2019) 'Detection of building damage caused by Van Earthquake using image and Digital Surface Model (DSM) difference', *International Journal of Remote Sensing*. Taylor & Francis, 40(10), pp. 3772–3786. doi: 10.1080/01431161.2018.1552816.

4. Janalipour, M. and Mohammadzadeh, A. (2016) 'Building Damage Detection Using Object-Based Image Analysis and ANFIS from High-

Resolution Image (Case Study: BAM Earthquake, Iran)', *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. IEEE, 9(5), pp. 1937–1945. doi: 10.1109/JSTARS.2015.2458582.

5. Li, Y. *et al.* (2019) 'Building damage detection from post-event aerial imagery using single shot multibox detector', *Applied Sciences (Switzerland)*, 9(6). doi: 10.3390/app9061128.

6. Merlin, G. S. and Jiji, G. W. (2019) 'Building Damage Detection of the 2004 Nagapattinam, India, Tsunami Using the Texture and Spectral Features from IKONOS Images', *Journal of the Indian Society of Remote Sensing*. Springer India, 47(1), pp. 13–24. doi: 10.1007/s12524-018-0858-z.

7. Naito, S. *et al.* (2020) 'Building-damage detection method based on machine learning utilizing aerial photographs of the Kumamoto earthquake', *Earthquake Spectra*, pp. 1–22. doi: 10.1177/8755293019901309.

8. Nex, F. *et al.* (2019) 'Structural building damage detection with deep learning: Assessment of a state-of-the-art CNN in operational conditions', *Remote Sensing*, 11(23). doi: 10.3390/rs11232765.

9. Pham, T. T. H. *et al.* (2014) 'Towards a rapid automatic detection of building damage using remote sensing for disaster management: The 2010 Haiti earthquake', *Disaster Prevention and Management: An International Journal*, 23(1), pp. 53–66. doi: 10.1108/DPM-12-2012-0148.

10. Sui, H. *et al.* (2014) 'A novel 3D building damage detection method using multiple overlapping UAV images', *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 40(7), pp. 173–179. doi: 10.5194/isprsarchives-XL-7-173-2014.

11. Turker, M. and Sumer, E. (2008) 'Building-based damage detection due to earthquake using the watershed segmentation of the post-event aerial images', *International Journal of Remote Sensing*, 29(11), pp. 3073–3089. doi: 10.1080/01431160701442096.

12. Xu, J. Z. *et al.* (2019) 'Building Damage Detection in Satellite Imagery Using Convolutional Neural Networks', *33rd Conference on Neural Information Processing Systems (NeurIPS 2019), Vancouver, Canada*, (NeurIPS). Available at: http://arxiv.org/abs/1910.06444.

13. Ye, X. *et al.* (2017) 'Building-Based Damage Detection from Postquake Image Using Multiple-Feature Analysis', *IEEE Geoscience and Remote Sensing Letters*. IEEE, 14(4), pp. 499–503. doi: 10.1109/LGRS.2017.2651050.

****

Brief about the authors and their papers

(i) Ms. Usha Batra is an eminent Architect, retired as Special Director General from Central Public Works Department. She has dealt the subject of Repairs, Rehabilitation and Retrofitting. In her paper she has brought out the necessity of rational approach to consider the source of the cause of the deterioration and symptoms together because treating only the symptoms without adequate understanding of the cause of the problems leads to defects camouflaged beneath the finishes.

(ii) Shri Krishna Kant is an eminent civil engineer and UN Expert in the field who retired as Chief Engineer from Central Public Works Department. He has brought out the necessity of holistic approach for retrofitting to achieve sustainability.

(iii) Dr. J. Bhattacharjee, former Chief Engineer & Jt. Director General, (MES/ MOD) is an eminent Civil Engineer. In his paper he has discussed Methodology for Repair, Rehabilitation and Retrofitting in detail along with case study of major rehabilitation of wharves along with other repair works of caissons, dry dock costing Rs.50 million (App.) at Bombay (Mumbai), India where he has successfully used various admixtures.

(iv) Shri Jit Kumar Gupta, is an eminent town planner, and academician. In his paper he has brought out the appropriate construction technologies, integrated with proper repair, maintenance and retrofitting, need to be evolved and made operational, to make India global leader in safety and sustainable construction practices.

(v) Dr. K. M. Soni, an eminent civil engineer, has retired as Additional Director General from Central Public Works Department. In his paper he has brought out that in general, maintenance of civil structures is not given due importance in the country. Maintenance cost of industrial and IT equipments may vary from 5 to 10% of its original or replacement cost whichever is higher still their maintenance is given due importance but same concept is lacking in civil structures, be public or private buildings, roads or irrigation structures even if maintenance cost may be 2-3% of

replacement cost. Such a mindset leads to early deterioration of structures, which needs to change.

(vi) Shri A. K. Jain is an eminent town planner with the credit for drafting master plan of Delhi and author of several books. In his paper he has brought out that Restructuring, Redevelopment and Urban Renewal need to be based on circular concepts of renewal, recycling and reengineering and aim at net zero water, energy and land consumption which involves environment sensitive recycling of land and buildings, readjustment, rezoning and repurposing of old, dilapidated structures.

(vii) Dr. Saurab Gupta is a PhD Scholar, Indian Institute of Technology, Kanpur. In his paper he has discussed the different remote sensing techniques used in building damage detection and necessity of accurate analysis of destruction for helping engineers and planners to provide a plan for rehabilitation in the affected area.