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GOVERNMENT OF INDIA

MINISTRY OF RAILWAYS

Retrofitting of Existing Buildings

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Centre

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Advanced

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TECHnology

Excellence in Maintenance

Maharajpur, GWALIOR - 474 005

Retrofitting
of
Existing Buildings

Foreword

Many devastating natural calamities like earthquakes, cyclones etc. have occurred in past and may occur any where in future. Under the impact of seismic forces (earth quake), the civilisation suffers the maximum loss in terms of damage of buildings. Such buildings need to be retrofitted/repaired structurally/non-structurally to withstand such forces.

Although, maintenance is ongoing process. Retrofitting of existing buildings is an essential activity that makes the buildings safe to use for a long time and reduces maintenance considerably.

Through this handbook CAMTECH has made an attempt to provide the knowledge about structural stability of the building by adopting suitable techniques/ methods of repairing/ retrofitting.

I hope, this handbook will prove to be a valuable source of technical knowledge and will be quite helpful to civil engineering personnel in Railways.

CAMTECH/Gwalior ***S.C. Singhal***
Date : 16.09.2008 ***Executive Director***

Preface

Indian Railways, a big organization, has large number of buildings for its various infrastructural needs, viz., service buildings, staff quarters, passenger amenities, industrial sheds, bridge structures, etc and they need proper care and maintenance during their service life. The service life of a building is expected more than 50 years with normal maintenance. Although, all civil engineering structures and buildings are of prime importance and most of them constructed at the time of introduction of railway system in India and still continued along with the extension of railway network. Initially most of railway buildings were constructed in stone masonry/ brick masonry in lime mortar with tiled roof or jack arch terracing. Afterwards, with the production of cement in India, the construction started with stone masonry/ brick masonry in cement mortar along with RCC roof slabs and still continued in some part of India as per availability of local material.

In the recent past several devastating natural calamity like earthquakes, etc. have occurred and eventually the poorly structures/ buildings have become the victim of distresses of different kinds. The condition of the distressed buildings should be investigated so that the minimum restoration or retrofitting measures may be adopted to restore the same for effective load carrying system. The development of a general rule for retrofitting measure is rather difficult and to a large extent each structure must be approached as a strengthening problem on its own merits. It is necessary to take a decision whether to demolish a distressed structure or to bring back the same to its normalcy by preferring the restoration or retrofitting measures.

This handbook presents the technical details about various retrofitting techniques/ repairing methods involving suitability of repair materials used for restoration of engineered and non-engineered buildings following the provisions of relevant Indian Standards. The handbook on '*Retrofitting of Existing Buildings*' is intended only for the guidance of civil engineering personnel involved in maintenance of buildings. *This handbook is not statutory and contents are only for the purpose of guidance.*

This handbook does not supersede any existing instructions from Railway Board, RDSO & Zonal Railways and the provisions of IRWM, BIS codes & reports on the subject.

We welcome any suggestion from our readers for further improvement.

CAMTECH/Gwalior ***Sushil Kumar***
Date : 28.08.2008 ***Director/Civil***

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ISSUE OF CORRECTION SLIPS

The correction slips to be issued in future for this handbook will be numbered as follows:

CAMTECH/2008/C/RETROFITTING/1.0/CS. # XX date …….....

Where "XX" is the serial number of the concerned correction slip (starting from 01 onwards).

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Chapter – 1

INTRODUCTION

A vast network of Railway track in India lies across the country covering almost all the regions, where many important civil structures are built. These structures or buildings may show some sign of distress during their service period and also under the effect of natural calamity like earthquakes, etc. The safety of these buildings is of great concern especially because the loss of most of the lives during collapse of buildings has been reported in the past. The most of the old buildings made of stone masonry/ brick masonry are in existence and require adequate maintenance. At present, most of the buildings are being constructed in Reinforced Cement Concrete, which is assumed to be more durable and stable. The new materials and techniques in the field of construction and maintenance are developed and adopted in strengthening of existing buildings so that the safety of public may be ensured.

Many existing buildings do not meet the seismic strength requirements due to design inadequacy, material degradation over time or alteration carried out during the service life of the building. There may be some of the reasons for deterioration of buildings, e.g. the *construction of the buildings* is never exactly as per designer's specifications and a number of defects and uncertainties crop up during the construction; the *quality of the material* deteriorates with time and the *assessment of an existing building* becomes a time dependent problem. It is, however, most important to ensure the safety of such buildings against various loads including loads of natural disasters like earthquakes, floods, cyclones and landslides etc. by applying appropriate retrofitting techniques. The term 'retrofitting' is mainly used in context with the strengthening of weak buildings to make them strong enough to withstand seismic forces through various repairing methods. The main purpose of retrofitting (restoration) is to structurally treat the buildings with an aim to restore its original strength. The retrofitting may be adopted, if the cost of repair and strengthening of building is less than about 50% of the reconstruction cost.

In chapter-2 titled as *General Considerations*, some of the pre-checks required to be essential for fixing the criteria to take a decision whether to dismantle and rebuild a damaged structure/ building or to do repairs/ seismic retrofitting have been covered.

In chapter-3 titled as *Repair Materials and Techniques*, the various common materials used for repairing the common defects arising during service life of building and also some of special materials along with their application through various retrofitting/ repairing techniques/ methods have been detailed out.

In chapter-4 titled as *Retrofitting of Non-engineered Buildings*, the buildings in this category are those, which are constructed without taking into account the strength calculation or engineering practice and an attempt has been made to make such buildings strong enough to withstand seismic forces. Only masonry buildings either made of stone or brick have been covered.

In chapter-5 titled as *Retrofitting of Engineered Buildings*, the RCC buildings, which have systemic and rational approach in their design and construction have been taken for discussing different techniques for retrofitting.

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Chapter – 2

General Considerations

Some of the pre-checks required to be essential for fixing the criteria to take a decision whether to dismantle and rebuild a damaged structure/ building or to do repairs/ seismic retrofitting, have been covered.

2.1 General

Before attempting any repair procedure it is necessary to have a planned approach to investigate the condition of the building. This will require a thorough technical inspection and an understanding of the behaviour of the structural component to be repaired/ retrofitted. For this purpose, a single technique may not be adequate and a combination of techniques has to be adopted to get a truly representative data on the condition of the building. It is also very important to select the most appropriate material and repair methodology for achieving durable, effective and economic repairs as well as matching the response of repaired sections with the main structure, and also to ensure the compatibility of materials in any repair job.

2.2 Inspection of building

An inspection is a qualitative assessment of damaged building, based on the experience and skill of the engineer. Being a qualitative method, it is bound to have subjectivity. To reduce the element of subjectivity, the inspection should be performed by teams of at least two engineers. A systematic inspection provides a fair idea about the irregularities in building configuration, construction defects and most importantly, the signs of distress and deterioration of the structure. It is helpful in deciding the extent of investigation and selection of materials & techniques to enhance the structural performance of building. In addition, it helps in

- identifying the buildings, which are under risk of collapse due to any of the natural hazards like earthquakes, floods, and tsunami etc.
- initial shortage of shelter by identifying buildings, which are safe and can be occupied.
- providing valuable statistical data for proper planning of aid.
- reviewing the prevailing design and construction practices.
- identifying the buildings, for which more detailed investigations are required to assess the safety and to design retrofitting schemes.

2.3 Evaluation of building

Evaluation is an integral component through which the strength of the existing structure is estimated. This helps in deciding the strategy and system of retrofitting and also to assess the adequacy of the proposed retrofit scheme.

- A preliminary evaluation of building is carried out which involves broad assessment of apparent physical condition, robustness, structural integrity and strength of structure, including simple calculations.
- If the results of preliminary evaluation for strength, overall stability and integrity are acceptable, no further action is required. Else a detailed evaluation is required unless exempted.
- A detailed evaluation when required will include numerical checks on stability and integrity of the whole structure as well as the strength of each member. Conventional design calculations for these checks will use modified demands and strengths.

2.4 Restoration

Restoration is a process by which a damaged building is structurally treated with an aim to restore its original strength. The action will involve cutting portions of wall and rebuilding them, inserting support, underpinning foundation, strengthening a weak component etc. The appropriate repair methods are to be carried out component wise depending upon the extent of damage. Some of the common restoration techniques to strengthen the structural elements of building are:

- Removal of portions of cracked masonry walls and piers and rebuilding them in richer mortar (use of non-shrinking mortar will be preferable).
- Addition of reinforcing mesh on both faces of the cracked wall, holding it to the wall through spikes or bolts and then covering it, suitably, with cement mortar or micro-concrete.
- Injecting cement or epoxy like material which is strong in tension, into the cracks in walls.
- The cracked reinforced cement elements may be repaired by epoxy grouting and could be strengthened by epoxy or polymer mortar application like shotcreting, jacketing, etc.

2.5 Repairs

When a building or structure is affected by any of the natural causes, it may suffer both structural and non-structural damages. The damage to the building should be assessed in detail prior to taking up the structural and non-structural repairs. The repairs to non-structural/ architectural elements may be carried out, if one is sure that the original strength provides an adequate level of safety for future earthquake disasters. Any attempt to carry out only repairs to non-structural/ architectural elements neglecting the required structural repairs may have serious implications on the safety of the building. Although, such repairs do not restore the original structural strength of structural components in the building and only need to be taken up after the structural repairs are carried out. The non-structural repairs involve one or more of the following:

- Patching up the defects such as cracks and fall of plaster;
- Repairing doors, windows, replacement of glass panes;
- Checking and repairing electric conduits/wiring;
- Checking and repairing gas pipes, water pipes and plumbing services;
- Re-building non-structural walls, smoke chimneys, parapet walls, etc;

- Re-plastering of walls as required;
- Re-arranging disturbed roofing tiles;
- Re-laying cracked flooring at ground level; and
- Re-decoration — white washing, painting etc.

2.6 Seismic Strengthening or Retrofitting

Every structure is prone to the most serious dynamic forces called seismic forces. The seismic resistance of old existing non-engineered buildings is lowered with passage of time due to material property degradation and structural strength loss. This deterioration may occur due to climatic, biological or chemical causes. The actions taken to upgrade the seismic resistance of an existing building so that it becomes safer under future earthquakes, is called seismic strengthening (retrofitting). Strengthening of a building will involve either *component strength enhancement* or *structural system modification* or *both*. It is expected to improve the overall strength in the following ways:

- Increasing the lateral load resistance by reinforcing or by introducing new walls (shear) and columns.
- Introducing the continuity between the components of the structure to achieve ductile performance. This will include connection of wall with roof, including bands and ties between walls and introducing connections between roof and walls and wall to wall.
- Eliminating existing weakness in an existing building by introducing symmetry in plan, changing location of mass, reducing large openings etc.
- Avoiding brittle modes of failure. This will include improving anchorage and providing bracings in walls.

The extent of modification has to be determined based on the principle of introducing sufficient anchorage of all elements, providing bracing to vertical load carrying members in order to avoid premature mode of failure and to ensure continuity of all structural components in a building.

2.7 Maintenance records

The record of the procedures for periodic inspection of buildings and documenting defects like cracks, excessive deflections, corrosion of reinforcement etc., in logical manner, and recording of structural repairs already carried out should be maintained. Generally, the structural drawings are not easily available and attempt should be made to get the information about original design, construction, repairs and extensions of the building. Any change in usage of the building should also be recorded.

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Chapter – 3

Repair Materials and Techniques

The various common materials used for repairing the common defects arising during service life of building and also some of special materials along with their application through various retrofitting/ repairing techniques/ methods have been detailed out.

3.1 General

Cement and steel are the most common materials for repair works of various types of buildings. In many situations suitable admixtures may be added to cement mortar/cement concrete to improve their properties such as non-shrinkage, bond, etc. Steel in the form of bolts, threaded rods, angles, beams, channels, expanded metal and welded wire fabric can also be used. Wood, bamboo, casuarinas are the most common material often used for providing temporary supports and scaffolding, etc, and will be required in the form of rounds, sleepers, planks, etc.

3.2 Repair materials

Most of the repair and retrofitting materials suitable to different applications and working conditions are available in market under various brand names. The retrofit engineer should be familiar with these materials while designing the retrofit scheme for a building. Some of the materials and techniques, which are available for best results in the repair and strengthening operations generally, can be broadly classified as:

3.2.1 Injection Grouts

The flow-able plastic materials called Grouts, which can be injected into a structural member under pressure to fill interior space within the concrete or masonry created due to cracks, voids or honeycomb are used for repairing of cracks, strengthening of masonry and honeycombed concrete. The grout should have negligible shrinkage to fill the gap/ void completely and should remain stable without cracking, de-lamination or crumbling. The grouts can also be used in repairing of minor or medium cracks, in strengthening of old masonry structures and particularly in strengthening of monumental structures. The compatibility of original material and the grout must be ensured.

- **Polymer grouts:** The most commonly used polymers in concrete are polyester, epoxy, vinyl ester, polyurethane and acrylic and out of these, epoxy is most popular. The polyurethane and acrylic resins are used in underground and water seepage conditions. These grouts are available in three component materials having (i) liquid resin content (ii) curing agent or hardener, and (iii) aggregate or dry filler; and two component materials having curing agent packaged with the aggregate. The basic resins and curing agents are added with modifiers to achieve desired properties. *The manufacturer's literature should be studied in details before specific use of such materials.*

- *Epoxy based injection grouts* possess low pot life, non-resistant to ultra violet exposure and high temperatures, non-shrink, flow-able, effective in sealing cracks, excellent bonding with almost all building materials, good chemical resistance.
- *Acrylic polymer based injection grouts* possess improved flexural and tensile properties, resistance to cracking, segregation, improved impermeability, chemical resistance, rapid setting. Shrinkage may reduce/increase resistance to corrosion of Steel, Dynamic load/vibrations resistant.
- *Lignosulphate based injection grout admixture* lowers viscosity of cement slurry, compensates drying & plastic shrinkage.

- **Fibre-reinforced grouts:** Polypropylene, Steel or Glass fibres may be used in Portland cement or shrinkage compensating mortar to provide improved flexural strength, impact resistance and ductility. These grouts require skilled handling to avoid segregation of fibres.

- **Cement - Sand grouts:** These are cheapest and require high water and cement contents for injection purpose. These results in shrinkage and cracking of grout at hardening and to minimize this, suitable shrinkage compensating agents are required. Use of cement-sand grouts is very common in masonry buildings, but not very common in concrete.

- **Gas-forming grouts:** The gas bubbles, which expand the grout to compensate shrinkage, are generated on reaction of some ingredients (usually Aluminium and Carbon powder contained in grout) with the cement liquor. These grouts being temperature sensitive and not suitable for high temperature application require proper confinement to develop strength and volume stability, as the reaction forming gas bubbles may be too fast and may complete before placing of the grout.

- **Sulfo-aluminate gouts:** In these grouts either shrinkage-compensating cement or anhydrous sulfo-aluminate expansive additive is used with Portland cement. The additive results, in expansion at hydration. This produces expansion after the grout has set and is more reliable then gas-forming grouts. But the expansion of such grouts requires post-hardening curing and it will not be effective if moist curing is not available.

3.2.2 Replacement and jacketing materials

The materials used for replacing the damaged portions, increasing the size of members, enhancing the confinement and external reinforcement of the members in building should have good bond with existing material and should be non-shrinking. In case of damaged structures, material in some parts of members is to be replaced by new material. For strengthening existing members in deficient buildings, additional material including reinforcement is to be provided. A variety of strengthening and replacement materials is available.

- **Ordinary Portland cement Concrete and Mortar:** Possessing similar properties as the existing concrete, they are cheap and do not require special skills for application. They consist of high early strength cement and an expansive component to compensate the shrinkage. The common expansive agents (result in good bond) used are aluminium powder, coke powder, anhydrous calcium sulfo-aluminate and calcium oxide.

  Application:

  A) In case of concrete, use of higher strength (at least by 5 MPa) than the existing concrete is recommended. Maximum size of coarse aggregate is limited to 20 mm for ease in pouring the concrete through narrow spaces. To ease the compaction, workability is enhanced by adding super plasticizers. The surface of existing concrete is made as rough as possible and cleaned properly. After placing the forms, a final dusting should be done using compressed air to remove dust from the surface.

  B) Sometimes a special application of ordinary concrete (pre-placed concrete) is also used. In this method, the aggregate is first packed in the space to be concreted and the cement is applied in the form of grout intrusion. This concrete has very little shrinkage but requires skill in application.

  C) Dry pack is another application method of ordinary concrete. In this method, the concrete has very little water and has almost zero slump. The moisture is just sufficient to stick the material together when moulded into a ball by hand. The low water content results in reduced shrinkage, but makes compaction difficult and there are chances of voids being left. Dry packs are available under several commercial names and usually consist of fine sand, super-plasticizers and an expansive agent in appropriate proportion. This material is very suitable for jacketing.

- **Shotcrete:** Shotcrete has the same characteristics as ordinary concrete in which compressed air forces cement mortar or cement concrete (with coarse aggregate size maximum 10 mm) to be sprayed on a prepared concrete or masonry surface of a building under pressure with low water content through a nozzle. The force of the jet impingement on the surface compact the shotcrete material and produces a dense homogeneous mass. The reinforcement provided is generally welded wire fabric and deformed bars tacked onto the surface. This wire fabric or mesh reduces the shrinkage and improves the bond between existing concrete and shotcrete. Sometimes, to improve the bond between old and new material, surface coatings, such as epoxy bonding agents, latex modified cement slurries or neat cement slurries, are also used.

  Shotcrete requires no framework and can be applied on any surface including inclined and vertical surfaces and even on ceilings. This results in very good adhesion between old and new concrete and good compaction due to application under pressure. The low water-cement ratio results in high strength and low shrinkage. The permeability of shotcrete is also lower than that of ordinary concrete and results in better protection of steel against corrosion.

Shotcrete is applied using either wet mix or dry mix process. *In the wet mix process*, all the ingredients (cement and aggregate) including water are mixed together before they enter the delivery hose and the pump pushes the mixture through the hose and nozzle. Compressed air is introduced at the nozzle to increase the velocity of application. *In the dry mix process*, compressed air propels the mixture of damp aggregate (sand) and cement through the delivery hose to the nozzle where water is added through a separate hose. The dry mix and water through the second hose are projected on to a prepared surface. The dry mix process is generally used in repair of concrete elements. The skill of the crew is very important due to the fact that the water/cement ratio cannot be controlled quantitatively as it is mixed at nozzle and controlled visually by the operator.

Note: *Before application of shotcrete, damaged concrete is removed and the surface is thoroughly cleaned by sand blasting to remove all dirt and to expose the aggregate. Steel is cleaned on full circumference of bar to bare metal.*

- **Polymer modified concrete and mortar:** Polymers are long molecule hydrocarbons, built by combination of single units called monomers. The process is called polymerization. Small diameter particles of polymers emulsified in water are called polymer latexes. These latexes form continuous film at drying. Adding polymer latexes to ordinary mortar and concrete is the most common method of making Polymer Modified Mortar (PMM) and Polymer Modified Concrete (PMC). Cement hydration in PMM/PMC results in drying of latex and formation of the film of polymers. This film binds the cement hydrates together to from a monolithic network in which the polymer phase interpenetrates throughout the cement hydrate phase. The resulting matrix binds the aggregate more strongly and enhances the properties of mortar/ concrete.

  The PMM/PMC has better workability and water retention properties than ordinary concrete/mortar. This reduces the requirement of water curing considerably. Polymer modification does not result in any appreciable increase in compressive strength of concrete, but it results significant increase in tensile and bending strength of concrete. The main advantage of PMM/PMC is its improved adhesion and bond with existing concrete and significantly reduced permeability. The reduced permeability results in reduced risk of corrosion of reinforcing steel.

  Note: *The polymer mortars are two phase systems which forms co-matrix with cement. In cementations water phase, fine polymer particles of size 0.1 to 0.2 microns are dispersed. In cement polymer system, the polymer particles join and chain link reinforcing and there by increasing tensile and flexural strength. They achieve greater plasticity and tend to reduce the shrinkage stress. Hence they vastly improve the property of plain cement mortar.*

- **Fibre-reinforced plastics (FRP):** Fibre-reinforced polymer/ plastic is an advanced material recently developed for strengthening of RC and masonry structure. It has been found to be a replacement *of* steel plate bonding and is very effective in strengthening of columns by exterior wrapping. The main

advantage *of* FRP is its high strength to weight ratio and high corrosion resistance. FRP composites are formed by embedding a continuous fibre matrix in a resin matrix that binds the fibre together and also provides bond between concrete and FRP. The commonly used fibres are Carbon fibres, Glass fibres and Aramid fibres, and the commonly used resins are polyester, vinyl ester and epoxy. FRP is named after the fibre used, e.g. Carbon Fibre Reinforced Polymer (CFRP), Glass Fibre Reinforced Polymer (GFRP), and Aramid Fibre Reinforced Polymer (AFRP).

Table as shown below gives a typical range of properties for three types *of* fibres. This range may change from one brand to another and with change in fibre content.

Uni-directional advanced composite materials	**Fibre content (%by weight)**	**Density *(kglm3)***	**E (Long.) (GPa)**	**Tensile strength (MPa)**
Glass fibre/polyester GFRP laminate	50-80	1600-2000	20-55	400-1800
Carbon/epoxy CFRP laminate	65- 75	1600-1900	120-250	1200-2250
Aramid/epoxy AFRP laminate	60-70	1050-1250	40-125	1000-1800

- **Epoxy:** Epoxies come in the category of polymers and the polymerization process (in case of epoxies) takes place when two materials called the *epoxy resin* and *hardener* come in contact by thoroughly mixing in specified proportion. They are excellent binding agents and have good mechanical strength, chemical resistance and ease of working. These are being used in civil engineering for high performance coatings, adhesives, injection grouting, high performance systems, industrial flooring or grouting etc. The low viscosity resins can be injected into fine cracks. The higher viscosity material is used as binding agent for surface coating or filling larger holes and cracks. They may also be used for gluing steel plates to the distress members. These are used for the following:

  - to bond plastic concrete to hardened concrete
  - to bond rigid materials to one another
  - for patch work
  - for painting over concrete to give colour, resistance to chemicals, water and to give abrasion resistance.

- **Epoxy mortar:** The Epoxy mortar is made using epoxy resins (of either low viscosity or higher viscosity) and suitable sized aggregate (sand). They have high compressive strength, high tensile strength and low modulus of elasticity than cement concrete and can be used for larger void spaces. In cement mortar or concrete, the inclusion of epoxy can be considered as an incorporation of a second binder into the mix.

3.2.3 Common Materials used in Repair techniques

- **Gypsum cement mortar:** Based on hydraulic binder these readymade formulations are tailor made to give repair mortar material which is flow-able and shrinkage free. Hence they can be applied in complicated locations and only addition of water is required at site. Cementatious mortars such as gypsum cement mortar have limited use for structural applications and are intended for hand/trowel applications.

- **Quick-setting cement mortar:** This material is non-hydrous magnesium phosphate cement with two components, that is, a liquid and a dry powder, which can be mixed in manner similar to cement concrete. These are patented mortars generally come in pre-packed condition and can be classified as (i) Unmodified cementatious (ii) Polyester or Epoxy resin based (iii) Polymer modified and cementatious (iv) Cement/ pozzolanic-modified. Different types of hand applied mortars used for various surface treatments, indicating their properties and the defects they are intended to treat.

Sl. No.	Defect	Repair mortar type	Properties
1	Minor surface defect	A two pack polymers modified cementatious screed.	Gives a fair face finish. Good water-proofing properties. Resist acids and gases.
2.	Surface cavities and honeycombed concrete	Highly adhesive, thixotropic mortar	Water proof and anti-carbonation finish. Good resistance to pollution.
3.	Powdery surfaces	A two components surface stabilizer	Binds powdery surfaces and evens out absorption characteristic.
4.	Surface protection	Resin rich water based elastic co-polymer	Highly resistant to CO2 diffusion and self cleaning.
5.	Surface barrier	A water based co-polymer	Resistant to fungal attack.
6.	Non-structural cracks	Non shrinking polyol filler	Easily applied elastic compound and cures at low temperature
7.	Minor voids of approximate size 50 x 50 x 50 mm	Rapid curing polymer modified cementatious co-polymer	High Strength when compacted in layers
8.	Major voids approximate size 100x100x100mm	Heavy duty thixotropic fibre reinforced polymer modified cementatious mortar.	Can be applied up to 100mm thick. Easy to mould.
9.	Bonding agent	Polymer modified cementatious surface impregnant	High penetration into porous concrete creating enhanced adhesion
10.	Protection of steel reinforcement	A highly alkaline two component system of cementatious powder and polymer dispersion which react chemically to passivate steel	High penetration and enhanced adhesion to protect steel.

- **Micro-concrete:** Based on hydraulic binders these readymade formulations are tailor made to give concrete which is flow-able and free of shrinkage. They are applied in complicated location and in thin sections such as those met with in jacketing. Micro-concrete can be made either as normal strength or high strength depending on requirement.

- **Fiber-reinforced concrete:** Fiber reinforced concrete has better tensile strength and toughness compared to conventional concrete. They have also improved energy absorption capacity. These compositions offer high tensile strength, durability, ductility and enhanced energy absorption capacity. They are being increasingly used for structural strengthening.

- **Ferro cement:** Ferro cement is a type of reinforced cement mortar commonly made of hydraulic cement mortar reinforced with closely spaced layers of small diameter wire mesh. The mesh may be made of metallic or other suitable materials. Fineness of mortar matrix and its composition should be compatible with opening and tightness of the reinforcing system, it is meant to encapsulate. The matrix may contain discontinuous fibers. Well designed Ferro cement wraps can be an economical alternative to CFRP wraps especially for non engineered construction.

3.2.4 Bonding agents

Bond between old and new concrete and reinforcement is important for effectiveness of repair/ retrofitting available for enhancing the bond:

- **Application of adhesives at the interface:** Polymers and epoxy are the adhesives used for bonding between old and new concrete and reinforcement. After removal of the concrete cover, the existing concrete surface and steel are cleaned by sand or water blasting. After cleaning and drying, concrete and steel is painted by epoxy/polymer or polymer modified cement grout. If the new steel is to be welded, it is welded prior to coating of the concrete and steel. This coating provides enhanced bond between the old and new material and reduces the risk of corrosion in steel.

- **Surface interlocking:** To improve the surface interlocking, the existing concrete surface is coated with epoxy/polymer and a layer of coarse sand is applied above the coating.

- **Mechanical bonding and reinforcement:** Mechanical bonding consists of keys and anchors provided in the existing members at regular interval. Such type of anchors employs wedging action to provide anchorage. These can provide resistance against shear and tension. Some of these anchorages are specialized patented products which can be designed for a required tension or shear force.

- **Metal plates, steel and aluminum etc.:** Steel plates can be bonded to concrete members as external reinforcement to increase their strength and load carrying capacity, to improve stiffness thus reducing deflection and cracking and to enhance shear capacity. The steel plate is attached to the structure either by

anchor bolt or by chemical or epoxy bonding. Bolts are often used in conjunction with adhesive to provide mechanical anchor for the plate at the ends to prevent premature de-bonding due to peeling. The bolting also helps support the plates whilst the adhesive cures. Steel plates can also be bonded by epoxy glueing the member surface. This requires a careful preparation of the member surface and application of epoxy layer. Steel plates can also be provided in the form of jackets either by gluing to surface or by grouting. However, these jackets are not very effective as these try to separate out from the members due to Poisson's effect, loosing confinement.

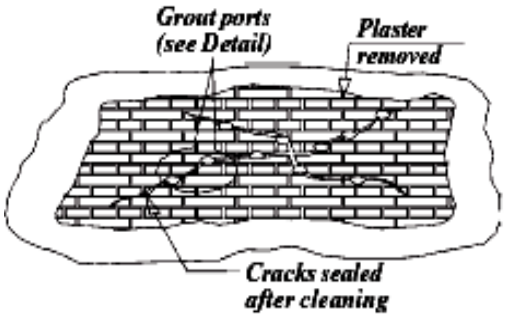
3.3 Repair and Strengthening Techniques

Strengthening means the structural enhancement of existing weak members in such a way as to restore or increase their ultimate strength in bending, shear or direct tension and compression. Some of the common forms of repair and strengthening techniques are as below:

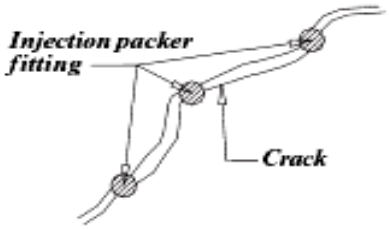
3.3.1 Repair of Minor and Medium Cracks

Even fine cracks in load bearing members, which are un-reinforced, like masonry or plain concrete, will reduce their resistance against loads. Hence they should be marked carefully and critical ones repaired either by injecting strong cement or chemical grout or by providing external bandage. Cracks in width smaller than 0.75 mm can be effectively repaired by pressure injection of epoxy.

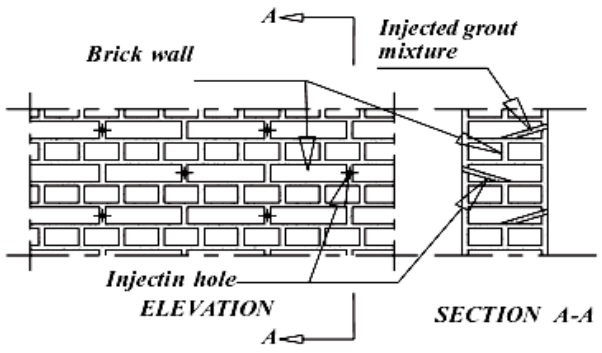
The surfaces are thoroughly cleaned of loose materials and plastic injection ports are placed along the length of the cracks on both sides and secured in place with epoxy seal (Fig-a,b). The ports can be installed at intervals approximately equal to thickness of the element being repaired.



(a) Grout or Epoxy injection in cracks



(b) Grout Ports Details



After hardening of the seal low viscosity epoxy resin is injected into one port at a time sequentially beginning at the port of the lowest level and moving upwards. The resin is pushed through the packer till it is seen flowing from the other end or a port at a level higher than where it is injected (Fig-c). The injection port is closed at this juncture and the packer is moved to the next higher port.

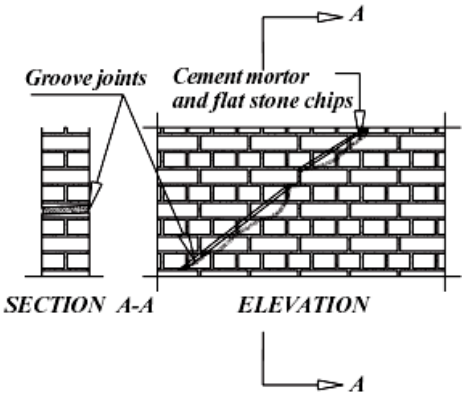
(c) Grout or Epoxy injection in an existing weak wall

This operation is repeated sequentially until we reach the top most port and the whole crack is filled with grout. Longer cracks will permit longer packer spacing depending on thickness of the member. This technique can be used for all types member (beams, columns, walls or slabs). They can be utilized to repair small cracks in individual masonry blocks or fill large continuous cracks.

3.3.2 Repair of Major Cracks and Crushed Concrete

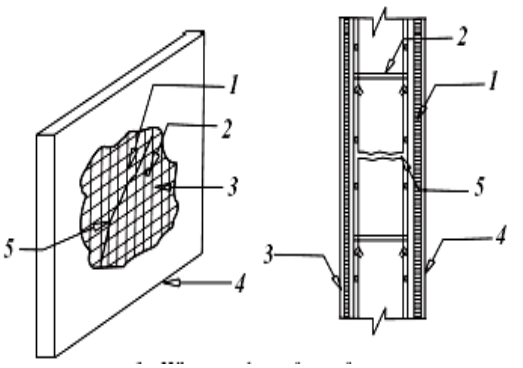
For cracks wider than about 5 mm and where brickwork or concrete is crushed, a treatment other than injection may be followed as per the procedure indicated below:

(a) Loose material in the crack is removed and any of the repair mortar mentioned in Table above for Quick Setting Cement mortar is filled.
(b) If necessary the crack is dressed to have a “V groove” at both faces.
(c) At places where cracks are wide, fillers like flat stone chips can be used.



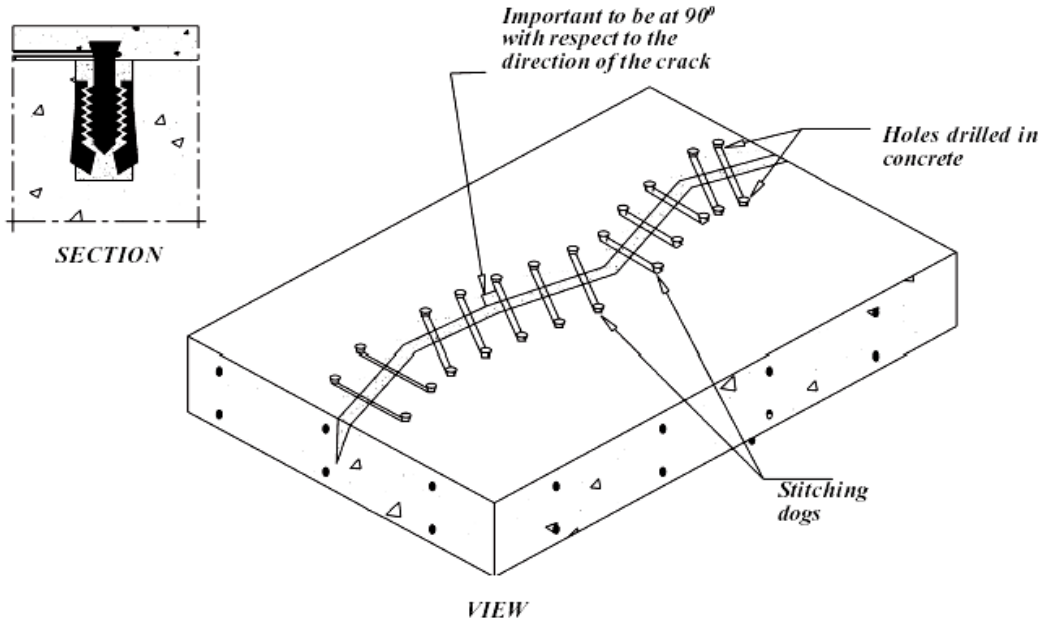
Cement mortar and flat-stone chips placed as filler in wide cracks

(d) Additional shear and/ or flexural reinforcement are provided in the location of the repairs based on structural necessity.
(e) The added steel has to be protected properly by sufficient polymer mortar to prevent it from corrosion.
(f) In case of walls or roof slabs additional mesh reinforcement is included either on one or both sides. This mesh reinforcement is generally nailed, tacked and tied by binding wire.



Mesh reinforcement repair for walls / roof slab 1. Wire mesh on front face 2. Clamps 3. Wire mesh on back face 4. Cement plaster 5. Crack

f) To prevent widening of the cracks they can be stitched. The stitching consists of drilling small holes of size 6 to 10mm on both side of the crack, cleaning the holes and anchoring legs of stitching dogs with short legs. The stitching dogs are variable length and orientation as shown in figure. The spacing of reinforcement should be reduced at the ends of the crack. Stitching will not close the crack but prevent further propagation and widening.

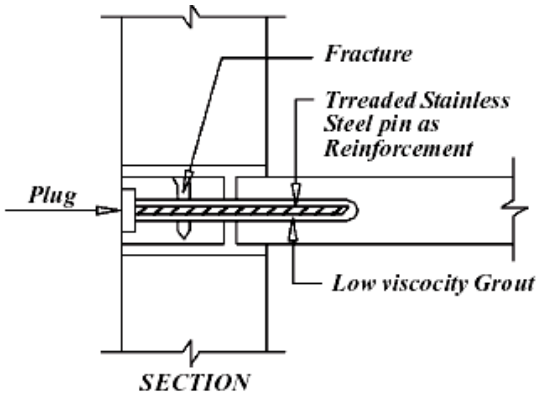


Repair by Stitching

3.3.3 Excessively yielded and buckled reinforcement

In several instances the reinforcement is severely damaged showing signs of either buckling or elongation due to excessive yielding. The element can be repaired by adding additional steel with old steel by lap welding. Additional stirrup ties are added in the locations of damages and then jacket concreted to provide required confinement of concrete in the repaired zone.

Additional reinforcement will sometime have to be pinned into either masonry or concrete. In such cases, a hole larger than the bar diameter is drilled. The hole is filled with grouting material. The reinforcement is then pushed into place and held till the grout hardens.



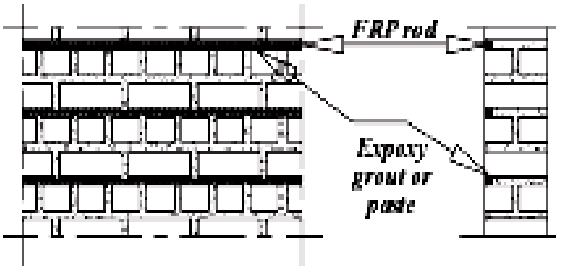
Pinning technique

3.3.4 Retrofitting by Fiber Reinforced Plastic

FRP composites are tailor-able, flexible and are easy to apply. Hence they can be used in retrofit operation. They have thin profile and hence they can be made architecturally pleasing. They don't reduce the usable floor space. They can be used for masonry strength enhancement in the following ways:

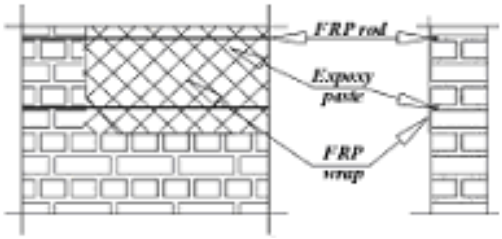
- **Near surface mounting technique**

In this technique grooves are cut horizontally through mortar bed joints and vertically if needed. The depth of cut is about 25mm. The grooves are half filled with epoxy adhesive. Small diameter (6mm) FRP rods as shown in figure are inserted and pressed with another layer of adhesive.



Application of near surface mounting technique

- **Surface mounting technique**



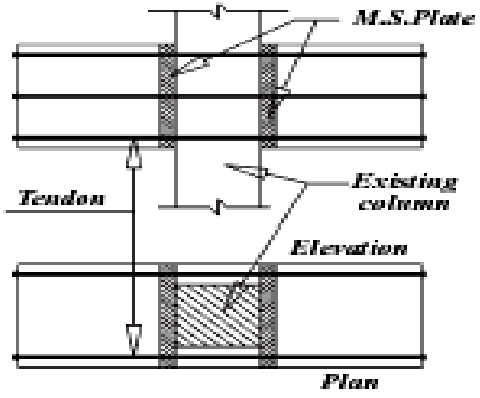
Anchoring system for FRP wraps

FRP strips are applied to masonry walls vertically and or diagonally to improve their out of plane capacity in both way bending. The diagonal strip application enhances the in-plane shear capacity by acting as tension chord of the diagonal brace.

- **Overlay technique**

The use of overlays to strengthen masonry walls is a well proven technique. This technique involve applying a layer of epoxy sealant to the surface of a masonry wall, impregnating the FRP wraps with epoxy saturant, placing the overlay on the wall surface, and finally finishing with a layer of epoxy saturant. Bond is the key factor that determines the success of FRP retrofit system. An undesirable mode of failure is the peeling off of FRP layer due to insufficient bond length.

3.3.5 Strengthening by pre-stressing



Transverse pre-stressing of bracket

Over loaded or damaged beams can be effectively strengthened by externally placed tendons. Tendons can be anchored to the sides near the ends or behind the diaphragm. Even timber trusses can be selectively pre stressed i.e. either individual member pre-stressing or structural truss system pre-stressing. Indeed even a bracket failure can be corrected by transverse pre-stressing.

3.3.6 Infilling

Weak R.C. frames can be stabilized by providing brick infilling at chosen location. Brick infilling will increase the later load capacity. The infilling will also affect the centre of stiffness of a building. Hence careful choice of infilling should be made so that increase in stiffness and strength of the frame in filled does not make other frames or members vulnerable.

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Chapter - 4

Retrofitting of Non-engineered Buildings

The buildings in this category are those, which are constructed without taking into account the strength calculation or engineering practice and an attempt has been made to make such buildings strong enough to withstand seismic forces. Only masonry buildings either made of stone or brick have been covered.

4.1 General

The buildings made of rubble and coursed stone masonry, un-reinforced brick and block masonry are under the category of *Non-engineered buildings*, which are constructed by local artisans employing local construction practices and materials. No strength calculation or engineering practice is involved in construction of such buildings. These buildings, which lack in strength and ductility against natural forces like earthquakes etc, can be strengthened by taking safety measures and using various techniques of retrofitting and also by achieving Integral Box action.

4.2 Integral Box Action

In the load-bearing wall buildings, walls serve as partitions and bear the load from roof and floor slabs, which are directly supported on the walls. The function of wall is to resist and transfer the load (lateral load resulting from earthquake and wind) to the ground.

In a building, there are four or more than four walls, which act as a box under lateral load. The resistance of box under lateral load is much higher than the resistance of individual walls because of the walls parallel to the lateral load act as webs and the walls orthogonal to load act as flanges. In many cases, the damage initiates at comers, resulting in loss of box action and walls start acting independently leading to collapse of building. The source of weakness in the walls is opening, which results in reduction of effective cross-sectional area of wall resisting lateral loads. If the openings are very near to comers, these hamper the integral box action by weakening the joints. To avoid this damage the opening perimeter need to be strengthened by proper reinforcement.

The overall lateral strength and stability of bearing wall buildings is very much improved, if the integral box like action of room enclosures is ensured. This can be achieved by use of pre-stressing and providing horizontal bands.

4.3 Strengthening of Walls

4.3.1 In case of Buildings made of Rubble Masonry

Most of the buildings in stone have rubble masonry with mud or cement-sand mortar and the walls are usually made in two wythes giving smooth finish along the two faces

of wall and the space, in between, is filled with smaller stone pieces. The failure of these walls is mainly due to no proper interconnection or interlocking to the inner and outer Wythes.

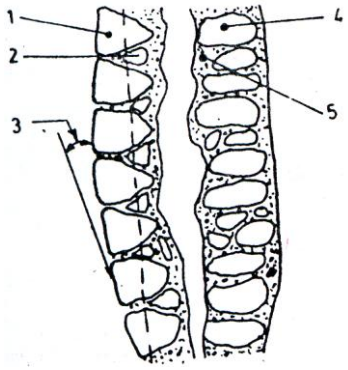
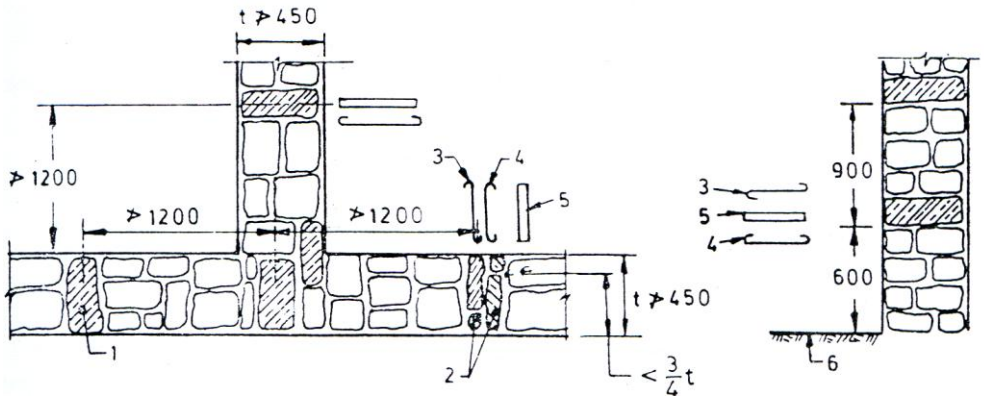


Figure shows the *wall delaminated with buckled wythes* in which *1. half-dressed conical stone, 2. small alignment stone, 3. rotation of wythe, 4. random rubble, 5. mud or weak lime mortar.*

The walls should be interconnected by providing sufficient number of 'through stones' to avoid splitting during earthquake shaking. The following options may be considered to be effective as remedial measures:

- The 'Through' stones of full length equal to wall thickness should be used in every 600 mm lift at not more than 1.2 m apart horizontally. If full length stones are not available, stones in pairs each of about ¾ of the wall thickness may be used in place of one full length stone so as to provide an overlap between them.



Sectional plan of wall **Cross-section of wall**

Figure shows *through stone and bond element* in which *1. through stone, 2. pair of overlapping stone, 3. S-shape tie, 4. hooked tie, 5. wood plank, 6. floor level*

- In place of 'through' stones, 'bonding elements' of steel bars 8 to 10 dia bent to S-shape or as hooked links may be used with a cover of 25 mm from each face of the wall. For this purpose, a hole in the wall is to be made at selected location by gently removing the stones from the two sides of the wall. The space created by removal of stones, is filled with concrete and a steel rod bent to S-shape or as hooked links.
- Also, wood bars of 38 mm X 38 mm cross section or concrete bars of 50 mm X 50 mm section with an 8 mm dia rod placed centrally may be used in place of 'through' stones. The wood should be well treated with preservatives so that it is durable against weathering and insect action.

In addition to the above strengthening of individual walls, unsupported length and height of walls and size and placing of openings is also to be controlled as per codal requirements. The integral box action of the building is to be ensured by providing seismic belts at lintel and roof level and vertical reinforcement at comers and junctions is to be provided.

4.3.2 In case of Buildings made of Rectangular Masonry Units

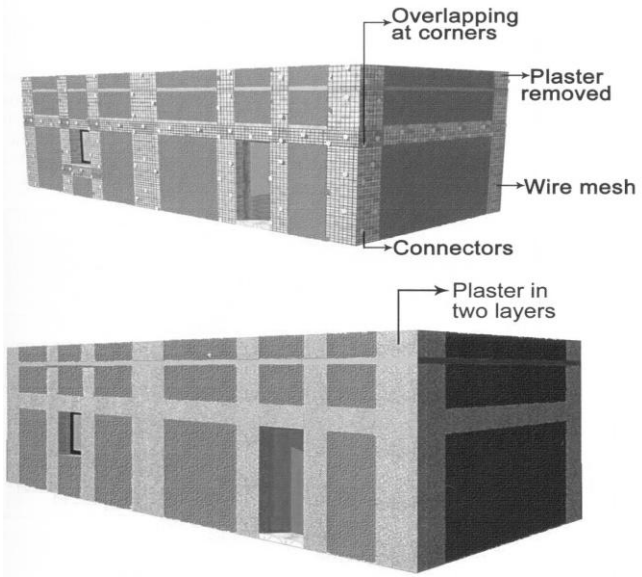
Buildings made of Rectangular Masonry Units are much stronger than rubble stone masonry and perform better during earthquakes. This masonry is constructed in cement-sand or mud mortar. Some old construction exists in lime-surkhi mortar. Retrofitting of these buildings includes strengthening of individual walls while ensuring integral box action.

- **Strengthening by Injection Grouting**

The walls having cracks, voids, loose pockets or degradation of mortar can be strengthened by grouting either by using shrinkage compensated cement slurry or polymer grouts or epoxy. Polymer/epoxy grouting is costly and is normally not used in masonry. Shrinkage compensated cement slurry grouting is considered satisfactory in ordinary masonry buildings. The grout to be injected usually consists of shrinkage compensated cement and water with flow-able consistency.

- **Strengthening by Ferro-cement**

To provide additional strengths to severely damaged/ deteriorated masonry walls, Ferro-cement plates can be provided on both the faces of walls. It consists of following steps:

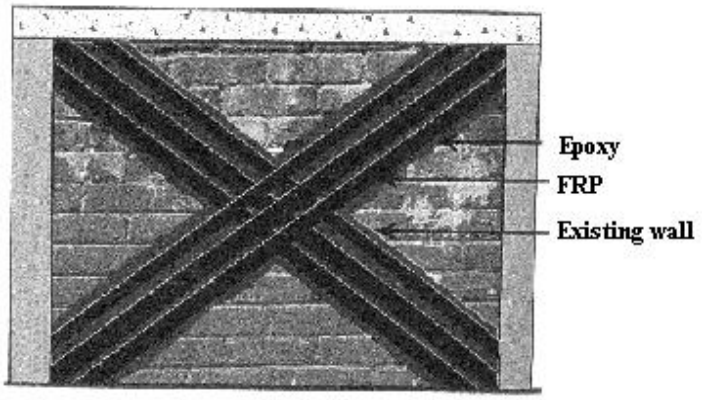


- The plaster on both sides of the wall is removed, the mortar joints are raked out up to 15-20 mm depth, surface is cleaned and wet with water and a coat of cement slurry or polymer enhanced cement slurry is applied.
- A 10 mm thick coat of cement sand plaster (1:3 - cement: coarse sand) or 1: 1.5:3 micro concrete is applied. The surface of the plaster is roughened to have good bond with the second coat.
- Welded wire mesh is fixed on the surface of plaster/ micro concrete using 150 mm long nails. The wire-mesh and nails are galvanized to protect them from corrosion. Alternatively the wire-mesh on the two sides of the wall can be anchored together using 3 mm galvanized wire or bolts passing through holes drilled in the wall. The anchors are used at every 450 mm. After clamping the wire-mesh on the two sides of wall, the wires/bolts are grouted in the holes.
- After fixing the wire-mesh, second coat of plaster or micro-concrete (16-20 mm

thick) is applied.

- **Strengthening by FRP Strips**

Masonry walls can also be strengthened by epoxy glueing the FRP strips. Another method of strengthening masonry walls has been employed in some historical buildings. In this method, vertical cores are drilled in the thick masonry walls and filled with reinforced concrete. The vertical RC members so created act as columns and support the masonry wall, without affecting its external appearance.



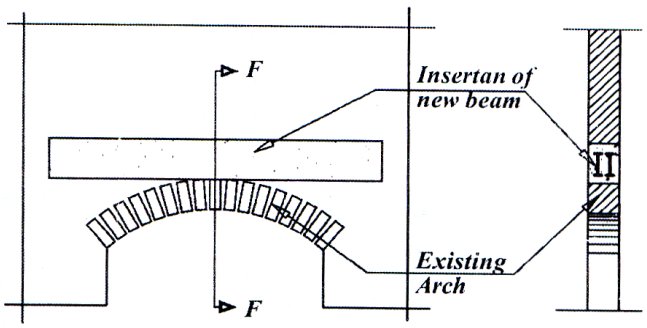
4.4 Control of unsupported length, height and openings

Masonry walls are weak in out of plane action. Large unsupported lengths and heights need to be supported laterally. These supports can be provided either by cross walls or by buttresses. The cross walls and buttresses need to be properly connected with the existing wall.

Openings result in weakness in masonry walls. The total length of openings in masonry should generally be restricted to one third of the length of the wall. Further the openings should not be very close (less then 600 mm) to each other or comers. If these conditions are not satisfied, some of the openings have to be closed completely or partially. Proper bond of old and new masonry has to be ensured while closing the opening. Teething and steel anchors can be used for this purpose.

4.5 Strengthening of Arches

Old buildings have masonry arches over the openings and under severe shaking during earthquake, these arches get loosened and arch action is lost. To avoid this, steel tie-rods are provided at the springing of the arches by drilling holes and grouting the steel bars.



Another method of strengthening masonry arches is relieving them from the load by providing a RC or steel lintel just below or above the arch. For providing a steel lintel above an arch, two steel channels or I-sections are provided on both sides of walls by partially removing the masonry and interconnected by bolts and covered by concrete.

4.6 Retrofitting of Roofs and Floors

- In case of Pitched roofs, which are most vulnerable during earthquake and they are cladded with heavy, brittle and loose stone pieces or tiles. These tiles fall during shaking and cause injury. To avoid falling, they should be replaced by lightweight corrugated GI sheets properly connected to the walls through rafters.

- In case of sloping roofs, which have tendency to open up during earthquakes and there is a relative motion between eaves and crown that results in loosening and falling of cladding. For seismic safety, the roof should move as a whole and there should not be any relative motion of different members. This can be achieved by proper bracing in horizontal, vertical and inclined plane. For proper connection with the walls, anchor bolts are to be grouted into roof band/ wall to hold the rafters. In case of seismic belts, the bolts may be anchored to the roof belt.

- In case of wooden floors, the relative movement of planks and beams can be avoided by providing bracings and another layer of planks perpendicular to the existing planks. Floor consisting of pre-cast elements or steel sections with stones or tiles need to be integrated. This integration can be achieved by providing a RC topping on the floor and a RC edge beam with partial bearing on masonry walls.

- In case of jack-arch roofs and floors, supported by steel girders, the girders undergo relative movement during earthquake and result in collapse of roof. The relative motion is to be seized by providing steel strips or bars welded to the bottom of girders. These bars/strips should also be properly anchored to the walls.

- In case of pent roofs, hipped roofs in general have shown better structural behaviour during earthquakes than gable ended roofs.

4.7 Strengthening of Foundations

Strengthening of foundations is a costly affair and requires skill, but sometimes it may be necessary. The bearing area of the strip footing is increased by providing RC beams on both sides of the wall. These beams are interconnected at several locations through gaps created in the wall. This results in effective transfer of load from the wall to the added RC beams.

In addition to this, the drainage condition around the building is to be improved to avoid saturation of soil. A concrete apron around the building is helpful in avoiding direct soaking of the soil in the vicinity of the foundation.

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Chapter – 5

Retrofitting of Engineered Buildings

The RC buildings, which have systemic and rational approach in their design and construction, have been taken for discussing different techniques for retrofitting so that they may be able to withstand the seismic forces.

5.1 General

A large number of existing RC buildings need systematic retrofitting to make them safe for the occupants and the construction is going on at a much larger scale in the growing towns and developed mega cities. These buildings are considered to be engineered buildings, as a structural engineer is usually engaged in design and construction of these buildings.

Concrete construction is generally expected to give trouble free service through out its intended design life. However, these expectations are not realized in many constructions because of structural deficiency, material deterioration, unanticipated over loadings or physical damage. Premature material deterioration can arise from a number of causes, the most common being when the construction specifications are violated or when the facility is exposed to harsher service environment than those expected during the planning and design stages. Physical damage can also arise from fire, explosion as well as from restraints, both internal and external, against structural movement. Except in extreme cases, most of the structures require restoration to meet its functional requirements by appropriate repair techniques.

Concrete constructions, although, require proper care in the form of regular maintenance and buildings, which remain for several years without getting due attention may suffer due to water stagnation, paint pealing, plaster break-off, fungus growth, cracking of external rendering and cover concrete. Penetration of moisture into reinforced concrete components promotes corrosion process and further damages the concrete cover. These or similar to these are common and widespread problems/ defects, which should be given proper and effective treatment prior to further deterioration of the building.

5.2 Earthquake induced forces in RC building

Many existing buildings designed in past perform well under gravity loading due to which superficial defects occur and can be easily repaired, but they fail during natural calamity, if not been designed as per seismic strength requirements.

A typical RC building in which the horizontal members (beams and slabs) and vertical members (columns and walls) supported by foundations that rest on ground comprises a system of RC columns and connecting beams, called a RC frame. The RC frame participates in resisting the earthquake forces, which on shaking generates inertia forces in the building. Earthquake-induced inertia forces primarily develop at the floor

levels and travel downwards through slabs and beams to columns and walls, and then to the foundations from where they are dispersed to the ground. As inertia forces accumulate downwards from the top of the building, the columns and walls at lower storeys experience higher earthquake-induced forces and are therefore designed to be stronger than those in storeys above.

The infill walls usually made of brick masonry tend to resist the horizontal movement and develop cracks under severe ground shaking but help share the load of the beams and columns until cracking. Earthquake performance of infill walls is enhanced by mortars of good strength, making proper masonry courses, and proper packing of gaps between RC frame and masonry infill walls. An infill wall may be life threatening and fall out of plane, if it is unduly tall or long in comparison to its thickness.

For a building to remain safe during earthquake shaking

- columns (which receive forces from beams) should be stronger than beams
- foundations (which receive forces from columns) should be stronger than columns.
- connections between beams & columns and columns & foundations should not fail so that beams can safely transfer forces to columns and columns to foundations.

Note: If columns are made weaker, they suffer severe local damage, at the top and bottom of a particular storey. This localized damage can lead to collapse of a building, although columns at storeys above remain almost undamaged.

5.3 Strengthening of Existing members

Existing members of a building structure can be strengthened by selecting suitable scheme for strengthening. A number of techniques based on Steel / FRP plate bonding, RCC jacketing and FRP jacketing are available for strengthening of individual members. The choice of the technique depends on the specific weakness and demand on the member. Following points are to be considered in strengthening of individual members:

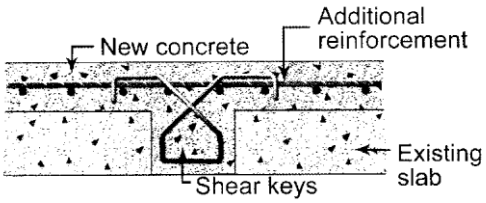
- A detailed study of manufacturer claimed properties of these materials is required before selecting a suitable material. Short-term as well as long-term properties are to be considered.
- The load transfer between old and new material can take place through several mechanisms, such as, compression against pre-cracked interfaces, adhesion between non-metallic materials, friction between non-metallic materials, load transfer through resin/glue layers, clamping effect of steel, dowel effect of steel, etc. It should be ensured that more than one mechanism of load transfer between new and old material are present.
- As far as possible, the anchorage lengths of reinforcement in new concrete should be as per codal specifications. However, in case of anchorage into old concrete, smaller anchorage lengths may be sufficient if special grouts are used to anchor the bars in drilled holes.

- Anchoring of additional bars can also be accomplished by welding them with existing bars. For this purpose, spacers can be provided between old and new bars to provide a gap for intrusion of concrete. The weld is to be designed to develop full strength in the new bar.

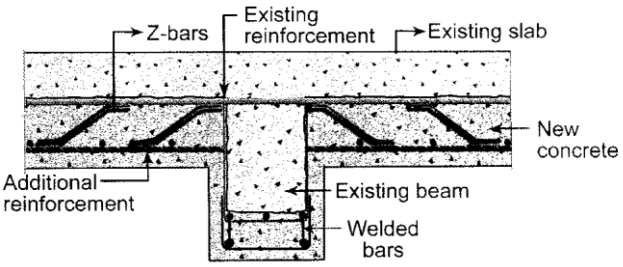
5.3.1 Strengthening of Slabs

Although, the slabs are strong enough to transfer load between different lateral load resisting vertical elements and if the building has irregularity in the form of opening in slab, the slab diaphragm may not be adequate to transfer forces between different elements. In such a condition, the strengthening is needed. In case of additional shear walls also the adequacy of the diaphragm needs to be evaluated and strengthening is to be done, if required.

RC slabs can be strengthened either by *over-laying* or by *under-laying*. In over-laying, thickness of slab is increased by cast in place concrete on the upper side. In under-laying, additional reinforcement is placed below the slab and thickness is increased using shotcrete. Here, it is important to emphasize the need of ensuring bond between old and new concrete.



Strengthening of Slabs by over-laying



Strengthening of Slabs by under-laying

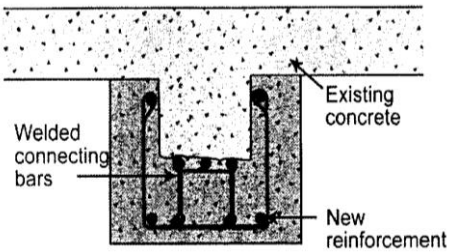
5.3.2 Strengthening of Beams

Beams can be strengthened either by RC jacketing or by gluing steel/ FRP plates. In RC jackets, reinforcement and concrete can be added either on three sides or on all the four sides. The longitudinal reinforcement of the jacket is to be welded with the existing longitudinal reinforcement through Z shaped links. Alternatively, the longitudinal reinforcement is to be anchored through a collar. The stirrups are either to be grout-anchored into slab or nailed into beam web using a strand. For placing the stirrups, closely spaced holes are to be made through slab. These holes may also be used for pouring concrete from the top.

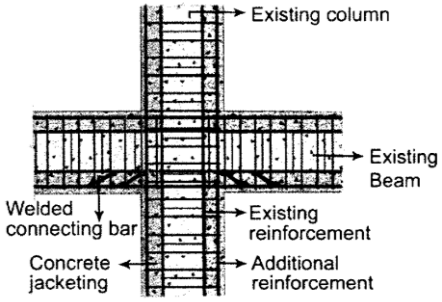
- Beams can also be strengthened by providing RC underlays on the lower face of the beam. However, these overlays can increase only flexural capacity of the beams.
- Another alternative to strengthen beams is by bonding of steel plates or FRP sheets. Steel plates or FRP sheets can be glued at bottom on three sides or on four sides of a beam. For effective action under earthquake loading, the joint is also to be strengthened.

Note: In case of jacketing on three sides, pouring of the concrete from top is not

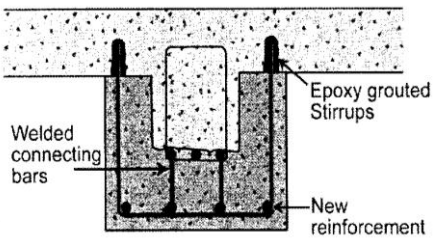
possible and shotcrete is to be used. Jackets on three sides can increase the flexural and shear capacity of beams under vertical loads only. These are not much effective under lateral loads, as the strengthening near joints is not effective. Jacketing on four sides of all the beams and columns meeting at a joint is the most effective solution, as it provides scope for strengthening of joint also.



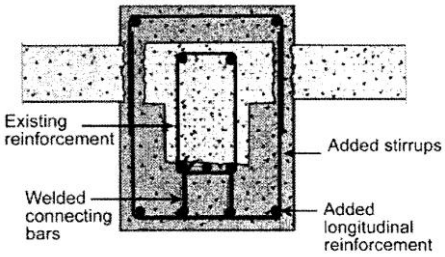
Stirrups anchored by strands



Jacketing on four sides of beams and columns



Beam Jacketing on three sides

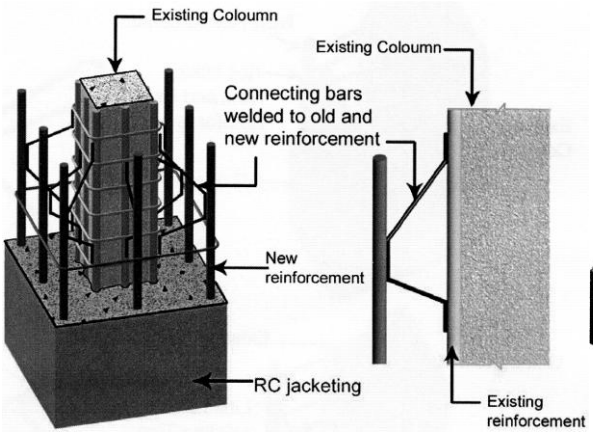


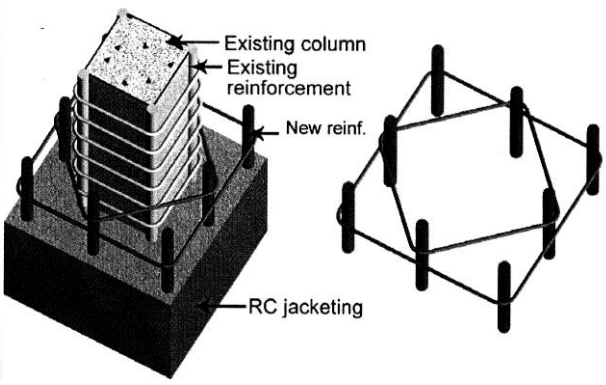
Beam Jacketing on four sides

5.3.3 Strengthening of Columns

Columns can also be strengthened by RC jacketing or by encasement using steel plates or FRP sheets. RC jackets are most effective if applied on all the four sides, but sometimes these may also be applied on only one or more sides of column. Two points are to be kept in mind in jacketing of columns (i) bond between the old and new material and transfer of forces to new reinforcement, and (ii) confining of concrete through proper placing and anchoring of transverse reinforcement.

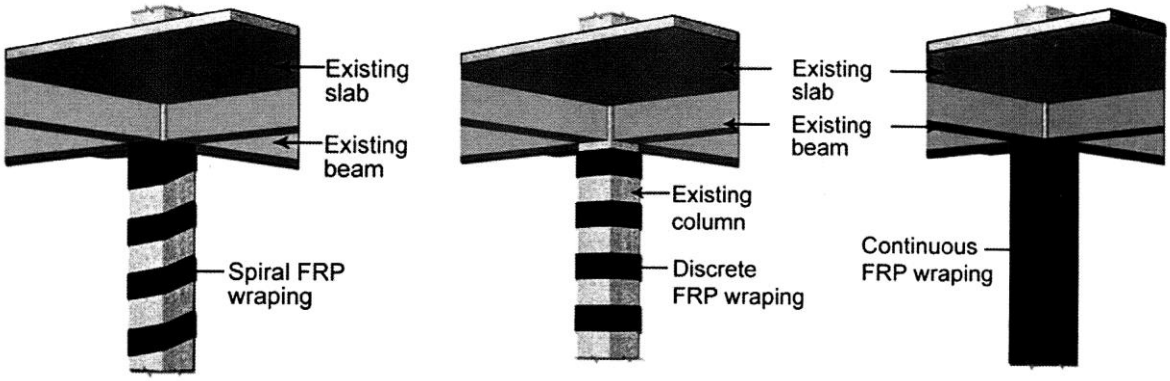
There are two alternative arrangements of reinforcement for jacketing of columns on four sides.



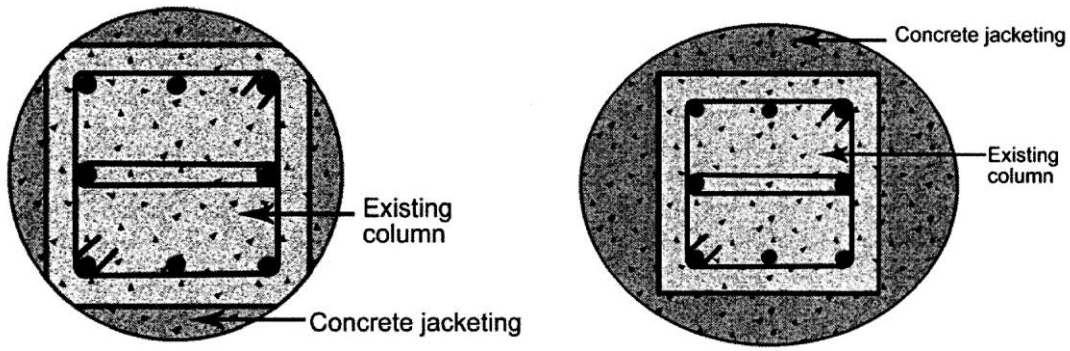


These jackets are very effective in increasing axial and shear strength. If the jackets are limited to the story height, these are not much effective against bending moment. Jackets should protrude through the slab to be effective in flexure.

Steel jackets have a problem that these tend to separate out due to Poisson's effect during loading. FRP encasement can be applied (i) by wrapping the columns using FRP straps, (ii) by complete encasement by FRP sheets, or (iii) by partial wrapping by FRP straps/sheets. Wrapping by FRP straps provides the possibility of pre-stressing the strap and hence is more effective.



Steel/FRP jackets are more effective if provided in elliptical shape as compared to rectangular shape. The column shape may be modified to elliptical shape for this purpose.



5.3.4 Strengthening of Walls

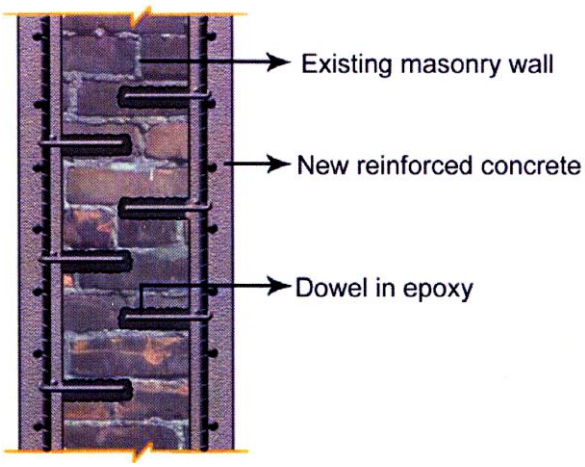
Existing masonry and RC walls can also be strengthened by providing RC jackets on one or both sides of the walls. It is customary to have half brick thick partitions in the interior of buildings. These partitions are unsafe under out of plane action during earthquake. Out of plane strengthening of partitions can be clubbed together with lateral strengthening of building by providing RC jackets to the partitions.

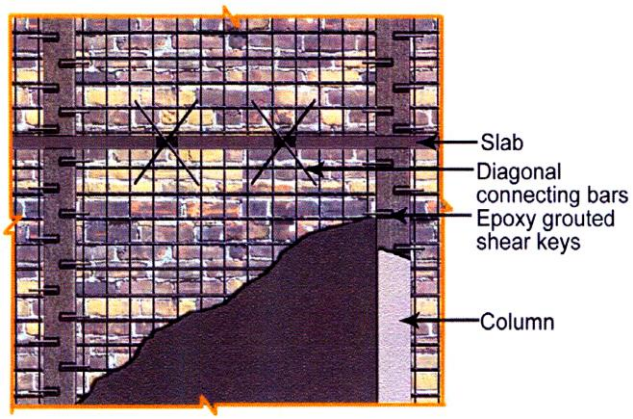
Some basic rules have been suggested for strengthening of walls by RC jacketing:

- The strength of new concrete must be at least 5 MPa greater than that of existing concrete.

- The minimum thickness of jacket should be 50 mm on each side.
- The minimum horizontal and vertical reinforcement should be 0.25% of the jacket section.
- The minimum reinforcement with which the ends of the wall are strengthened should be 0.25% of jacket section.
- The diameter of the ties at the well ends should not be less than 8 mm with a maximum spacing of 150 mm.
- The jacket must be anchored to the old concrete with dowels spaced at no more than 600 mm in both directions.

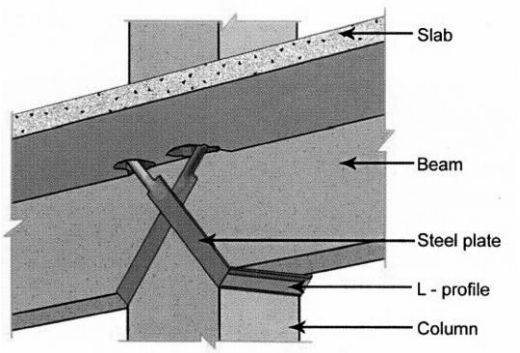
It is also important that the jacket should be able to transfer forces to slab diaphragms. This can be achieved by providing epoxy grouted anchors and diagonal connecting bars through holes made in slabs.

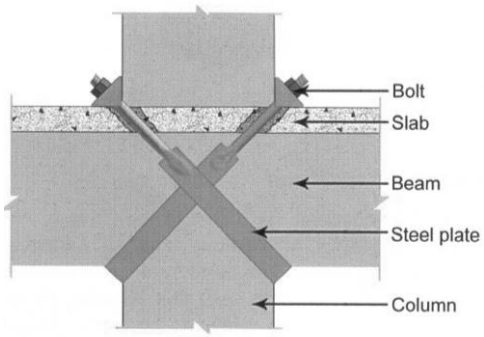




5.3.5 Strengthening of Joints

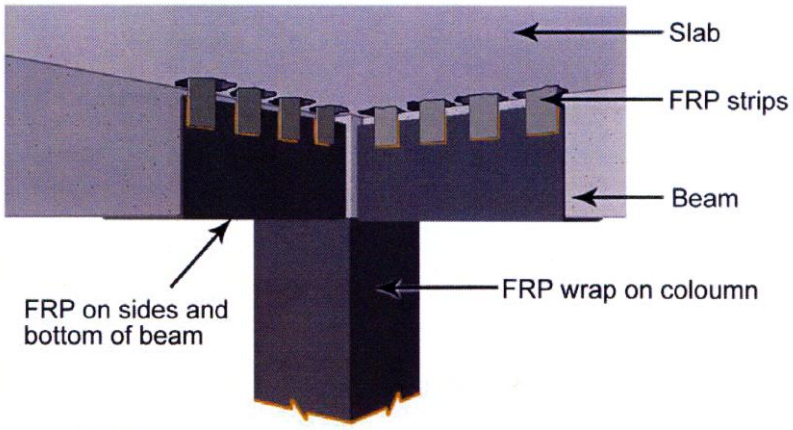
Strengthening of beam-column joints in RC building is perhaps the most difficult task in retrofitting of existing buildings. The joints are expected to behave rigidly during earthquake and their failure is to be avoided. In a planar joint (where two beams are meeting in plane) X-shaped collars may be provided. These collars have arrangement for pre-stressing. After providing collars the joint is covered by welded wire mesh and gunnite.





Glued steel plates or FRP sheets can also be used to strengthen a joint. This method does not alter the dimensions of the joint. There is a problem with steel plates that due

to Poisson's effect, the jacket tends to separate from the concrete and confinement is not effective. To avoid this, crimpled steel jackets are suggested. These jackets develop smaller longitudinal strains and hence smaller transverse strain and result in more effective confinement.



Note: RC jacketing is a very effective method of joint strengthening. However, placement of new reinforcement with proper confinement at joints is quite difficult. Several holes are to be punched through existing columns and beams for placing confining reinforcement. Pouring of concrete and getting a good bond between old and new concrete is also quite difficult.

5.3.6 Strengthening of Foundation

The foundations of an RC building can be strengthened by (i) increasing the bearing area with or without strengthening of column, and (ii) anchoring of column jacket reinforcement into foundation with or without strengthening of footing. The column moments maximum at base require proper anchorage of jacket reinforcement in to the footing. This can be accomplished by drilling holes into existing concrete of footing and epoxy grouting the longitudinal reinforcement of jacket. Another possibility is to provide full anchorage length for longitudinal reinforcement by extending the column jacket at the top of footing.

If the bearing area under a footing is not sufficient, it is to be increased by increasing the size of the footing. If the column is also being jacketed, it is easier to transfer the forces from the extended footing area to column jacket. There is a component of force, which tends to split the new concrete from old concrete. To avoid this splitting, sufficient number of closed rings with sufficient overlap or welded connection are to be provided around the footing.

If the bearing area is to be increased without strengthening of the column, soil pressure on the extended area is to be transferred to the existing footing. This is difficult as excavation is required below the existing footing. The building is to be properly supported and settlement is to be avoided. As can be seen from the force flow diagram, in this case also, there is a tendency of the new concrete to split from the old concrete. To avoid this, as in previous case, sufficient numbers of well anchored/welded hoops are required.

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OUR OBJECTIVE

To upgrade Maintenance Technologies and Methodologies & achieve improvement in productivity and performance of all Railway assets and manpower which inter-alia would cover Reliability, Availability, and Utilisation.

*The contents of this handbook are for guidance only & are **not statutory**. It also does not supersede any existing specification and instructions from Railway Board, RDSO, and Zonal Railways & the provisions of IRWM, BIS Codes/Reports on the subject. If you have any suggestion & any specific comments, please write to us:*

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