UNIT-I

OBJECTIVES:

- To gain the knowledge on quality of concrete and need for rehabilitation

SYLLABUS:

Introduction:

Deterioration of structures with aging; Need for rehabilitation

Learning Outcomes:

At the end of the lesson, the student will be able to

- know about physically and chemically induced deterioration
- identify the distress in concrete

INTRODUCTION

The overall durability of concrete is relatively good; otherwise it could not have become the most abundantly used building material in the world. Concrete is also a building material whose durability properties can be improved quite easily and in a versatile manner simply by selecting its constituents appropriately or by using proper admixtures. However, these possibilities have not been exercised sufficiently because too often the cheapest possible concrete type has been selected for the structure, despite the demanding environmental conditions to which it will be exposed. Not only have economical considerations during the building phase governed the choice of concrete type, but also lack of knowledge of different deterioration mechanisms and of the ways to improve the durability properties of concrete have been the reasons why the service lifespan of many contemporary concrete structures has been unexpectedly short.

At the global level, the cost of renovating deteriorating concrete structures is huge. It is usually the case that relatively inexpensive measures taken at the design and erection stage could have increased the service lifespan of these structures by a factor of two or even three.

In this chapter, the causes and deterioration mechanisms will be reviewed. The emphasis has been on the most important deterioration features which affect large volumes of concrete structures.

Repair

Actions that improve the functioning of a member of a structure. The member is lighter defective or deteriorated or damaged due to any reason such as earthquakes, cyclone, flood, fire, explosive, vehicle collision, corrosion cracking etc. the action may not be intended regain the original strength of the member completely.

Rehabilitation

Actions that improve the strength of a structure or a member which is deteriorated or damaged due to various reasons. Rehabilitation includes repair. The action is intended to regain the original strength of the structure or member.

Retrofit

Actions that improve the strength and other attributes of the integrity of a structure or a member with respect to resisting seismic forces. The structure or member need not be deteriorated or rehabilitation. The action is intended to mitigate the effects of future earthquakes.

Restoration

Actions that improve the strength and appearance of a structure. The term is used mostly for historical structures. Restoration may include repair for a deterioration or damaged structure.

Deterioration

The process that adversely affects the performance of a structural over time due to detects and damages occurred by naturally occurring chemical, physical or biological actions, repeated actions such as those causing fatigues, normal or severe environmental influences.

Causes of deterioration

i. Deterioration due to corrosion
ii. Environmental effects
iii. Poor quality material used
iv. Quality of supervision
v. Design and construction flaws

i. Deterioration due to corrosion

- Spelling of concrete cover
- Cracks parallel to the reinforcement
- Spelling at edges
- Swelling of concrete
- Dislocation
- Internal cracking and reduction in area of steel reinforcement.

ii. Environmental effects

Micro-cracks present in the concrete are the sources of ingress of moistures atmospheric carbon di-oxide into the concrete which attack reinforcement and with various ingredients of concrete. In aggressive environment concrete structure will be severely reduces.

iii. Poor quality material used

Quality of materials to be used in construction, should be ensured by means various tests as specified in the IS codes. Alkali-aggregate reaction and sulphate attack results in early deterioration. Clayey materials in the fine aggregates weaken the mortar aggregate bond and reduce the strength. Salinity causes corrosion of reinforcing bars as well as deterioration of concrete.

iv. Quality of supervision

Construction work should be carried out as per the laid down specification. Adherence to specified water-cement ratio controls strength, permeability durability of concrete. Insufficient vibration may result in porous and honey combined concrete, where as excess vibration may cause segregation.

V. Design and construction f laws

Design of concrete structures governs the performance of concrete structures. Well designed and detailed concrete structure will show less deterioration in comparison with poorly designed and detailed concrete in the similar condition. The beam-column joints are particularly prone to defective concrete, if detailing and placing of reinforcement is not done properly inadequate concrete cover may lead to carbonation depth reaching up to the reinforcement, thus, increasing the risk of corrosion of the reinforcement.

ROLE OF MOISTURE IN CONCRETE DETERIORATION

Concrete can be considered as one of the most non-homogeneous and demanding engineering materials used by mankind. This man-made artificial stone consists of aggregates having a wide dimensional range from sub- micron sized particles to several centimeters. Aggregate particles are usually surrounded by a highly porous transition zone, differing from the less porous bulk matrix of hydrated and partially hydrated cement paste. Void dimensions range from nanometer sized gel pores of calcium silicate hydrates to micrometer sized capillary pores and larger pores of several millimeters covering a dimensional range of over six orders of magnitude. The pore system is partially filled with water. The glue phase of calcium silicate hydrates is also very complicated, comprising amorphous and crystalline phases. One of the general features of concrete is the large number of cracks that are induced into it in normal climatic conditions. These defects are partly due to shrinkage tensions caused by the contraction of matrix gel and by moisture and temperature gradients between different parts of the concrete structure.

Effects of water–binder ratio and different binders

Almost all the durability problems of concrete are related to the pore size distribution of binder paste and to the degree of filling of pores by liquid. these features affect the pore water transport and subsequent pressures generated into the concrete matrix (concrete skeleton). How the deleterious substances can penetrate into concrete is mainly governed by the dimensions of the entrances between larger capillary pores and by the air-filled portion in the pore system. Cracks on the outer surface of the concrete structure also increase the penetration of water and deleterious substances into concrete. When the intruding deleterious substance is in the gaseous phase, diffusion takes place much faster if a considerable part of the pore volume is air-filled. Depending on the deterioration mechanism, there is usually a relative humidity range measured in the pore system, during which the deterioration mechanism proceeds at an increased rate. For example, the carbonation rate of concrete is highest at 50–70% relative humidity in ambient air. When the penetrating deleterious substances are in ionic form, the penetration rate depends on the concentration differences in pore water between the surface and interior concrete. Also, pressure difference between the different parts of the structure can act as the driving force which governs the penetration rate of the deleterious substances. In this type of transport mechanism, the dimensions of the entrances between much larger capillary pore voids and the size of the intruding molecules govern the permeability of concrete. In the case of the diffusion mechanism, Fick's first law is not adequate to model the transport mechanism of concrete, because there is also a counter- diffusion of ions having opposite charge which strongly affects the process. Similarly, in the case of liquid penetration, Darcy's law has been proven to be too simple. The effect of entrance dimensions between capillary pores and the air volume in them cannot be modeled with proper accuracy simply by using the material properties such as water/cement ratio or air content. Drying and wetting of concrete pore structure has a significant effect on the penetration rate, and this complicates the transport mechanism. Therefore, simple first-order diffusion and transport formulae cannot be applied in analyzing the deterioration rates in concrete. Additionally, the introduction of large air-filled protective pores (dimensions 0.02–0.1mm) by air-entraining admixtures successfully hinders the capillary flow of pore water and, therefore, air-entrainment affects all types of corrosion mechanisms in which deleterious substances intrude inside concrete from the surface of the structure.

If the binder is pure Portland cement, capillary pore volume can be calculated quite accurately as a function of water/cement ratio, hydration degree, and air content of fresh concrete. However, the effects of the entrance dimensions between larger capillary pore voids are not known sufficiently well to calculate the diffusion or permeability coefficients. The effect of additional binders such as condensed silica fume on total capillary porosity can be calculated but, again, knowledge of how it affects the entrance dimensions is not adequate. The effects of other secondary cementitiuous materials such as fly ashes are known to an even lesser degree. Hydration of ground granulated blast furnace slag (GGBS) produces in concrete a microstructure which differs remarkably from that when Portland cement alone is used. Hydration of GGBS resembles a surface reaction of the binder particles. If proper curing measures are applied, the permeability of slag concrete is much smaller compared to Portland cement-based concrete when both concrete types are produced with the same water/binder ratio. However, carbonation of slag concretes coarsens the pore structure and, during later ages, permeability of slag concretes is increased (Matala, 1995). Carbonation also increases the permeability of concretes in which secondary cementitious materials have been used. Such pozzolanic materials are condensed silica fume and fly ash. Additional hydration of cracked concrete can sometimes heal the structure if there is moisture available. In regions subject to freeze–thaw deterioration in particular, this healing during summer times can increase the lifespan of the structure. The variation in diffusion or permeability coefficients in different concretes produced by different cements and secondary cementitious materials is quite large. However, decreasing the water/cement or water/binder ratio and increasing the curing time makes all concretes more impermeable against penetration of deleterious substances and, thus, the estimated lifespan is increased. There exists also large deviation in the estimated lifespan due to different deterioration mechanisms. Therefore, no general rules can be given and different deterioration rates have to be assessed for different corrosion mechanisms.

Pore water transport and pore water tension- induced stress state

The pore system of concrete is seldom saturated by pore water. Therefore, there is a tensional stress state in pore water which causes compression in concrete. The tension in pore water can be calculated by applying Kelvin's equation:

$$P-P_o = R.T/V_w .In\ P_v/P_{vo}$$

In which R is ideal gas constant 8.314 J/mol/K, T is temperature in K, v_w is specific volume of water in m^3/mol, p_v is vapor pressure of pore water, p_{v0} is the saturation vapor pressure, and p_0 is atmospheric pressure 0.1 MPa.

When concrete begins to dry from the surface, the pore water tension generated causes compression on the surface concrete layer which decreases the permeability of the surface. However, during cyclic moisture loads, this compression is alleviated and cyclic moisture loads increase moisture transport through the surface layer. Then, the moisture flow is significantly increased compared to the situation when concrete dries without wetting and drying cycles. During freeze–thaw loads, the transport of water causes considerable pressure differences in the concrete cross-section which can exceed the tensional capacity of concrete. Similarly, cyclic freeze–thaw loads can pump large quantities of external water into concrete, causing increased freeze–thaw stresses. The inside of concrete also dries due to hydration causing self-desiccation, which generates large pore water tensions inside the structure. Together with shrinkage stresses, these generate cracks into concrete which can increase the transport of deleterious substances into it.

Physically induced deterioration

Corrosion loads and mechanisms of concrete and reinforcement can be divided into those of external and those of internal origin. External origin mechanisms usually include freeze–thaw deterioration, chloride ingress, carbonation, sulfate attacks, and acid attacks. Effects of alkalis on certain aggregates or deteriorations due to delayed ettringite reaction are included in internal origin mechanism. However, in this chapter the deterioration mechanisms are divided into physically and chemically induced mechanisms according to the main deterioration feature. The initiation of the deterioration mechanism can be caused by a single cause but, thereafter, the deterioration can continue as a combination of several other mechanisms. It can be quite difficult to assess which is the original cause of the initial corrosion.

Freeze–thaw deterioration

Two types of deterioration mechanisms are apparent in concrete structures exposed to freeze–thaw loads. In surface scaling, flakes of the outer surface disintegrate and the other mechanism, internal damage, is associated with cracking on the surface or interior of the structure. The causes of these mechanisms are different. large surface scaling is observed in concrete structures produced by a high water/cement ratio and low air content when the moisture content in the surface layer is high. The moisture content in the surface layer is high in situations when water is in direct contact with the surface or where there is heavy rain falling on the concrete structure. In these situations, cyclic freeze–thaw loads cause a pumping effect which increases the moisture content and degree of filling of the pore system at the surface to a large degree.

Effect of salts

If there are salts on the surface of concrete during freeze–thaw loads or if additional salts have intruded into the pore water, the deterioration is significantly more severe compared with normal concretes. Salts increase the surface scaling of the structure, and the deterioration can proceed very rapidly after only few freeze–thaw cycles. This seems to indicate that the main deterioration mechanism in salt-freezing is of physical origin. There are several research results that seem to indicate that a 2–4% salt concentration in the surface water layer causes severe deterioration and, if the salt concentration is higher, the deterioration decreases. However, some salts, especially calcium chloride, in large concentrations and after long exposure, can also cause chemical corrosion in concrete.

Estimated service lifespan assessment

In the 2004 Finnish concrete code (CAF, 2004), a calculation method for estimating service lifespan with regard to frost exposure and carbonation is presented. the expected service lifespan can be estimated by equation:

$$t_L = t_{Lr} \cdot A \cdot B \cdot C \cdot D \cdot E \cdot F \cdot G$$

Where t_L is the estimated service lifespan, t_{Lr} is the reference service lifespan (50 years) and *A*–*G* are lifespan coefficients reflecting various factors.

Table: Factors influencing frost resistance in Finnish concrete code

Coefficient	Factor	Design parameters
A	Materials, porosity	Air content and water/cement ratio
B	Design, structural details	Structure type, coating
C	Performance of work	Curing time
D	Interior climate	–
E	Exterior exposure to weather	Frost exposure class, Geographical direction
F	Working load	–
G	Maintenance measures	Inspection and maintenance frequency

Non-uniform volume changes and temperature gradients

Cracks on the concrete surface and around large aggregate particles can drastically increase the permeability of concrete. Cracks form a route for deleterious substances to penetrate into concrete, and this decreases the service lifespan of the structure. Cracks caused due to inadequate reinforcement against mechanical loads and cracking caused by fire loads.

Cracks can be generated in concrete at early ages, during the first days or weeks, due to hydration or production technology-related reasons. at later ages, the non-uniform volume changes are mainly caused by chemically induced reasons such as reinforcement corrosion, carbonation, and alkali- aggregate reactions.

Chemically induced deterioration

Carbonation, corrosion of steel reinforcement, effects of acids and sulfates, delayed ettringite formation, and alkali–aggregate reactions are the chemical reactions causing deterioration of concrete structures which will be discussed in this section. Carbonation of the surface layer of concrete does not damage concrete as such. It is important because it reduces the pH value in the pore water. This is a prerequisite for corrosion of steel reinforcement in situations when there are no chlorides in concrete pore water. Similarly, the ingress of chlorides into concrete can be caused by physical means, but chlorides substantially enhance the corrosion of steel reinforcement and, therefore, their effects will be considered together with reinforcement corrosion.

Carbonation

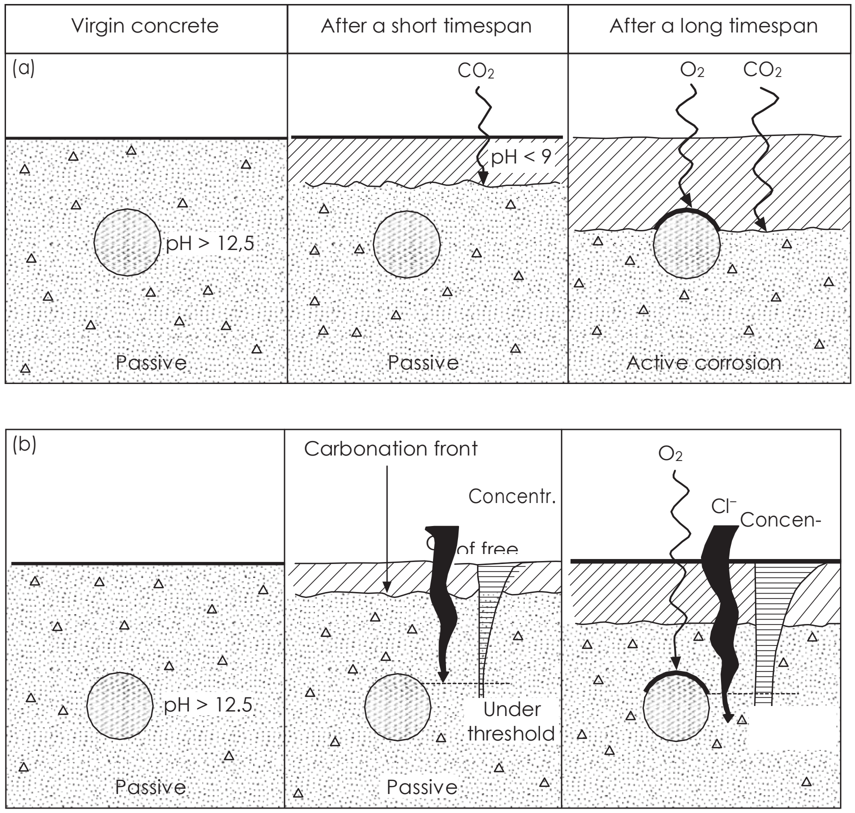
Air contains a small amount of carbon dioxide (0.03% in rural areas and 0.3% in large cities) and it dissolves into the pore water of concrete producing carbonic acid. Carbonic acid reacts readily with calcium hydroxide situated in pore water in dissolved and crystalline form. Reaction products are water and $CaCO_3$ or its polymorphs aragonite and vaterite. Calcium hydroxide is mainly responsible for the high alkalinity of pore water in concrete (pH-value 12.4–13.5) while $CaCO_3$ is nearly neutral (pH ~ 7). In this way, carbonation decreases alkalinity in pore water. Carbonation reaction needs a suitable amount of water to proceed. The highest rate of carbonation occurs at a relative humidity between 50 and 70% in the ambient air. When concrete is very dry or nearly saturated, carbonation rate is minimal. the reaction product of carbonation, $CaCO_3$, is larger than $Ca(OH)_2$ and, thus, the pore volume in concrete decreases when calcium carbonate precipitates on the pore walls of concrete. This decreases permeability of concrete.

When most of the available Ca $(OH)_2$ in the pore water has been consumed, C–S–H gel will also begin to disintegrate. eventually, all concrete constituents possessing CaO in their structure will carbonate after a long time. The compressive strength of carbonated, normal-strength concrete remains nearly unchanged because $CaCO_3$ and its polymorphs also carry loads in a manner similar to that of the virgin concrete. Carbonation of reinforced concrete structures poses no durability problems if the structure is situated in a dry environment, for example, indoors. However, if concrete is wet, carbonation of the reinforcement cover concrete can shorten the expected service lifespan significantly. Alkalinity of pore water forms a thin passivity layer of oxide on the reinforcement steel surface. This passivity layer completely protects the reaction of steel with oxygen and water, and reinforcement bars in non-carbonated concrete do not rust.

When carbonation has decreased the alkalinity of pore water near the surface of the steel bars to a pH value of approximately 9, the protective passivity layer on the steel surface is broken and, if oxygen and water are present, rusting of steel reinforcement begins according to test results, the depth of the carbonation layer from the surface of the concrete structure increases in proportion to the square root of time if the environment of the structure is under steady hygrometric conditions:

$$X = K \, . \sqrt{T}$$

Where x is the carbonation depth [mm], k is the carbonation coefficient [mm/ year0.5], and t is the exposure time [years]. This equation becomes effective after a couple of years carbonation.
The carbonation coefficient depends on the permeability of the surface layer of concrete and the relative humidity of the environment. When concrete is produced by using a low water/cement ratio, the carbonation rate decreases compared with low-strength concretes. If the surface is exposed to occasional rain so that the pore structure of concrete is nearly saturated part of the time, the carbonation rate is decreased compared with steady hygrometric conditions. the form of the carbonation depth equation is such that the rate of the penetration depth of the carbonated layer decreases with increasing time. An increase in the thickness of the reinforcement cover layer effectively increases the estimated service lifespan of the reinforced concrete structure by increasing the reinforcement corrosion initiation time.



Corrosion initiation of concrete reinforcement caused by carbonation or chlorides when concrete is wet: (a) carbonation- initiated corrosion and (b) chloride-initiated corrosion.

Four features which affect the carbonation rate have been examined above: carbon dioxide volume in the ambient air, permeability of the cover concrete over reinforcement, pore filling degree (moisture content) of the cover concrete, and the thickness of the cover concrete

Penetration of chlorides into concrete

Reinforcement corrosion is one of the major deterioration mechanisms of reinforced concrete structures worldwide. the presence of chlorides increases the severity of the corrosion attack considerably. Chlorides can penetrate into concrete which is in contact with de-icing salts or seawater. typical structures that are damaged by chloride-initiated reinforcement corrosion include bridges, car parking structures, and off-shore structures such as piers, dams, docks, and harbor structures.

Reactions in binder paste and aggregates

The chemically induced deterioration mechanisms to be examined in this section are sulfate attack, acid attack, and alkali–aggregate deterioration reactions.

Sulfate attack

Sulfate attack is initiated when water-soluble sulfates (SO_2 –) , originating from ground or from seawater, penetrate into concrete pore water and^{4}react with aluminates or calcium hydroxide in cement paste. Reaction products expand remarkably which causes crack propagation and decreases the strength properties of concrete.

Acid attack

Due to the high alkalinity of pore water (pH 12.5–14) in concrete, all binder paste constituents are stable in this environment. All strong acids ($pH < 4.5$) and many weak acids ($5.5 < pH < 6.5$) effectively decrease pore water alkalinity and attack $Ca\ (OH)_2$ and C–S–H gel of the binder paste. Most aggregates endure acid attack much better compared with the binder paste. Acid attack is a surface phenomenon similar to carbonation and, therefore, the penetration depth is a function of the square root of time. The decomposition of hydration products forms new compounds which, if they are soluble, may be leached out from the structure. Some compounds can be disruptive as such, for example, H_2SO_4 is a combination of acid attack and sulfate attack.

Alkali–aggregate reactions

There are two reaction types causing deleterious swelling of concrete in moist environment due to reactions between alkalis (na_2O and K_2O) and certain aggregates. In alkali–silica reaction, the reactive forms of silica are opal, chalcedony, and tridymite, which occur in opaline or chalcedonic cherts, siliceous limestones, and some volcanic rocks as rhyolites. Alkali–carbonate reaction is caused between some dolomitic limestone aggregates and the alkalis of the cement.

Need for rehabilitation

Distress Identification

Before attempting any repair procedure it is necessary to have a planned approach to investigate the condition of concrete and reinforcement. While the diagnosis of damage or deterioration in some cases is reasonably straightforward, it may not be so in many cases. Particularly difficult are cases in which the cause and effect phenomenon cannot be readily explained or when prognosis in terms of long-term performance of restored structure is to be made.

This will require a thorough technical inspection and an understanding of the behaviour of the structural component, which is being repaired. Inspection calls for detailed mapping of affected areas, documentation of type and location of symptoms and their history and photographic evidences. It may also include the environmental factors, which are likely to accelerate the damage process. Existence of concealed ducts, water lines, wet areas require special attention. Some areas impose severe limitations on access to damaged areas. A comprehensive inspection data helps in making an effective strategy for repair and rehabilitation.

Non-destructive evaluation (NDE) of concrete and components are well known and extensively used. While they are very good tools for establishing quality levels in new constructions, applying these techniques to damaged structures requires certain level of experience and understanding of limitations of these methods. Solving the problem successfully is entirely dependent on the ability of a team of experts engaged to do this job. Both field and laboratory tests are available. It is important to select the appropriate Non Destructive Evaluation (NDE) techniques and location of investigation. This is a specialized job and requires sophisticated instruments and trained personnel. 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.

Concrete normally provides excellent protection to reinforcing steel. Notwithstanding this, a large number of cases have been reported in which corrosion of reinforcement has caused damage to concrete structures within a few years from the time of construction. One of the most difficult problems in repairing a reinforced concrete element is to handle corrosion damage. Reinforcement corrosion caused by carbonation is arrested to a great extent through repairs executed in a sound manner. However, the treatment of chloride-induced corrosion is more difficult and more often the problem continues even after extensive repairs have been carried out. It invariably re-occurs in a short period of time. Repairing reinforcement corrosion involves a number of steps, namely, removal of carbonated concrete, cleaning of reinforcement, application of protection coat, making good the reduced steel area, applying bond coat and cover replacement. Each step has to be executed with utmost care. When chlorides are present in concrete, it is extremely difficult to protect reinforcing steel from chloride attack, particularly in cases where chlorides have entered through materials used in construction and residing in the hardened concrete. For such cases, new technologies are available which require specialists to execute the job.

Repair Management

Three distinct stages are to be recognized while taking up a repair job. The first stage involves documentation of damage, its type and extent, prognosis of repaired structure and recommendations on repair methodology. For major jobs it will be worthwhile to engage an independent consultant to do this job. The second stage requires preparation of detailed drawings, sketches, execution guidelines and notes, material and works specifications and tender document. The tender document should adequately cover various elements to the extent possible. Specific provisions in terms of material specifications should be included. It should clearly define modalities of payment, works measurements and records. This will facilitate in receiving a fair and competitive proposal for the repair works. Guidelines prepared for executing the job should be practical and flexible so as to encourage the ingenuity of the contractor executing the job. The third stage is actual execution of repairs. This is a specialized job and those who have the necessary expertise and resources in terms of tools and plants should be engaged. The supervising engineer should have a good understanding of the procedures and give an attentive supervision. In some cases it may become necessary to monitor the effectiveness of repairs by various tests before and after the repairs have been executed.

Various options in terms of techniques and repair materials are available for executing repair jobs. Selecting a most appropriate material and repair methodology is very important to achieve durable, effective and economic repairs. Matching the response of repaired sections with the main structure is an important task. Compatibility of materials and matching specifications are essential in any repair job. Just as building durable construction requires understanding of structural engineering, material science, and environment/ exposure conditions, repair jobs also require the same level of attention in these areas.

The buildings taken up for repair may have structural deficiency and in such cases it is necessary to consider provisions for strengthening through bracing and creating alternative load transfer framing to give additional reserve strength to the structure for adequate safety and serviceability response. If this aspect is overlooked, the symptoms are likely to reappear even after repairs have been carried out.

Familiarity with repair methodology and repair materials is very essential. General civil en1gineering practice does not offer much scope in this area. The engineer undertaking such specialized jobs should have good knowledge of new materials, repair methodologies, its limitation and the fundamentals of structural engineering to ensure safety and serviceability of the buildings during repair and thereafter.

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. What is meant by deterioration?
2. Define repair?
3. Define rehabilitation?
4. Define restoration?
5. Define retrofit?
6. List out various physical and chemical induced deterioration

II) Descriptive Questions

1. What are the causes of deterioration?
2. Describe briefly about freeze-thaw deterioration.
3. What are the effects of slats on deterioration?
4. How do we asses estimated service life span
5. Hoe carbonation effect in deterioration.
6. Describe briefly about reactions in binder paste

B. Question testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. What is the percentage of salt concentration in the surface water layer that causes deterioration
   a. 1-2 %
   b. 2-4%
   c. 2-5%
   d. 2-3%
2. What are the various causes for deterioration
   a. Environmental effects
   b. Poor quality materials used
   c. Quality of supervision
   d. All the above
3. Deterioration mechanisms are divided into
   a. Physically induced deterioration
   b. Chemically induced deterioration
   c. Both a and b
   d. None of the above
4. Air entrainment in the concrete increases
   a. Workability
   b. Strength
   c. The effects of temperature variations
   d. The unit weight
5. Increase in the moisture content in concrete
   a. Reduces the strength
   b. Increases the strength
   c. Does not change in the strength
   d. All of the above
6. The percentage of voids in cement is approximately
   a. 25 %
   b. 40 %
   c. 60 %
   d. 80 %
7. The property of fresh concrete, in which the water in the mix tends to rise to the surface while placing and compacting, is called
   a. Segregation
   b. Bleeding
   c. Bulking
   d. Creep
8. The property of the ingredients to separate from each other while placing the concrete is called

a. Segregation
b. Compaction
c. Shrinkage
d. Bulking

II) Descriptive Questions

1. Explain the various causes of deterioration.
2. How moisture content effects on deterioration of concrete
3. What are the various factors involve in physically induced deterioration.
4. What are the various factors involve in chemically induced deterioration.
5. What is the importance of learning rehabilitation of concrete structures?
6. Explain briefly about repair management.

UNIT-II

OBJECTIVES:

- To impart an awareness of damage assessment of various types of deteriorations.

SYLLABUS:

Types of damages, Sources or causes for damages, effects of damages, Case studies on Non destructive evaluation, Importance-Concrete behavior under corrosion, Disintegrated mechanisms, Moisture effects, Thermal effects

Learning Outcomes:

At the end of the lesson, the student will be able to

- identify the different types and causes of damages
- know the importance of concrete behavior under different conditions

Types of concrete damage

Damage to concrete structures can be categorized in different ways. The classification can be made in terms of damage types, causes, mechanisms of attack, frequency of defects, kinds of deficient structures, financial loss due to different defects, amount and extent of repair measures, etc. let us consider first the type of concrete damage, and then its causes and mechanisms.
Concrete damage can be of the following main types, this classification is based on the simple visual appearance of concrete defects.

1. scalling
2. spalling
3. curling
4. cracking

1. **Scaling** is one of the leading complaints of many homeowners and probably the easiest defect of a concrete surface to avoid. When concrete scales, for example, as a result of freezing and thawing cycles, the finished surface flakes or peels off. Generally it starts as localized small patches, which later may merge and extend to expose large areas. Light scaling does not expose the coarse aggregate. Moderate scaling exposes the aggregate and may involve loss of up to 2.5–10mm of the surface mortar. In severe scaling, more surface material is lost and the aggregate is clearly exposed and stands out. Scaling is primarily found in outside concrete flat work such as sidewalks, patios, and driveways. In most cases it is blamed on de-icing salts used on the concrete during the winter months. Despite these assertions, the truth is that properly specified, placed, and cured concrete should be able to endure the effects of typical de-icing agents.

2. Spalling can be described as the breaking of layers or pieces of concrete from the surface of a structural element. Spalling occurs often when concrete is exposed to the high and rapidly rising temperatures experienced in fires; however, it can be also a result of other mechanisms, such as steel corrosion or improper design/technology of pre tensioning steel for pre stressed concrete members.

There are four main types of concrete spalling:

Surface spalling – affects aggregate on the concrete surface, whereby concrete fragments typically up to 20 mm in diameter become detached

corner break-off or sloughing off – this tends to occur in the later stages of a fire and affects more vulnerable concrete on wall corners where it is heated on two planes

Explosive spalling – early rapid heat rise forcibly separates pieces of concrete at high pressure, with an 'explosive' effect; this form of spalling is considered as the most dangerous one;

Corrosion spalling – when reinforcing bars rust, their volume increases and steel cover becomes detached

3. Curling is the upward or downward bending of the edges of a concrete element (usually slab or beam), giving the concrete member a cupped shape. The curled edges are unsupported by the base, making them susceptible to cracking under heavy loads.

4. Cracking is a path of the (local) separation of a structural element or material into two, or more, pieces under the action of stress. Cracking, like corrosion of reinforcing steel, is not commonly a cause of damage to concrete. Instead, cracking is a symptom of damage created by some other cause. For example, cracking can be the result of one or a combination of factors, such as drying shrinkage, thermal contraction, restraint (external or internal) to shortening, sub grade settlement, and applied loads. While cracks may develop in concrete for a variety of causes, the underlying principle is the relatively low tensile strength of concrete.

Causes and mechanisms

Classification of concrete damage based on the causes and mechanisms, which are observed the most frequently by the eyes of the practicing civil engineer, and we will follow this classification in further sections:

1. Chemical attack
2. Fire
3. Static overloading
4. Impact
5. earthquakes
6. Malicious damage

1. Chemical attack

Damage due to chemical attack can be classified by following main categories:

a. Damage caused by acidic reactions;
b. Damage caused by aggregate reactions – for example, by alkali–silica reaction;
c. Damage due to chloride attack.

Acids react with calcium hydroxide, which is formed in the course of cement hydration. The products of acidic reactions are highly soluble and can be easily removed by leaching.

Acidic reactions occur in the cement paste matrix, but they affect the aggregate integrity, the process leading to the damage of concrete. Depending on the type of coarse aggregate, two different mechanisms of aggregate damage can be distinguished:

Granite aggregate – gradual dissolution of the cement paste matrix results in disintegration of the aggregate particles.

Dolomite or limestone aggregate – the acidic reaction in the cement paste matrix uncovers the aggregate surface, dissolves the aggregate material – the process significantly increases the contact of the acid with concrete, and therefore the rate of the dissolution of concrete in structures increases by many times. This is illustrated further in the case studies. In cases when concentrated acids leak, the process of dissolution occurs very rapidly – acids simply dissolve structures

2. Fire

Fires can be caused by accident, energy sources, or natural means, but the majority of fires in buildings are caused by human factors (e.g. discarded cigarettes). Once a fire starts and the contents and/or materials in a building are burning, then the fire spreads via radiation, convection, or conduction with flames reaching temperatures of between 600 and 1200 °C.
During the fire concrete undergoes severe micro structural changes, which are caused by complex physical and chemical mechanisms these lead to irreversible structural damage

The main harm in fire is caused by a combination of the effects of smoke and gases, which are emitted from burning materials, and the effects of flames and high air temperatures. The most serious form of damage to concrete under fire is explosive spalling, which occurs usually during the first 30 minutes after fire starts

spalling can be caused by improper methods of fire suppression. For example, spalling can also occur when concrete, exposed to the heat of a fire, is hit by a cold water stream from a fire fighting hose.

3. Static overloading

The type and extent of the damage due to overloading depend on the static scheme of the structure. In any case, the result of overloading is the development of high stresses exceeding the stress limits. For example, overloading of the beam or slab over the span results in appearance of 'bending' cracks in the areas of extreme bending moments. Overloading by the shear load in the areas adjacent to the supporting parts of the columns results in diagonal cracking in the vicinity of slab–column (beam–column) joints and separation of the column.

Even in the case when overloading results in the formation of small cracks, their appearance (or ignoring the need to repair them) can promote the accumulation of chlorides or other harmful species on the crack surfaces and in their vicinity when concrete is exposed to aggressive environments. The further stages of the damage will be dictated by inevitable corrosion of the reinforcement.

Mistakes in choosing the structural calculation scheme or in calculating the design loads result in overloading, and this often causes to damage to the structure or a part of it. The design and calculation of the structure on a regular uniform snow load, when the configuration of the structure provokes a formation of snow pockets

4. Impact

Dynamic overloading is another cause of damage to concrete and concrete structures. This section and the next sections deal, respectively, with impact and seismic loads as the main types of dynamic overloading.

The character of the impact damage in concrete structure depends, to a large extent, on the modulus of elasticity of concrete. In general,the higher the modulus of elasticity, the more brittle the material. This relation is known for high-strength concrete, which, in general, is more prone to brittle failure than normal-strength or low-strength concrete. During an earthquake, the structures absorb some energy, while the energy absorbed depends on the load and displacement. The small local displacement of high-strength concrete, for example, leads to significant growth of the load applied and, in turn to drastic growth of the local stresses and severe deterioration of the concrete, while in normal- or low-strength concrete the same energy is absorbed by local crushing or small spalling.

5. Earthquakes

The main difference between earthquake action on the structure and other cases of overloading is that the seismic load is not a local effect, but an overall load applied to the whole structure. The seismic loads are cyclic sign-changing loads. Basically, an earthquake is a special case of the dynamic overload closely related to the frequency of the structure itself. When the structure's frequency coincides with the earthquake frequency, resonance occurs in the structure or in its parts. Various consequences of earthquake such as settlements, ground breaks, and movements lead to unpredicted static overloading of structures and, as a result, to their failure.

Acceptable level of damage in performance-based design

Operational	Structural	Acceptable level of damage
Little or no loss serviceability	Minor or no damage	Degree I: Serviceable
Short-term loss of serviceability	Controlled damage	Degree II: Repairable
Long-term or complete loss of serviceability	Extensive damage in near collapse	Degree III: Near collapse
Complete loss of serviceability	Complete loss of structure	Degree IV: Collapse

Performance grades S, A, B, and C

Design earthquake		Performance grade
Level 2	**Level 1**	
Degree I: Serviceable	Degree I: Serviceable	Grade S
Degree II: Repairable	Degree I: Serviceable	Grade A
Degree III: Near collapse	Degree I: Serviceable	Grade B
Degree IV: collapse	Degree IV: Repairable	Grade C

6. Malicious damage

Faulty maintenance, human mistakes or wrecking/sabotage are considered here as cases of malicious damage. Both faulty maintenance and unintended human mistakes, such as smashing of vehicles, are a very frequent cause of the damage in the majority of industrial and transportation concrete structures. The consequences are different: from local spalling to the overall collapse of the structure

The following are common causes of damage to concrete:

1. Excess of concrete mix water
2. Faulty design
3. Construction defects
4. Sulfate deterioration
5. Alkali–aggregate reaction
6. Deterioration caused by cyclic freezing and thawing
7. Abrasion–erosion damage
8. Cavitations damage
9. Corrosion of reinforcing steel
10. Acid exposure
11. Cracking
12. Structural overloads
13. Multiple causes

Concrete behavior under corrosion

Embedded metal corrosion process

Concrete is a high alkalinity material. the pH of newly produced concrete is usually between 12 and 13. in this range of alkalinity, embedded steel is protected from corrosion by a passivating film bonded to the reinforcing bar surface. However, when the passivating film is disrupted, corrosion may takes place.

Corrosion Inhibitors

- High quality concrete
- High pH
- Concrete protects steel surface from corrosion

Corrosion promoters

- Oxygen
- Water
- Stray electrical currents
- Uneven chemical environment around reinforcement
- Environments that lower the pH
- chlorides

Disintegration mechanisms

Chloride penetration

Chlorides can be introduced into concrete by coming into contact with environments containing chlorides such as sea water or de-icing agents.

Penetration of chlorides starts at the surface and then moves inward.

Eventually the concentration of chlorides in contact with the reinforcing steel will cause corrosion when moisture and oxygen are present.

Accelerated corrosion takes place because of easy access of corrosive salts, oxygen and moisture.

It was demonstrated that a threshold level of 8000ppm of chloride ions was required to initiate corrosion when the pH was 13.2.

Cracks and Chlorides

Cracks and construction joints in concrete permit corrosive chemicals such as de-icing salts to enter the concrete and access embedded reinforcing steel

Steel corrosion may take place even in a high alkaline environment if chlorides are present. Chlorides are not consumed in the corrosion process, but instead act as catalyst to the process, but instead act as catalyst to the process and remain in the concrete.

The corrosion process is progressive, beginning at the intersection of the crack with the reinforcing bar, then progressing along the bar.

Dissimilar metal corrosion

Corrosion can takes place in concrete when two different metals are act into a concrete structure, along with an adequate electrolyte. A mist concrete matrix provides for a good electrolyte. This type of corrosion is knows as galvanic.

Below is a list of metals in order of increasing activity:

1. Zinc
2. Aluminum
3. Steel

4. Iron
5. Nickel
6. Tin
7. Lead
8. Brass
9. Copper
10. Bronze
11. Stainless steel
12. Gold

Aluminum has less activity than steel therefore the aluminum is the metal that corrodes.

Moisture Effects

Introduction

In fresh concrete, the space between the particles is completely filled with water. The excess water evaporates after the concrete hardness. The loss of moisture causes the volume of the paste to contract. This, in turn, leads to shrinkage stress and shrinkage cracking.

Drying Shrinkage

On exposure to the atmosphere, concrete loss some of its original water through evaporation and shrinks. Normal weight concrete shrinks from 400 to 800 micro strains (one micro strain is equal to 1 X 10-6 in. /in. (mm/mm)

Volume Change

Concrete changes length depending upon its moisture content. Moist concrete that dries out will shrink, while dry concrete that becomes moist will expand. Concrete may follow seasonal changes: hot, humid summers generate higher moisture contents, while cold, dry winters reduce moisture contents. Drying shrinkage values are based on an initial 100 percent moisture content reduced to an ambient relative humidity of about 50 percent.

Curling

Curling is a common problem with slabs cast on grade. Curling is caused by uneven moisture and temperature gradients across the thickness of the slab. Curling is increased as drying shrinkage progresses. The contraction of the top surface can only be relieved by the slab curling upward. Temperature gradients across a slab can create the same problems as moisture gradients. The typical situation is solar heating of the slab's top surface, causing a higher temperature on this surface. The top surface then has a tendency to grow in length relative to the bottom surface. Stress relief occurs when the slab curls downward.

Thermal Effects

Introduction

The effect of temperature on concrete structures and members is one of the volume change. The volume relationship to temperature is expressed by the coefficient of thermal expansion/contraction. Volume changes create stress when the concrete is restrained. The resulting stresses can be of any type – tension, compression, shear etc. the stress condition may result in undesirable behavior such as cracking, spalling and excessive deflection.

Thermal Volume Change

Concrete, like all materials, changes volume when subjected to temperature changes. An increase in temperature increases the volume of concrete; conversely, a decrease in temperature reduces the volume of concrete. The thermal coefficient of concrete is approximately 9×10^{-6} mm/mm/^{0}c.

Uneven Thermal Loads

Large exposed cooling towers can undergo uneven thermal stresses as the sun makes its way from east to west. The cooling tower has a relatively thin concrete shell, which is easily heated by sun. The sun rays hit only about 50 percent of the towers shell at any one time. The portion of the tower that is being heated expands in size relative to the cool side of the tower. An egg shaped cross section is formed, which moves as the sun moves, heating other portions of the tower.

Fire Damage

Fire effects concrete in extreme ways, some of them are

1. Uneven volume changes in affected members, resulting in distortion, buckling and cracking. The temperature gradients are extreme from 21^0c to higher than 800^0c at the source of the fire and near the surface.
2. Spalling is rapidly expanding concrete surfaces from extreme heat near the source of the fire.
3. The cement mortar converts to quicklime at temperatures of 400 ^{0}c, thereby causing disintegration of the concrete.
4. Reinforcing steel loses tensile capacity as the temperature rises.
5. Once the reinforcing steel is exposed by the spalling action, the steel expands more rapidly than the surrounding concrete, causing buckling and loss of bond to adjacent concrete where the reinforcement is fully encased.

Assignment-Cum-Tutorial Questions

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. Define scaling
2. What is spalling
3. What is curling
4. What is cracking
5. List out the corrosion promoters
6. List out the metals in order of increase the corrosion activity

II) Descriptive Questions

1. How spalling causes damage to concrete and write the types of concrete spalling
2. What are the main causes of damage to concrete
3. Classify the damage that occurred due to chemical attack
4. How the action of earthquakes effects in concrete damage
5. write about the malicious damages in concrete
6. How fire effects in concrete damage

B. Question testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. Light scaling does not expose the ---------------aggregate
   a. Coarse aggregate
   b. fine aggregate
   c. mortar
   d. reinforcement
2. In surface spalling the diameter of the aggregates detached is
   a. 10mm
   b. 15mm
   c. 30mm
   d. 20mm
3. Curling is -------------bending of the edges of a concrete element
   a. inward or outward
   b. inward or upward
   c. upward or downward
   d. inward or downward
4. the most serious form of damage to concrete under fire is explosive spalling, which occurs during the first ---------------minutes after fire starts
   a. 30
   b.20
   c. 50

d. 40

5. Impact loading is a type of
   a. dynamic loading
   b. static loading
   c. other loading
   d. All of the above
6. Normal weight concrete shrinks from-----------micro strains
   a. 400-700
   b. 400-800
   c. 800-700
   d. 400-600
7. Drying shrinkage values are based on an initial 100 percent moisture content reduced to an ambient relative humidity of about ----------percent
   a. 40
   b. 50
   c. 30
   d. 20
8. Reinforcing steel loses tensile capacity as the temperature-------
   a. rises
   b. downs
   c. remains constant
   d. none of the above

II) Descriptive Questions

1. Explain various types of concrete damage?
2. What are the various factors effecting the reinforcement in concrete?
3. Elaborately explain about the effects of temperature on concrete?
4. Explain about the effects of moisture on concrete?
5. Discuss briefly about the causes and mechanisms of concrete damage?
6. Explain the importance of concrete behavior under corrosion?

UNIT-III

OBJECTIVES:

- To impart an awareness on damage testing methods.

SYLLABUS:

Damage testing methods; Non-destructive testing methods**,** Visual investigation Acoustical emission methods- Corrosion activity measurement, chloride content, Depth of carbonation, Impact echo test, Ultrasound pulse velocity methods, Pull out tests.

Learning Outcomes:

At the end of the lesson, the student will be able to

- identify causes of distress and their sources
- assess the residual strength of the structure and its rehabilitability

STAGES

Stages for carrying out Condition Survey, largely depend on field conditions, user habits, maintenance, etc, and have a direct relation with the pattern of distress, whether localized or spread over.

Condition Survey of a building/structure is generally undertaken in four different stages to identify the actual problem so as to ensure that a fruitful outcome is achieved with minimum efforts & at the least cost. The four stages of Condition Survey are:

1. Preliminary Inspection
2. Planning
3. Visual Inspection
4. Field /Laboratory testing

VISUAL INSPECTION

1. Visual examination of a structure is the most effective qualitative method of evaluation of structural soundness and identifying the typical distress symptoms together with the associated problems.
2. This provides valuable information to an experienced engineer in regard to its workmanship, structural serviceability and material deterioration mechanism.
3. It is meant to give a quick scan of the structure to assess its state of general health.
4. The record of visual inspection is an essential requirement for preparation of realistic bill of quantities of various repair items.
5. Experienced engineers should carry out this work as this forms the basis for detailing out the plan of action to complete the diagnosis of problems and to quantify the extent of distress.
6. Simple tools and Instruments like camera with flash, magnifying glass, binoculars and gauge for crack width measurement, chisel and hammer are usually needed. Occasionally, a light

platform/scaffold tower can be used for access to advantage.

Table: Commonly Observed Order of Deterioration of RCC Building

Commonly Observed Order	Location of RCC component
First	Wet / water stagnating areas with RCC elements located on external direct exposed walls/slabs and frequented with alternate wetting/drying cycle.
Second	Thin exposed non structural RCC elements e.g. railings, facias, fins etc
Third	Terrace RCC slab with ineffective insulation, water proofing and drainage systems
Fourth	Wet areas with RCC elements located on inner unexposed walls and frequented with alternate wetting/drying cycle
Fifth	Beams/columns with one face exposed direct to sun and rain and the other face unexposed.
Sixth	Beams/Columns exposed to rain and sun from all sides.
Last	Beams/Columns/Slabs located in the interior of building.

NON-DESTRUCTIVE EVALUTION TESTS:

A number of non-destructive evaluation (NDE) tests for concrete members are available to determine in-situ strength and quality of concrete. Some of these tests are very useful in assessment of damage to RCC structures subjected to corrosion, chemical attack, and fire and due to other reasons.

Concrete strength assessment

A) Ultrasonic pulse velocity test (UPV)

Ultrasonic scanning is a recognized non-destructive evaluation test to qualitatively assess the homogeneity and integrity of concrete. With this technique, following can be assessed

1. Qualitative assessment of strength of concrete, its gradation in different locations of structural members and plotting the same

2. Any discontinuity in cross section like cracks, cover concrete delamination etc

3. Depth of surface cracks.

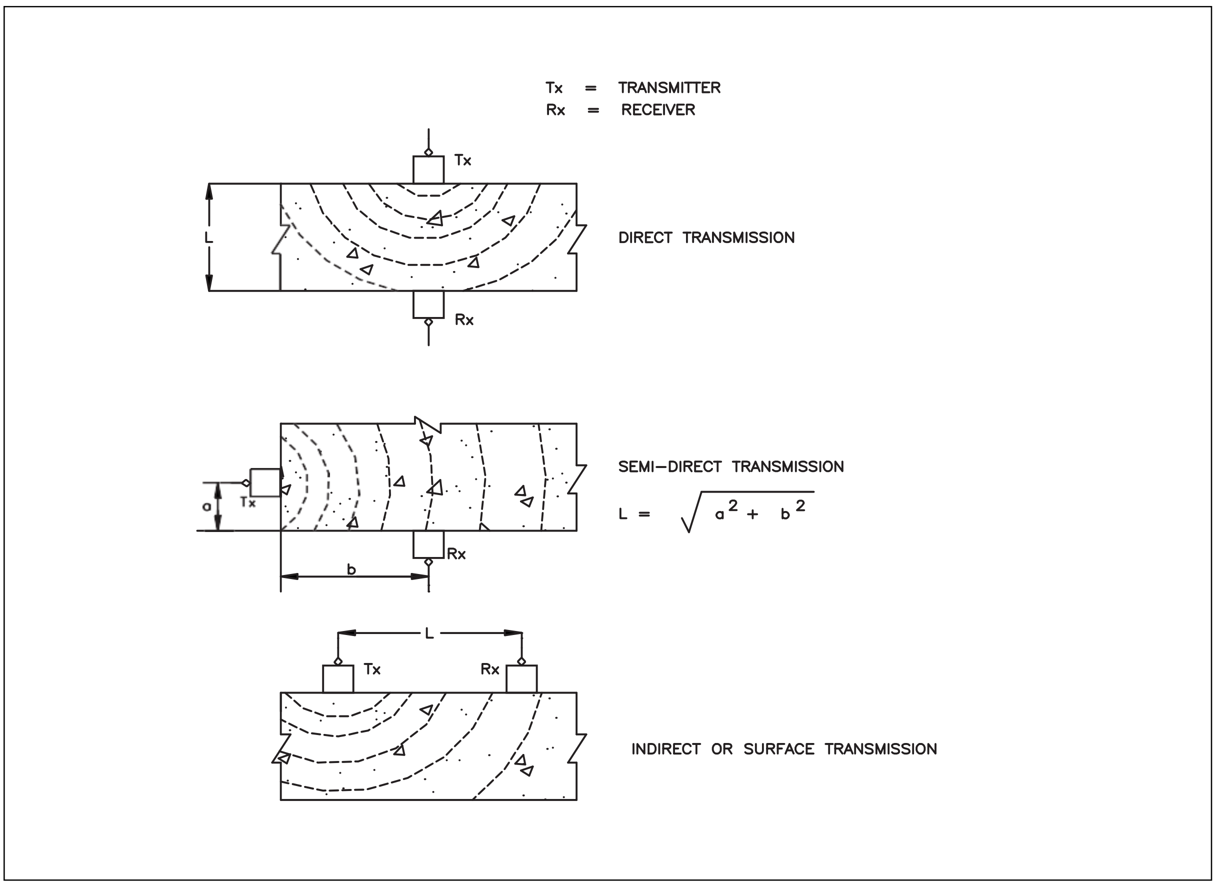
This test essentially consists of measuring travel time, ‘T’ of ultrasonic pulse of 50-54 kHz, produced by an electro-acoustical transducer, held in contact with one surface of the concrete member under test and receiving the same by a similar transducer in contact with the surface at the other end. With the path length, ‘L’ (i.e. the distance between the two probes) and time of travel, T the pulse velocity (V =

L/T) is calculated (fig 3.8). Higher the elastic modulus, density and integrity of the concrete, higher is the pulse velocity. The ultrasonic pulse velocity depends on the density and elastic properties of the material being tested. Though, pulse velocity is related with crushing strength of concrete, yet no statistical correlation can be applied.

The pulse velocity in concrete may be influenced by:

a) Path length
b) Lateral dimensions of the specimen tested.
c) Presence of reinforcing steel
d) Moisture content of the concrete.

The influence of path length will be negligible provided it is not less than 100 mm when 20 mm size aggregate is used or less than 150 mm for 40 mm size aggregate. Pulse velocity will not be influenced by the shape of the specimen, provided its least lateral dimension (i.e. its dimension measured at right angles to the pulse path) is not less than the wavelength of the pulse vibrations.



Method of propagating and receiving pulses

Table: General Guidelines for Concrete Quality based on UPV

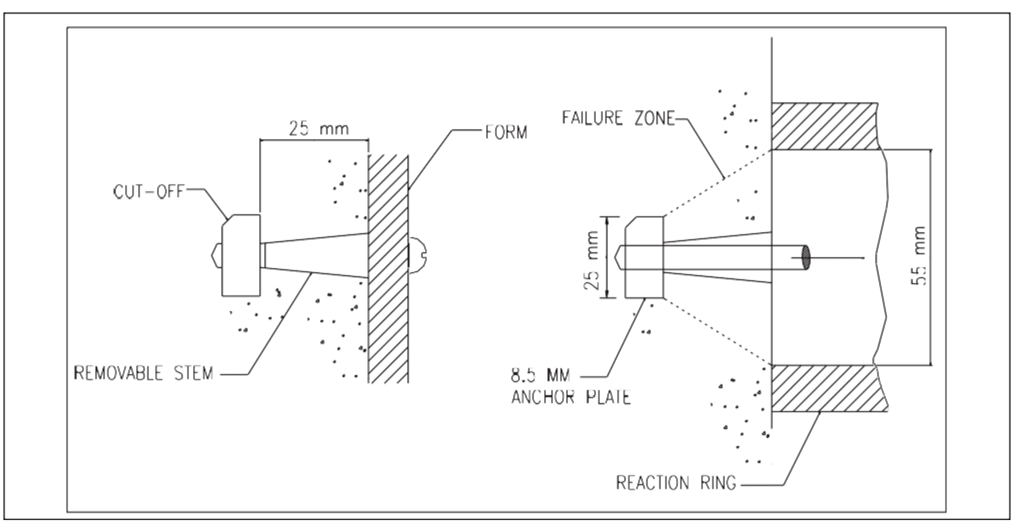
Pulse Velocity	Concrete quality
> 4.0 km/s	Very good to excellent
3.5-4.0 km/s	Good to very good, slight porosity mayexist.
3.0- 3.5 km/s	Satisfactory but loss of integrity is suspected
< 3.0 km/s	Poor and loss of integrity exist

B) Pullout (LOK) Test

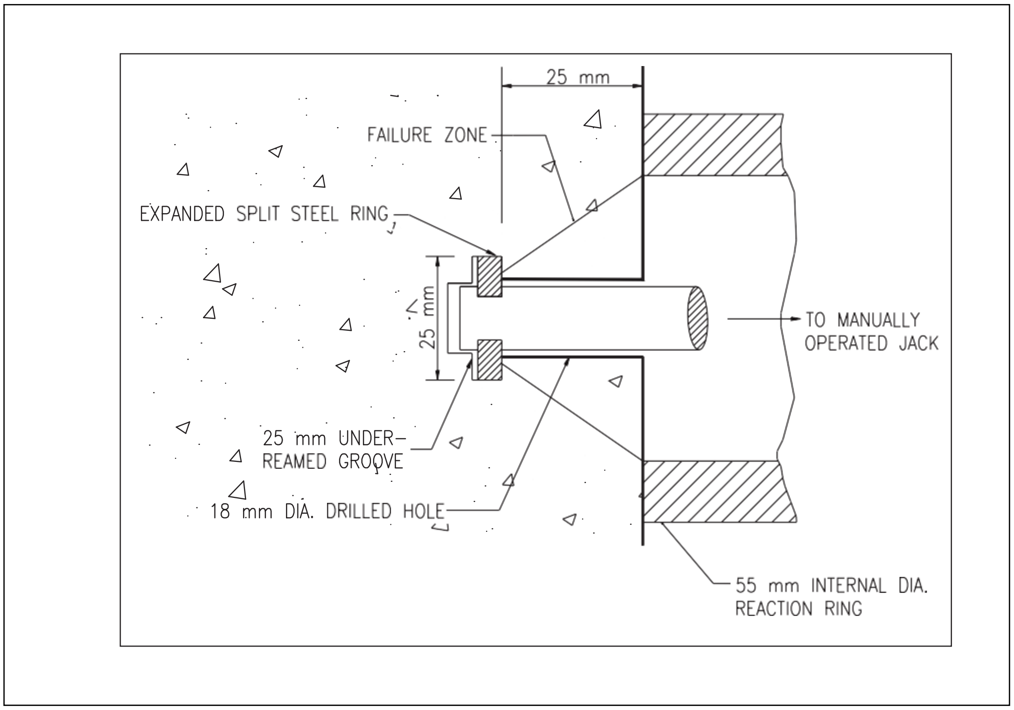
The fundamental principle behind pull out testing with LOK-test and CAPO test is that test equipment designed to a specific geometry will produce results (pull-out forces) that closely correlate to the compressive strength of concrete. This correlation is achieved by measuring the force required to pull a steel disc or ring, embedded in fresh concrete, against a circular counter pressure placed on the concrete surface concentric with the disc/ring.

For hardened concrete, an expandable steel ring is used instead. This ring expands to fit a specially drilled hole and routed recessin the concrete. The first method, shown in figure using the cast in steel disc, is called LOK test. The second method, shown in figure using expandable ring, is called CAPO-test (i.e. Cut and Pull out Test) the diameter of both the disc and ring is 25mm. The distance to the concrete surface is also 25mm. The inner diameter of the counter pressure is 55mm. The relationship between the pull-out force Fu in kN and compressive strength fc in MPa is given in figure

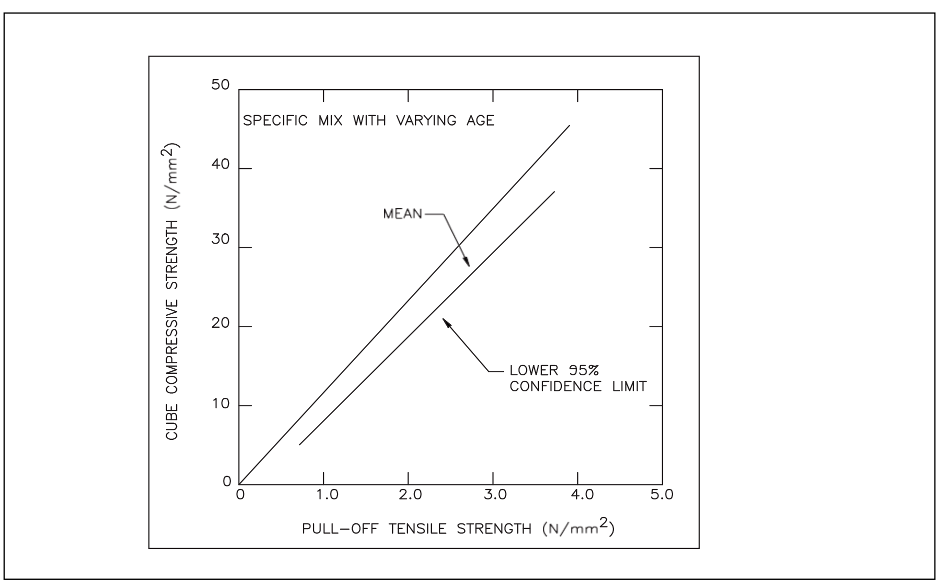
LOK test insert



CAPO test testing principle



Typical Pull out force Calibration Chart



Pull out tests are used to:

1. Determine in-situ compressive strength of the concrete.
2. Ascertain the strength of concrete for carrying out post- tensioning operations.
3. Determine the time for removal of forms and shores based on actual in-situ strength of the structure.
4. Terminate curing based on in-situ strength of the structure.

CHEMICAL TESTS:

A) Carbonation Test

This test is carried out to determine the depth of concrete affected due to combined attack of atmospheric carbon dioxide and moisture causing a reduction in level of alkalinity of concrete. A spray of 0.2% solution of phenolphthalein is used as pH indicator of concrete. The change of colour of concrete to pink indicates that the concrete is in the good health, where no change in colour takes place; it is suggestive of carbonation-affected concrete. The test is conducted by drilling a hole on the concrete surface to different depths up to cover concrete thickness, removing dust by air blowing, spraying phenolphthalein with physician's injection syringe and needle on such freshly drilled/ broken concrete and observing the colour change. The depth of carbonation is estimated based on the change in colour profile. The pH value can also be determined by analyzing samples of mortar collected by drilling from the site, dissolving the same in distilled water and thereby titration in laboratory.

B) Chloride Content

Chloride content can be determined from broken samples or core samples of concrete. Primarily, the level of chloride near the steel-concrete interface is of prime importance. Chlorides present in concrete are fixed (water insoluble) as well as free (water soluble). Though it is the water soluble chloride ions, which are of importance from corrosion risk point of view, yet total acid soluble (fixed as well as free) chloride contents are determined and compared with the limiting values specified for the concrete to assess the risk of corrosion in concrete. The total acid soluble chlorides are determined in accordance with IS: 14959 Part III 2001, whereas for assessment of water soluble chlorides the test consists of obtaining the water extracts, and conducting standard titration experiment for determining the water soluble chloride content and is expressed by water soluble chloride expressed by weight of concrete or cement. The method gives the average chloride content in the cover region. Further, a chloride profile across the cover thickness will be a more useful measurement as this can help to make a rough estimate on chloride diffusion rate. One recent development for field testing of chloride content includes the use of chloride ion sensitive electrode. This is commercially known as "Rapid chloride test kit-4". The test consists of obtaining powdered samples by drilling and collecting them from different depths (every 5 mm), mixing the sample (of about 1.5 gm weight) with a special chloride extraction liquid, and measuring the electrical potential of the liquid by chloride-ion selective electrode. With the help of a calibration graph relating electrical potential and chloride content, the chloride content of the samples can be directly determined.

Based on the chemical analysis, corrosion-prone locations can be identified as per the guidelines given in Table

Sl.No.	Test Results	Interpretations
1.	High pH values greater than 11.5 and very low chloride content	No corrosion
2.	High pH values and high chloride content greater than threshold values (0.15 percent by weight of cement)	Corrosion prone
3.	Low pH values and high chloride content (greater corrosion prone than threshold values of chloride 0.15 percent by weight of cement	increased risk of corrosion

CORROSION POTENTIAL ASSESSMENT:

a) cover meter survey

The necessity to provide adequate cover thickness to control corrosion needs no emphasis. A cover thickness survey is useful to determine existing cover thickness in a specific location, where a damage has been identified and elsewhere, for comparison on the same structure. The cover thickness can be measured non-destructively using commercially known cover meters. The cover meters are also used to identify the location and diameter of rebar. COVERMASTER and PROFOMETER are the commercially available instruments, which are used to measure the cover thickness and rebar size. Table shows how the cover meter readings are to be interpreted for corrosion assessment.

Sl.No.	Test Results	Interpretations
1.	Required cover thickness and good quality concrete	Relatively not corrosion prone
2.	Required cover thickness and bad quality cover concrete	Corrosion prone
3.	Very less cover thickness, yet good Quality cover concrete	Corrosion prone

b) Half cell potential survey

Corrosion being an electrochemical phenomenon, the electrode potential of steel rebar with reference to a standard electrode undergoes changes depending on corrosion activity.

A systematic survey on well-defined grid points gives useful information on the presence or probability of corrosion activity.The same grid points as used for other measurements, namely, rebound hammer and UPV could be used for making the data more meaningful.The common standard electrodes used are:

1. Copper - Copper sulphate electrode (CSE)
2. Silver - Silver chloride electrode (SSE)
3. Standard Calomel electrode (SCE).

The measurement consists of giving an electrical connection to the rebar and observing the voltage difference between the bar and a reference electrode in contact with concrete surface. Generally, the voltage potential becomes more and more negative as the corrosion becomes more and more active. However, less negative potential values may also indicate the presence of corrosion activity, if the pH values of concrete are less.

The general guidelines for identifying the probability of corrosion based on half-cell potential values as suggested in ASTM C 876 are given in Table

Table – Corrosion Risk by Half Cell Potentiometer

(*Source: Indian Concrete Journal, June 1998*)

Probability of Corrosion being active	**Half Cell Potential Reading Range**	
	$Cu-CuSO_4$ Electrode	**Silver-Silver Chloride Electrode**
>95 percent	More negative than – 350 mV	More negative than – 700 mV
50 percent	- 200 to - 350 mV	- 500 to - 700 mV
<5 percent	More positive than – 200 mV	More positive than – 500 mV

It is necessary to realize certain important parameters (listed below) which influence the measured potentials of the reinforcement.

i) The potentials of a rebar measured on the surface of, or within concrete may not be a true representation of the value at the surface of the steel
ii) The physical i.e. moisture content and chemical state of concrete i.e. presence of electrolyte ions can result in wide variation.
iii) The ohmic drop due to electrical resistance of the concrete also can induce variations with increasing concrete cover; the potential values at the concrete surface over actively corroding and passive slab become similar.

RESISTIVITY MEASUREMENT

Resistivity mapping

The electrical resistance of concrete plays an important role in determining the quality of concrete from the point of view ‘corrosion susceptibility potential’ at any specific location. This parameter is expressed in terms of “Resistivity” in ohm-cm.

For general monitoring, a resistivity check is important because long-term corrosion can be anticipated in concrete structures where accurately measured values are below 10,000 ohm- cm. Further, if resistivity values fall below 5,000 ohm-cm, corrosion must be anticipated at a much earlier period (possibly within 5 years) in the life of a structure. Table indicates the general guidelines of resistivity values based on which areas having probable corrosion risk can be identified in concrete structures.

Table: Corrosion Risk from Resistivity
(*Source: Indian Concrete Journal, June 1998*)

Resistivity ohmcm.	Corrosion Probability
Greater than 20,000	Negligible
	Low
10,000 – 20,000	High

The principle of resistivity testing in concrete is similar to that adopted in soil testing. However, when applied in concrete, a few drawbacks should be realized. The method essentially consists of using a 4- probe technique in which a known current is applied between two outer probes 100 mm apart and the voltage drop between the inner two elements at 50 mm spacing, is read off allowing for a direct evaluation of resistance R. Using a mathematical conversion factor, resistivity is calculated as per principle of four probe resistivity testing is illustrated in Fig

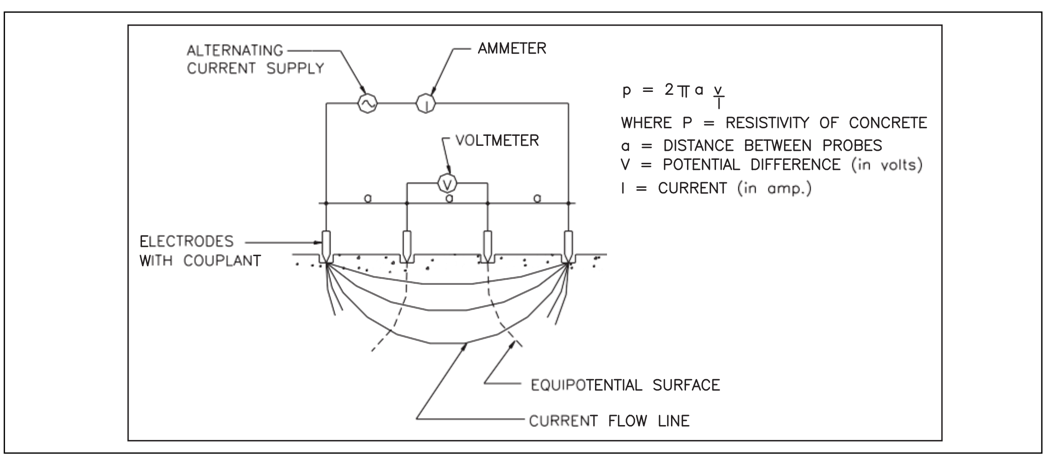


Fig-Resistivity meter (4 probe system)

The following drawbacks are important to note while analysing and interpreting the resistivity values:

a) The value obtained represents only the average evaluation over the depth regulated by the chosen probe spacing and not that of concrete at steel interface
b) The resistivity of concrete varies with varying moisture conditions
c) The instrument should have adequate 'IR' drop compensation for measurement.

STRUCTURAL INTEGRITY/SOUNDNESS ASSESSMENT

Impact-echo test

Most recent Non-destructive evaluation technique based on use of transient stress waves, has been used for detecting flaws in many different types of structures including plate like structures, such as bridge decks, slabs and walls beams and columns, layered structures and hollow cylindrical structures. To detect hidden damage and determine the extent of damage inside a concrete cross section (delamination, Honey-comb, cracks etc.)

UNIT - 4

GROUTING

Grout is a particularly fluid form of concrete used to fill gaps. **Grout**is generally a mixture of water, cement, and sand, and is employed in pressure **grouting**, embedding rebar in masonry walls, connecting sections of pre-cast concrete, filling voids, and sealing joints such as those between tiles.

a) Internal Grouting

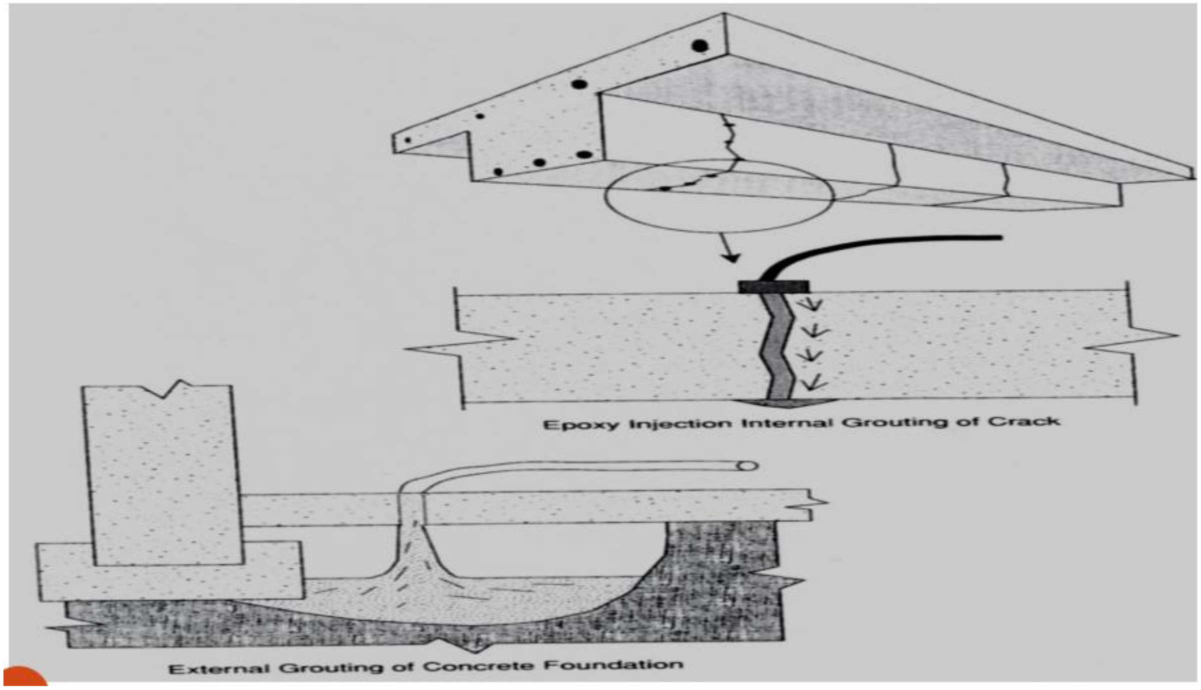
- Internal grouting is the placement of a flowable material into an unwanted discontinuity, such as a crack within the concrete member**.**
- The flow able material, upon reaching the discontinuity, will solidify and assume necessary structural properties.
- Internal grouting is used to repair fractured, honeycombed, or voided concrete placements.

The most common materials used for internal grouting are: **polymers and hydraulic cement-based materials**.

b) External Grouting

External grouting is the placement of a pumpable material

- Outside the structure, generally within the surrounding foundation soils or at the interface between the structure and the soil.
- The grouting materials can be used either to provide necessary load transfer between the structure and soil, or to displace unwanted settlement. Most materials used for external grouting include cement-based mixtures.
- Pavement sub sealing (slab stabilization) is a specialized external groutingtechnique used to fill small voids beneath the slab and/or stabilized base that have been caused by pumping action.



STRENGTHENING AND STABILIZATION

Stabilization is the process of halting a particular unwanted situation from progressing. Settlement of a structure can be stabilized by grouting to halt further movement.

Strengthening is the process of adding capacity to a member or structure.

- Concrete jacketing of an existing column will add compressive load carrying capacity.
- In some cases, the process involves a combination of halting an unwanted situation and, at the same time, adding capacity.

The following below involve in Strengthening and Stabilization:

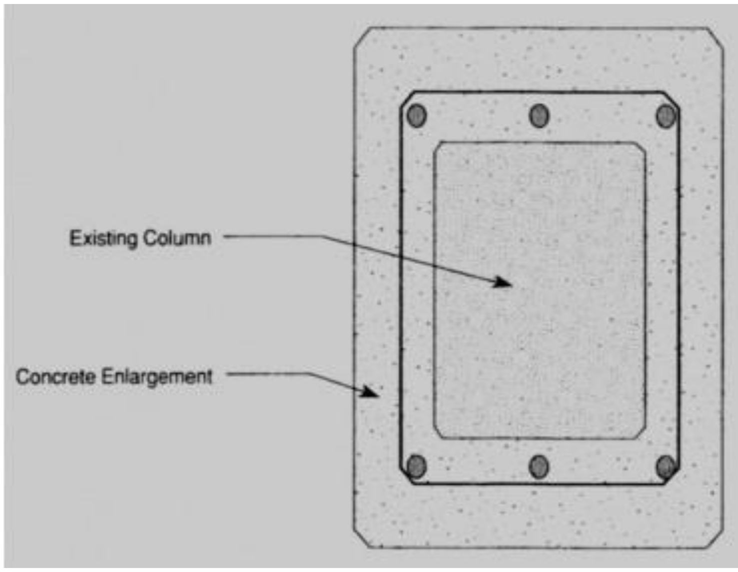
1. Introduction to Techniques/Design Considerations
2. Passive and Active Design
3. Material Behavior

1. Introduction to Techniques/Design Considerations

Enlargement

Enlargement is the placement of additional concreteand reinforcing steel on an existing structural member.

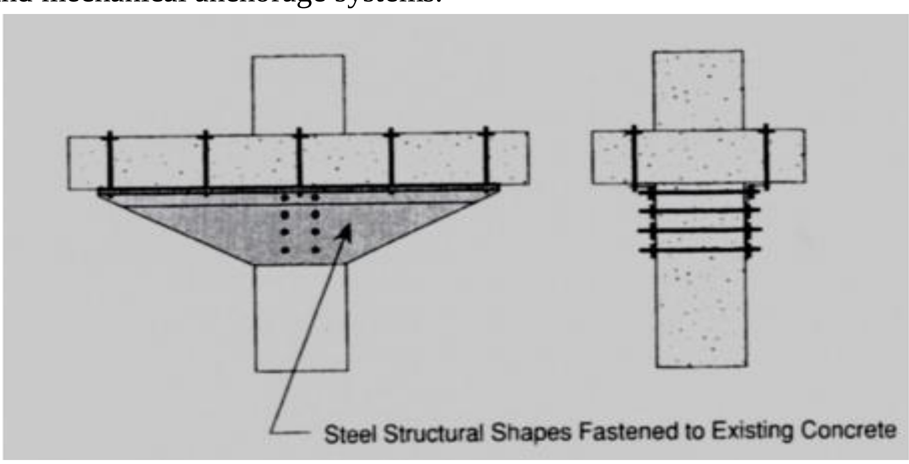
Beams, slabs, columns, and walls, if necessary, can be enlarged to add stiffness or load- carrying capacity in most cases, the enlargement is bonded to the existing concrete to create a monolithic member.



Composite Construction

Composite construction is a method wherein materials other than concrete are placed in concert with an existing concrete member to add stiffness or load carrying capacity.

- Steel is the most common material used in this technique.
- Steel plates and structural shapes can be fabricated to meet almost any configuration requirement.
- Load transfer in the composite member is accomplished by the use of adhesives, grouts, and mechanical anchorage systems.

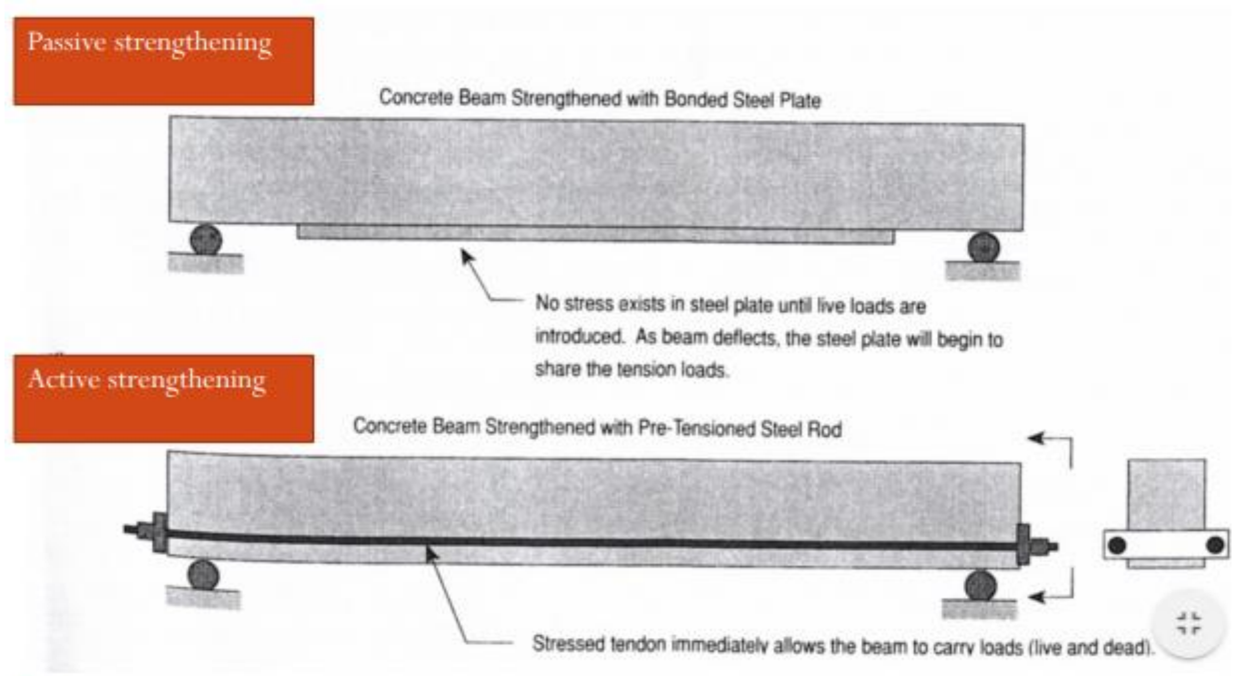


2. Passive and Active Design

Techniques in which repairs do not participate in stress sharing until additional loads (live or dead) are applied and/or until additional deformation occurs are called passive.

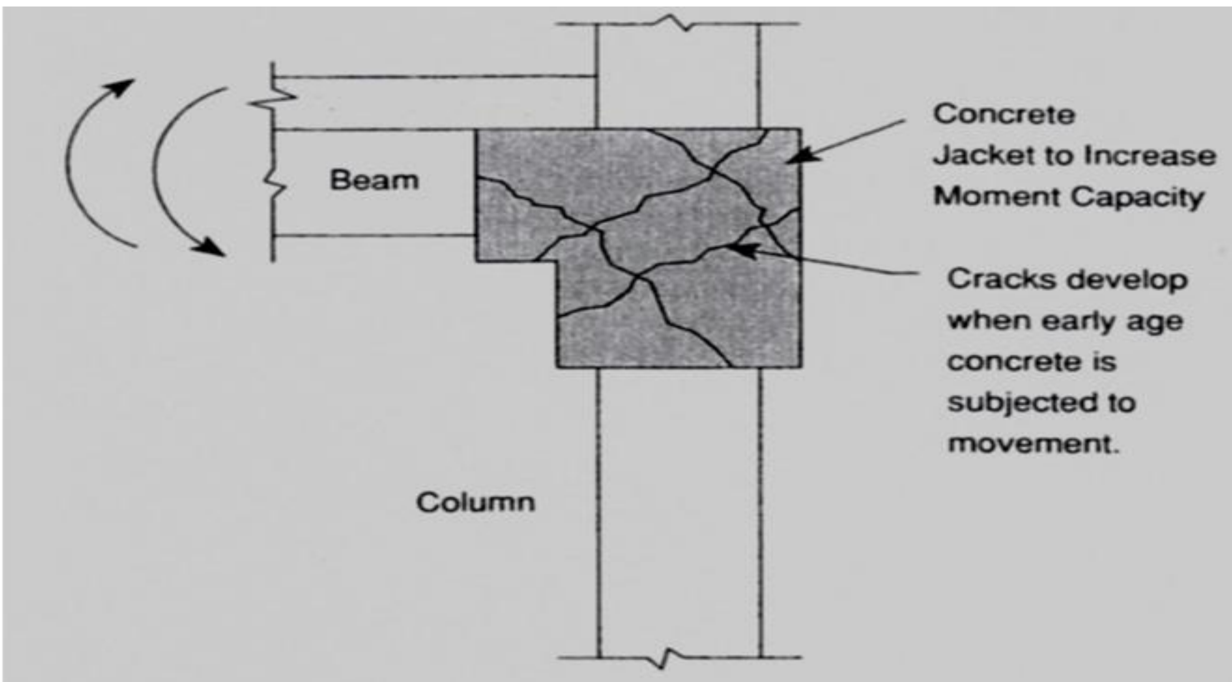
There are many situations in which additional deformation is not acceptable: the repairs must immediately participate in stress sharing. These repairs are called active.

- Active systems require either prestressing the repaired elements or temporarily removing the loads (both live and dead) from the existing elements, or a combination of the two.
- Active systems can be compared to elastic suspenders used to hold up pants.
- If the suspenders are placed in tension immediately (active), the pants will stay in their vertical position.
- On the other hand (passive), if the suspenders are placed loose or without tension, the pants will fall vertically until sufficient tension occurs in the suspenders to resist the weight of the pants.
- Passive systems work well when live load changes are anticipated. For example, upgrading a bridge to sustain heavier loads may require only a passive system.
- However, if a member is overstressed, the only choice may be to use an active repair technique that will immediately reduce the stress by sharing the loads, thus, eliminating the overstressed condition



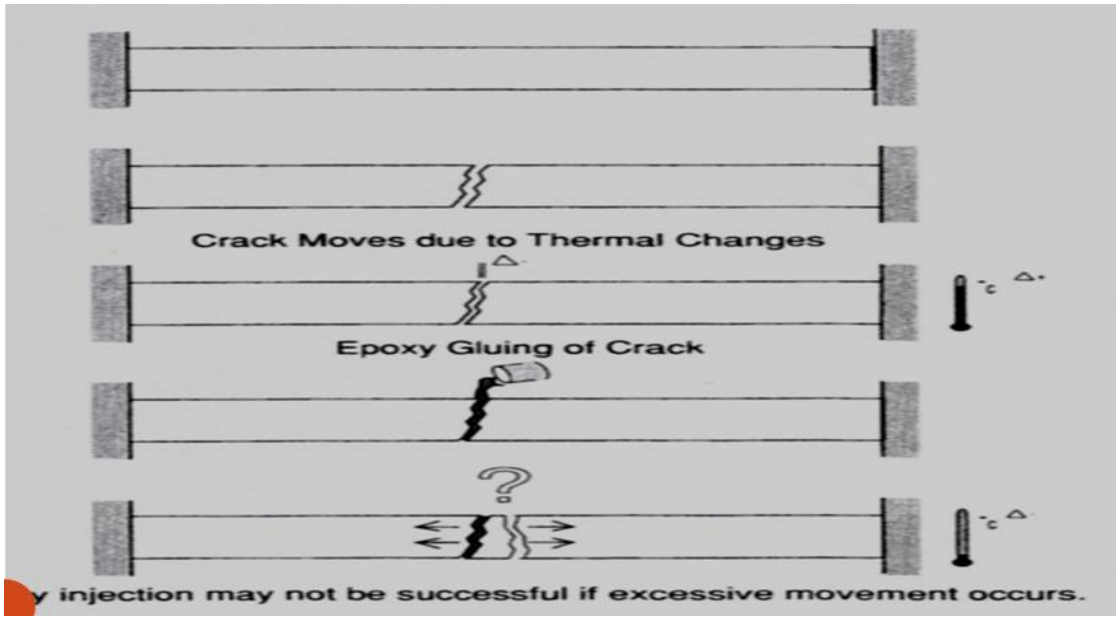
3. Material Behavior

- It is important to understand material behavior when considering repairs involving stabilization andstrengthening.
- One must consider material behavior, not only in its cured state, butalso during the placement and curingprocesses.
- Many stabilization and strengthening techniques involve the useof polymers, cement-based mortars, and concretes.
- These materials are weak during the curingprocess.
- If they are interfered with during this period, the result may be aless-than-anticipatedperformance.
- **For example**, when strengthening beam-column connections to increase moment capacity, some of the connections may be subject to continuous movement (rotation) from diurnal solar heating (Part One-Section Four, "Uneven ThermalLoads").
- If the repair includes the construction of a concrete collar, fracturing of the concrete will occur in the first 24 hours, rendering the repair questionable.



- A better solution, in this situation, would be to use steel plates in combination with embedded anchors andrapid- setting bondingadhesives.
- When considering strengthening and stabilization techniques, itis also important to consider both the static and the dynamic behavior of the structure or membersinvolved.
- A cracked beam may seem static, but in many cases, the crackmoves slightly due to changing live loads or thermally-inducedstrain.
- These movements may not be noticeable to the naked eye, but when the crack movement is measured with instruments, the crack may exhibit regular and significantmovement.
- Many repairs fail when epoxy is injected into moving cracks.

- Once epoxy is placed and cured, and the crack moves, tensilestress develops.
- If the tensile stress exceeds the tensile capacity of the member, anew crack will often develop adjacent to the existing repairedcrack.



BEAM SHEAR STRENGTHENING

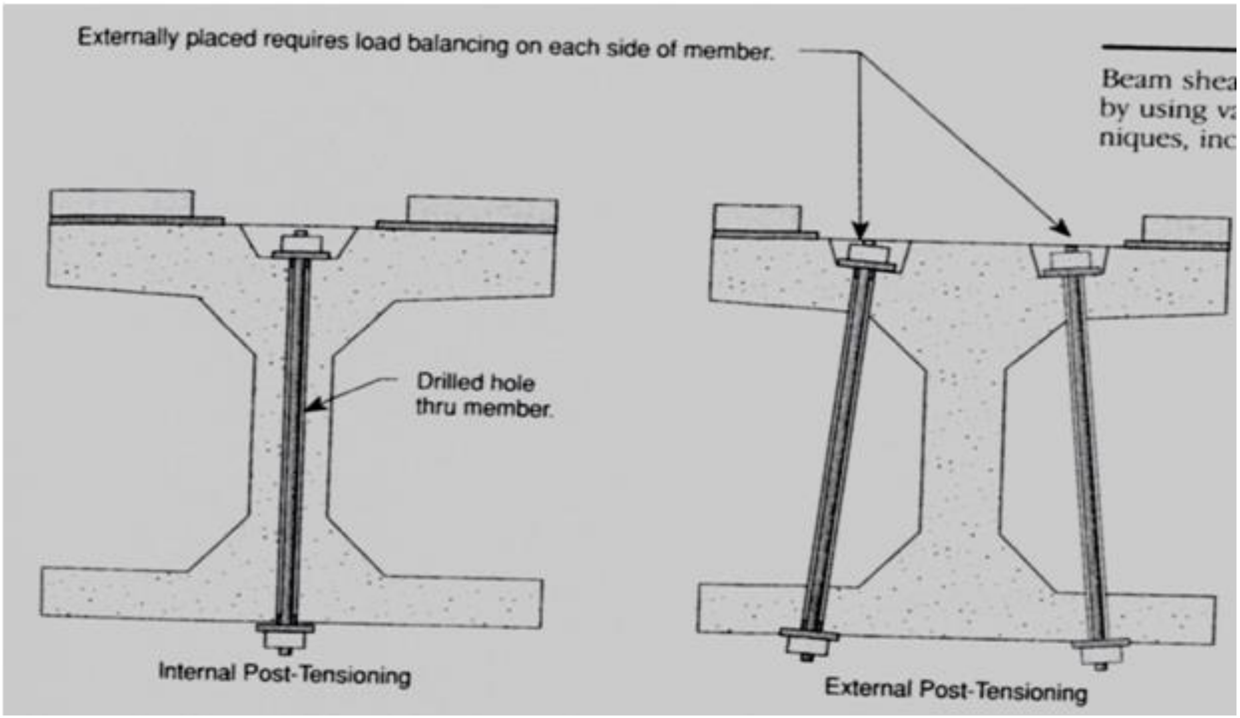
1. Introduction to Beam Shear Strengthening
2. Internally Placed Passive Shear Strengthening
3. Beam Shear Capacity Strengthening at Moving Hinge
4. External Post-Tensioned Straps

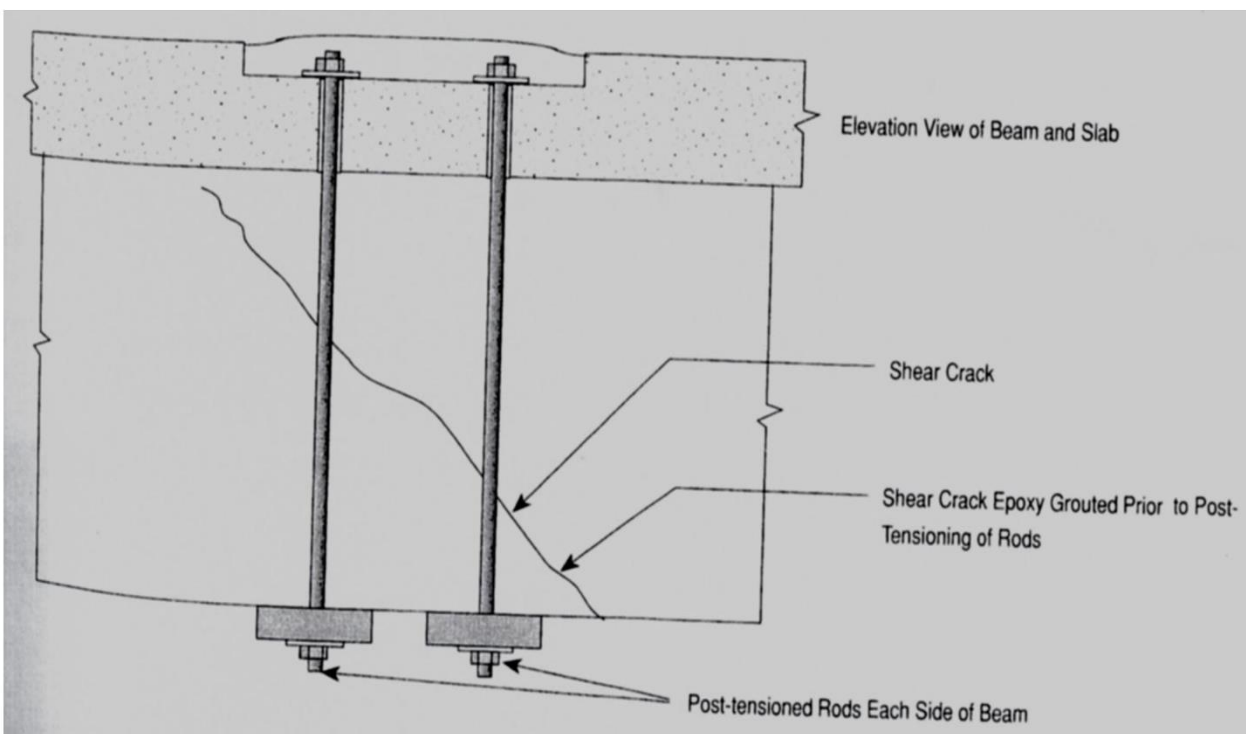
1. Introduction to Beam Shear Strengthening

Beam shear capacity can be increased by using various strengthening techniques, including:

- External post-tensioning
- Internal post-tensioning
- Internal mild steel reinforcement
- Bonded steel members
- Enlarging member's cross section

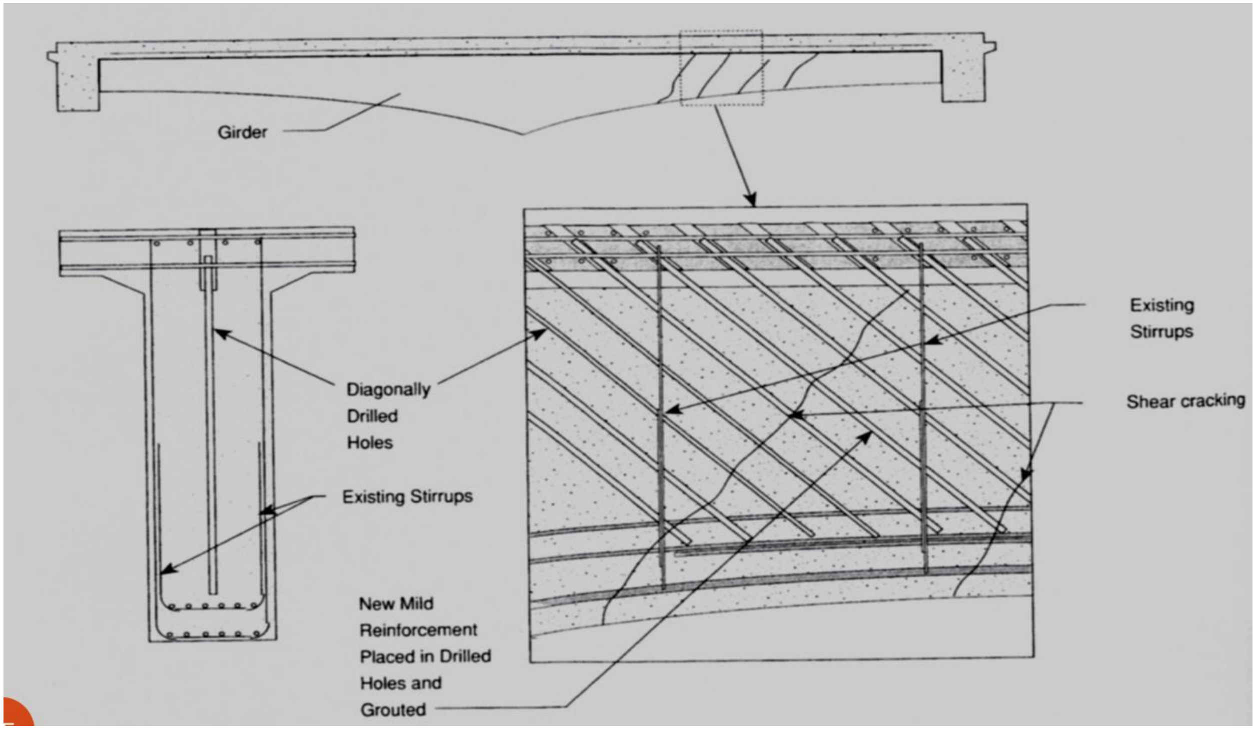
External post-tensioning and internal post-tensioning





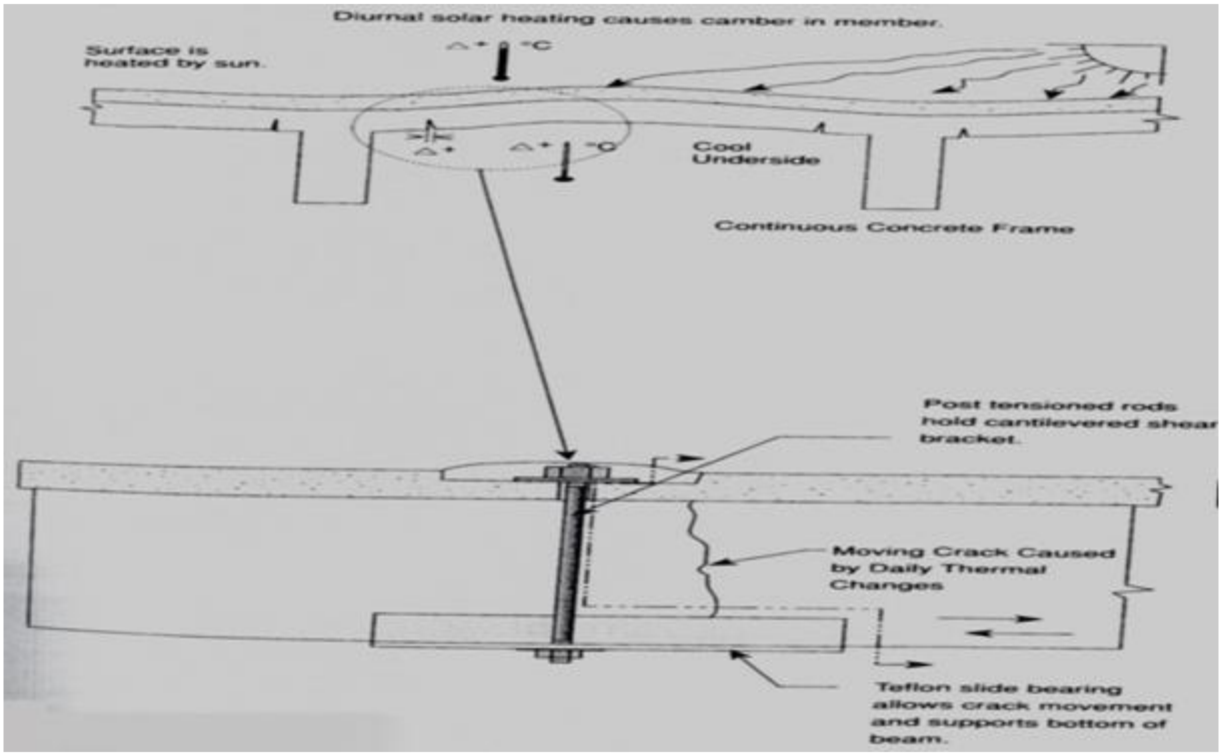
2. Internally Placed Passive Shear Strengthening

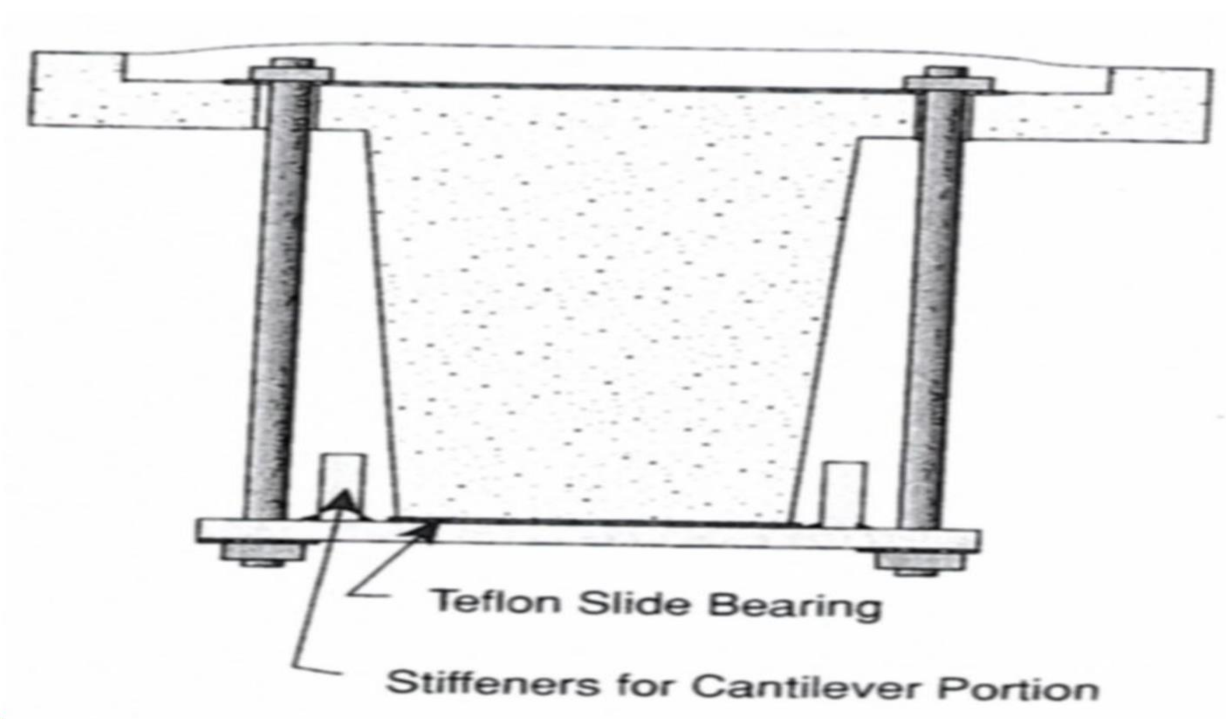
- Strengthening of existing members to increase their shear capacity can be performed by adding shear reinforcement.
- For example, the Kansas Department of Transportation has used mild reinforcement dowels inserted perpendicular to the direction of shear cracking, into drilled holes.
- The dowels are then grouted into place with epoxy.



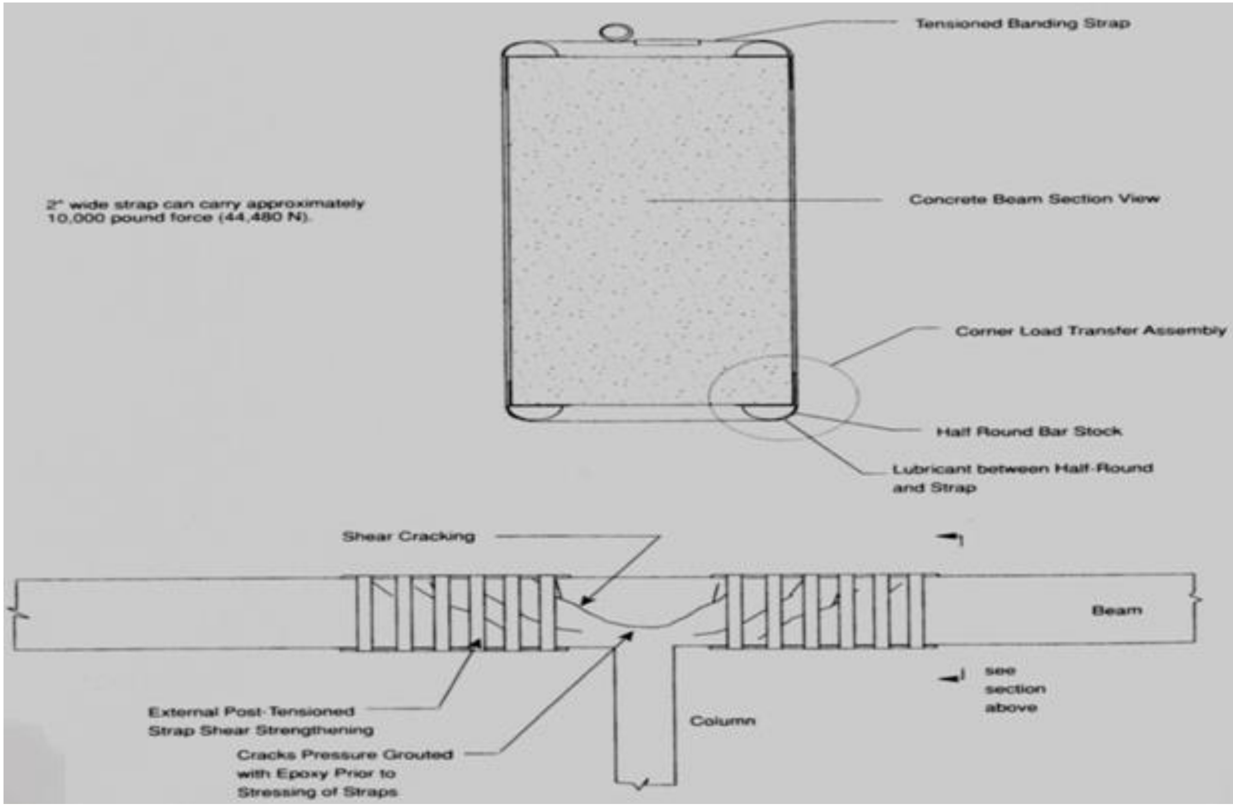
3. Beam Shear Capacity Strengthening at Moving Hinge:

- If a significant thermal gradient exists, in combination with insufficient tensile capacity in the bottom of the member, a hinge may form.
- Hinges may occur randomly in newly formed cracks, or may form in construction joints near the columns.
- Hinges open and close with daily temperature changes.
- Cracks can be a cause for structural concern, since they sometimes identify insufficient shear capacity.
- When strengthening the member by repairing cracks, consideration must be given to the need for providing movement of the hinge.
- Generally, any repair of a moving crack by bonding it with epoxy will fail.
- As an example of an effective method, the installation demonstrates how to strengthen a cracked beam with a post- tensioned shear clamp and a Teflon slide bearing allowing for hinge movement.


Diurnal solar heating causes camber in member.
Surface is heated by sun.
°C
Cool Underside
Continuous Concrete Frame
Post tensioned rods hold cantilevered shear bracket.
Moving Crack Caused by Daily Thermal Changes
Teflon slide bearing allows crack movement and supports bottom of beam.


Teflon Slide Bearing
Stiffeners for Cantilever Portion

4. External Post-Tensioned Straps:



SHEAR TRANSFER STRENGTHENING

1. Introduction to Shear Transfer Strengthening Between Members
2. Dowel Shear Device
3. Drilled Hole Shear Transfer Device
4. Grouted Subgrade
5. Cantilevered Shear Arm

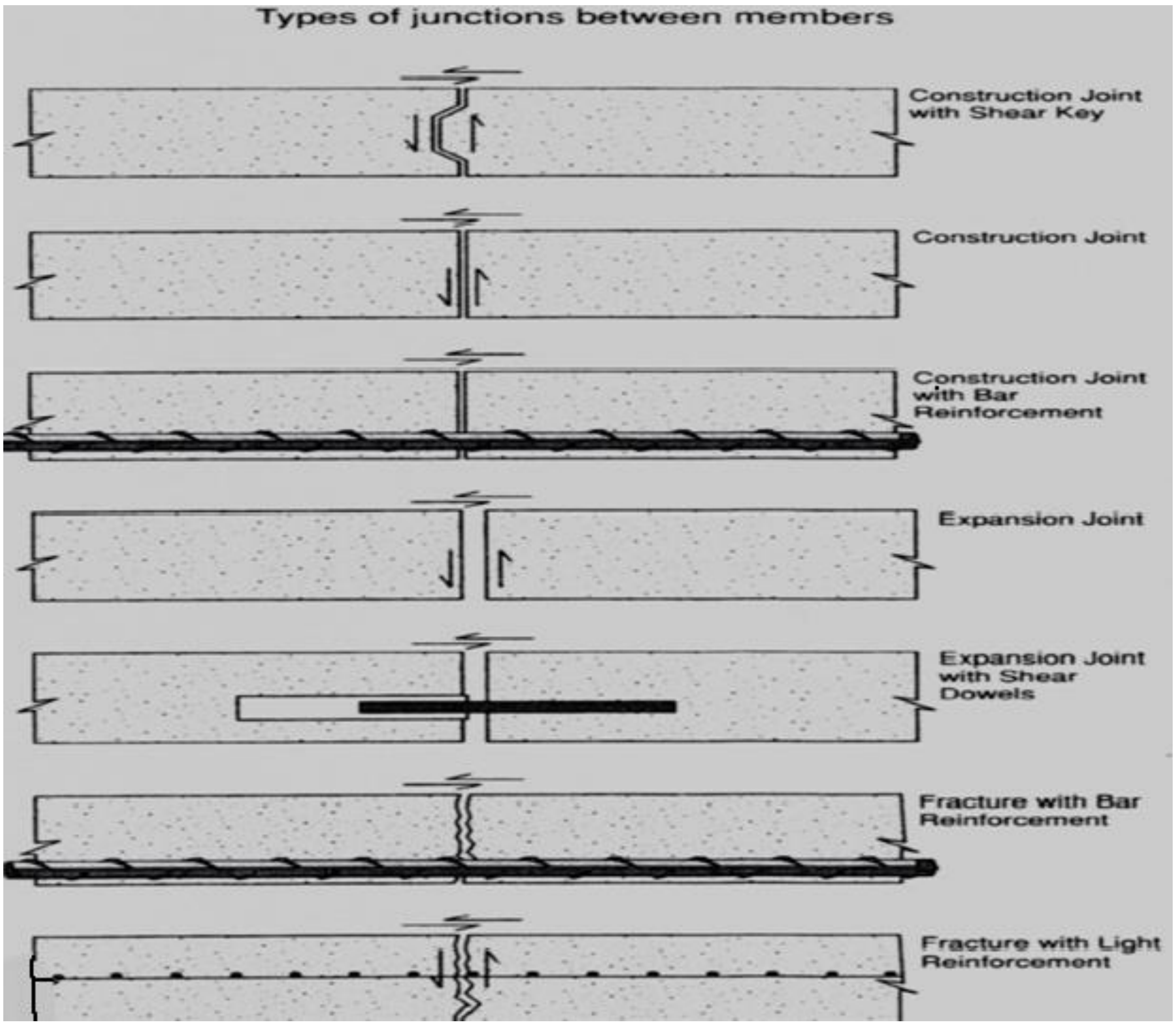
1. Introduction Shear Transfer Strengthening Between Members:

- Proper shear transfer between slabs and between other structural members is important when wheel loads cross the joint.
- The ability of a joint to transfer load (shear) from one side to another is very important to slab performance.

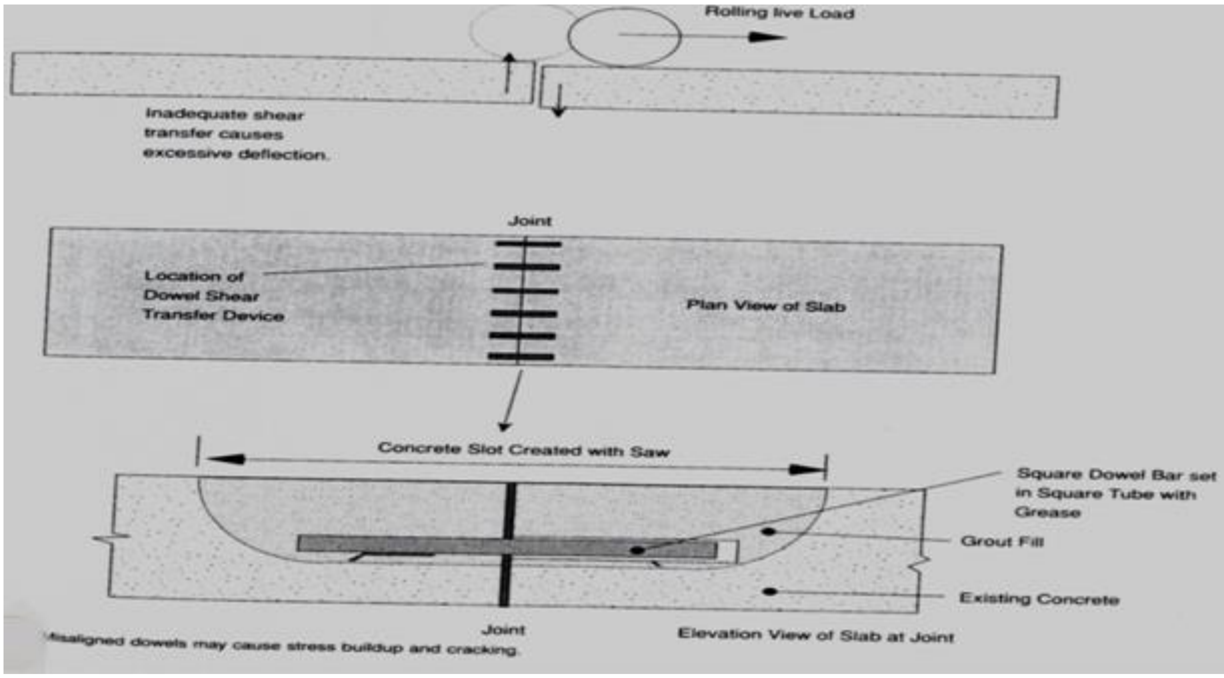
Poor load transfer results in the following:

- High deflections causing increased pumping and subsequently faulting.
- Loss of support beneath the slab resulting in slab breakup.

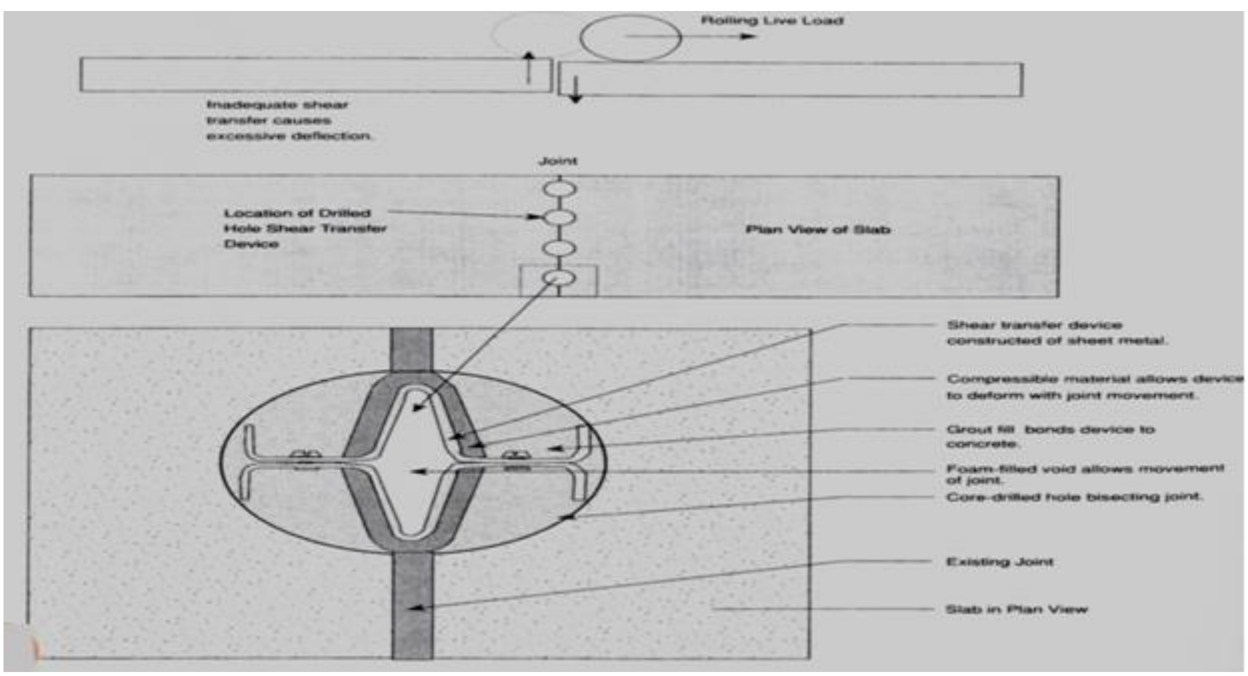
- Such problems most commonly occur in slab-on-grade and precast elevated floor systems.
- **Techniques available for strengthening and stabilizing to achieve proper shear transfer include:**
  - Dowel shear device
  - Drilled hole shear transfer device
  - Sawed slot dowel transfer device
  - Alternating cantilever
  - Hinge plate
  - Slab sub sealing/slab jacking



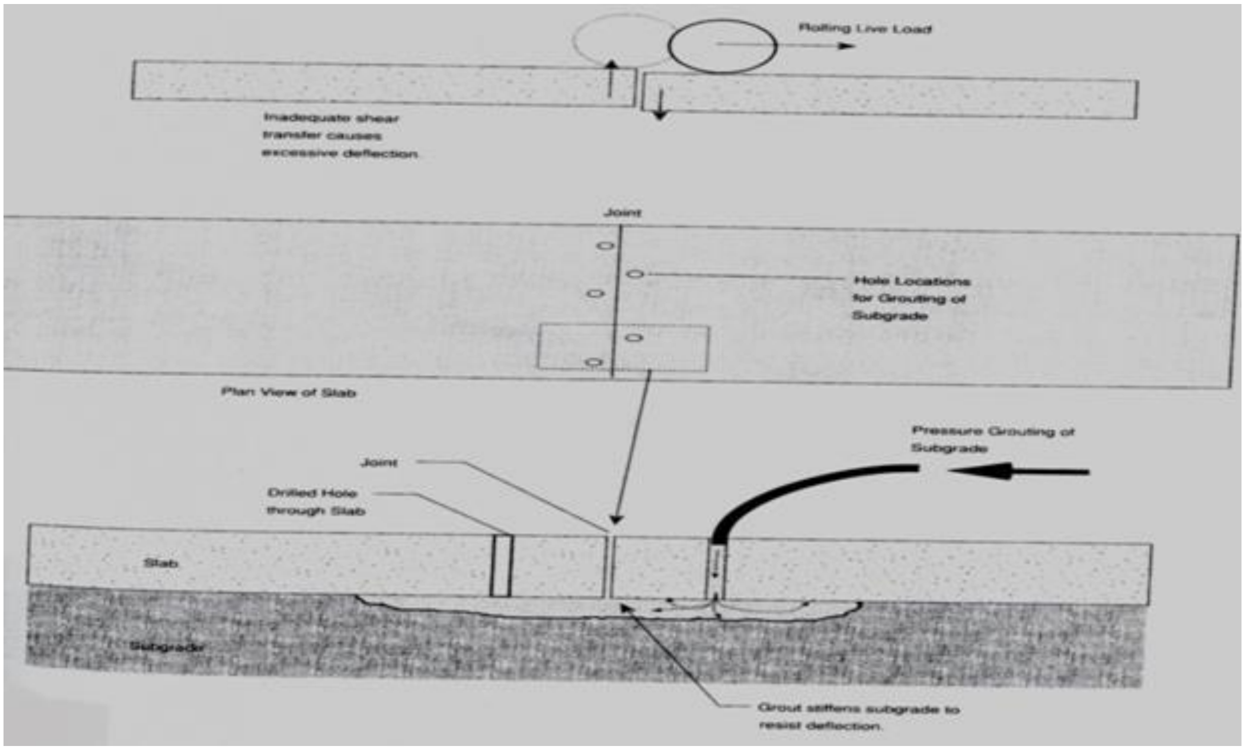
2. Dowel Shear Device



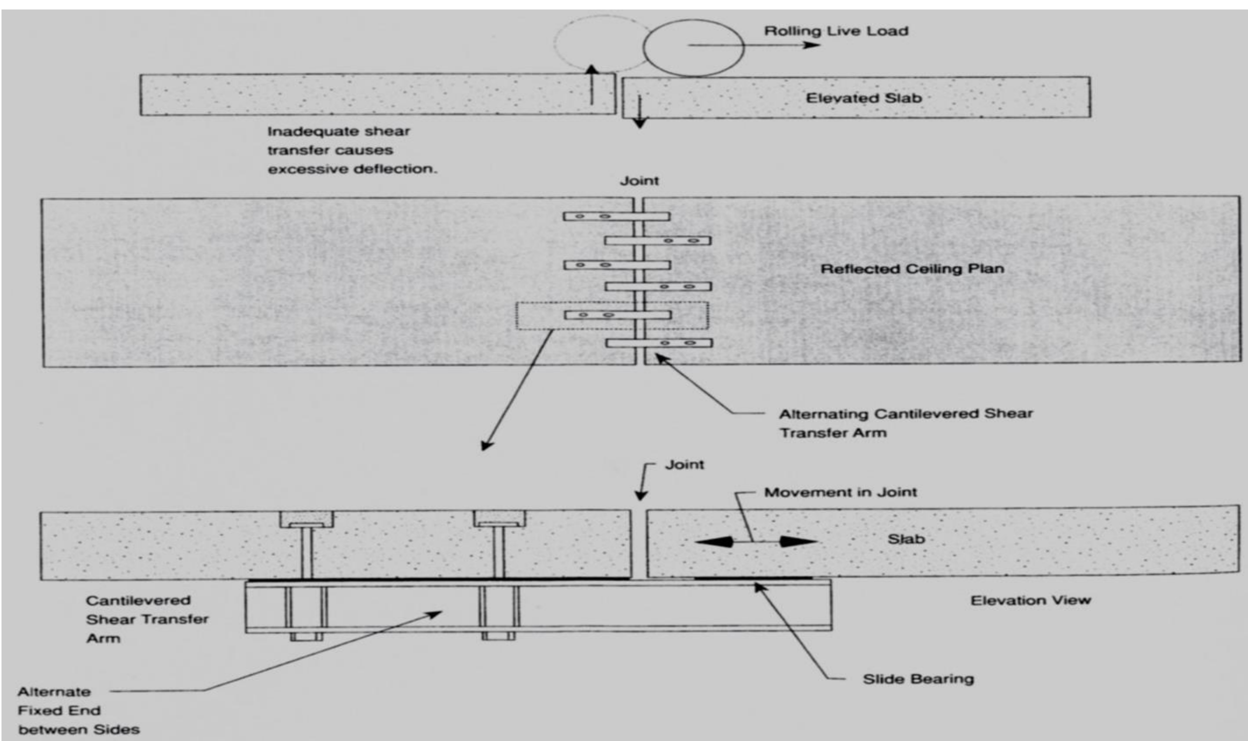
3. Drilled Hole Shear Transfer Device:



4. Grouted Sub grade:



5. Cantilevered Shear Arm:

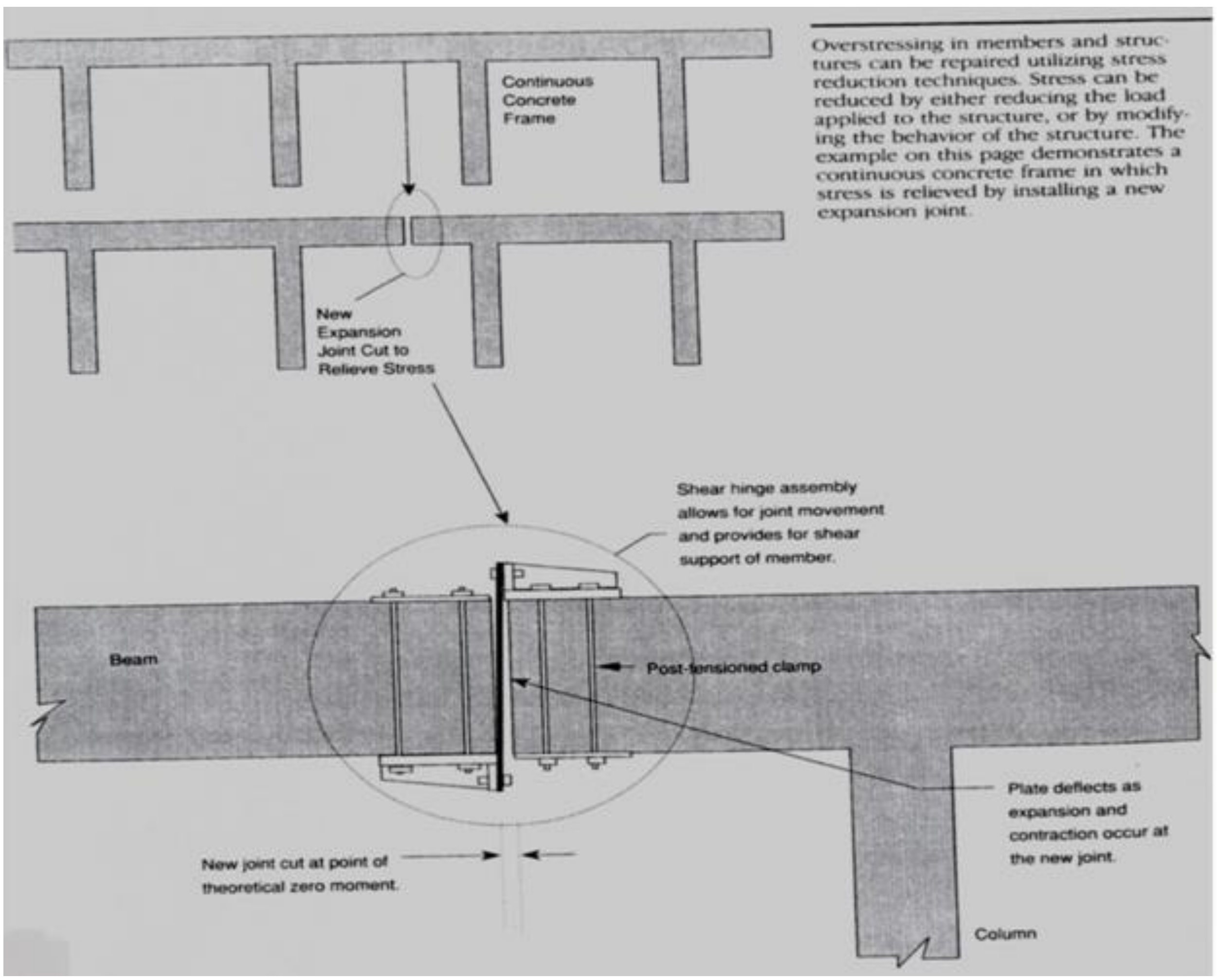


STRESS REDUCTION TECHNIQUES

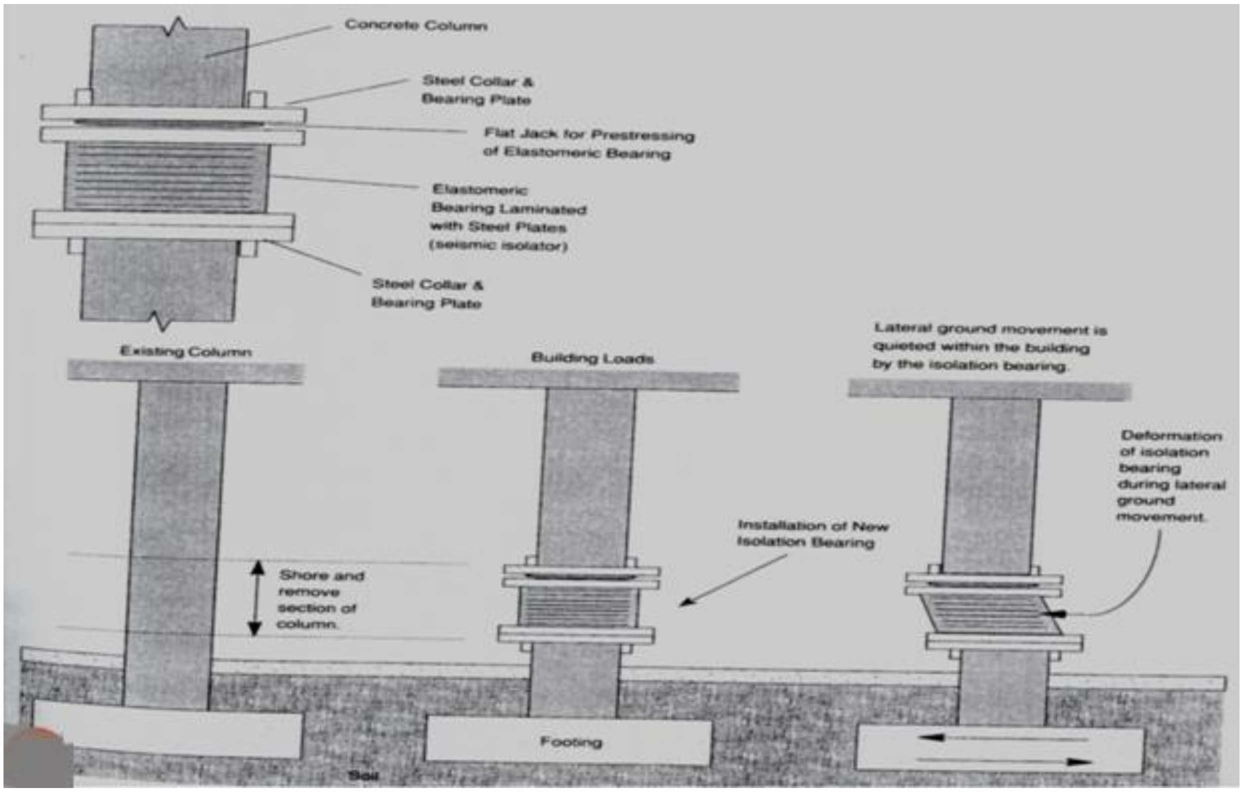
1. Installing New Expansion Joint in Continuous Concrete Frame
2. Lateral Ground Movement Isolation

1. Installing New Expansion Joint in Continuous Concrete Frame

- Overstressing in members and structures can be repaired byutilizing stress reduction techniques.
- Stress can be reduced by either reducing the load applied to the structure, or by modifying the behavior of the structure.
- The example on this page demonstrates a continuous concreteframe in which stress is relieved by installing a new expansion joint.



2. Lateral Ground Movement Isolation (Seismic Isolation):



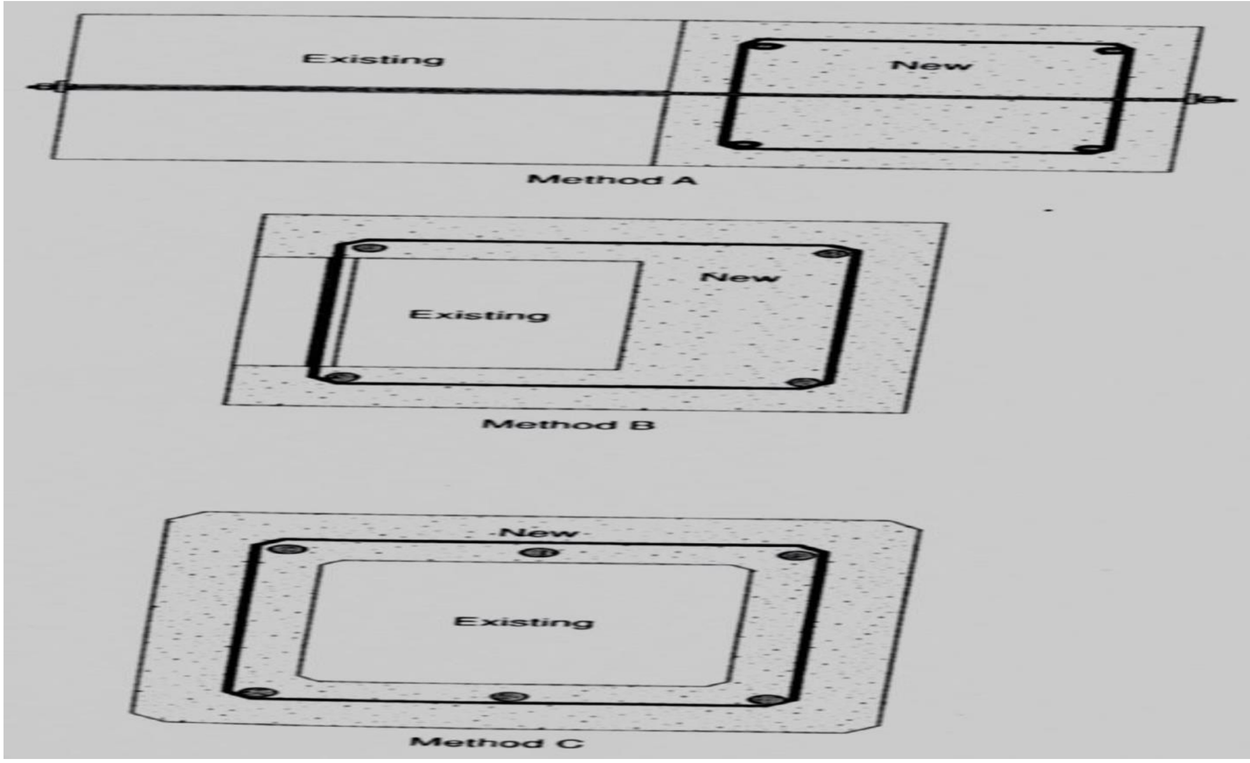
COLUMN STRENGTHENING

1. Compressive Strengthening by Enlargement
2. Shear Capacity Strengthening Using Shear Collars
3. Beam-column Moment Capacity Strengthening
4. Confinement strengthening

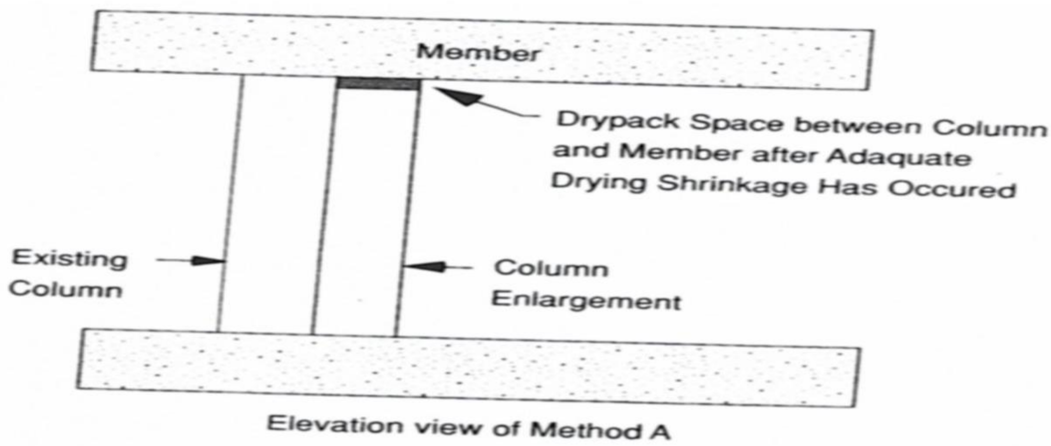
1. Column Compressive Strengthening by Section Enlargement:

- Enlarging the cross section of an existing column will strengthen the column by increasing its load carrying capacity.
- A column can be enlarged in various configurations.
- However, *the drying shrinkage effects* in the concrete used to enlarge the column must be considered.
- Drying shrinkage, if restrained, will induce tensile stresses in the new portion of the column.
- In the illustration, Method A will accomplish efficient load transfer if the new portion is cast with a bond breaker between the new and old concrete.

- After most of the drying shrinkage has occurred, the ties that link the old and new concrete can be installed.



- The gap between the new portion of the column and the existing member (to be partially supported by this column) can be filled with dry packing material.
- This will allow the new material to share its portion of the load.
- When **Methods B and C** are used, extreme care should be exercised to select concrete mix designs with very **low shrinkage** rates.
- ***Preplaced aggregate concrete*** generally offers the lowest drying shrinkage; it is therefore, an excellent material for column enlargements.

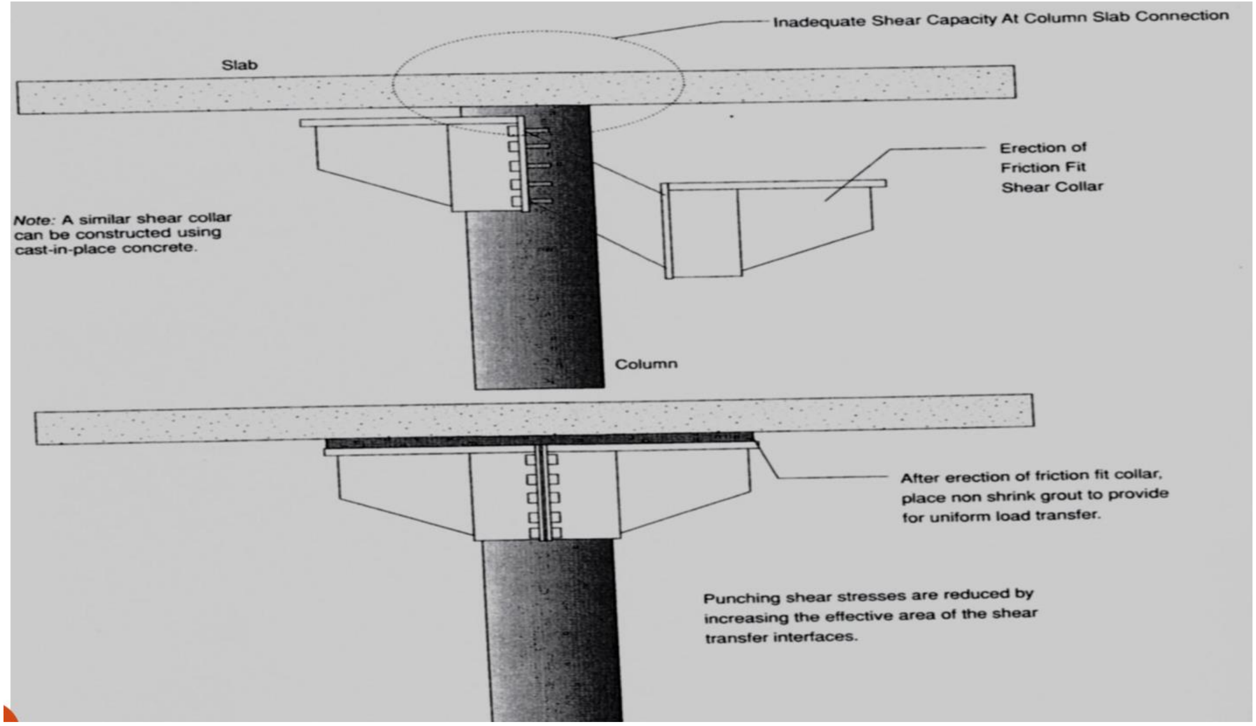


2. Shear Capacity Strengthening Using Shear Collars:

Shear stress occurs at the connection of floor systems and columns.

When additional shear capacity is required to resist punching shear, the following techniques are often used:

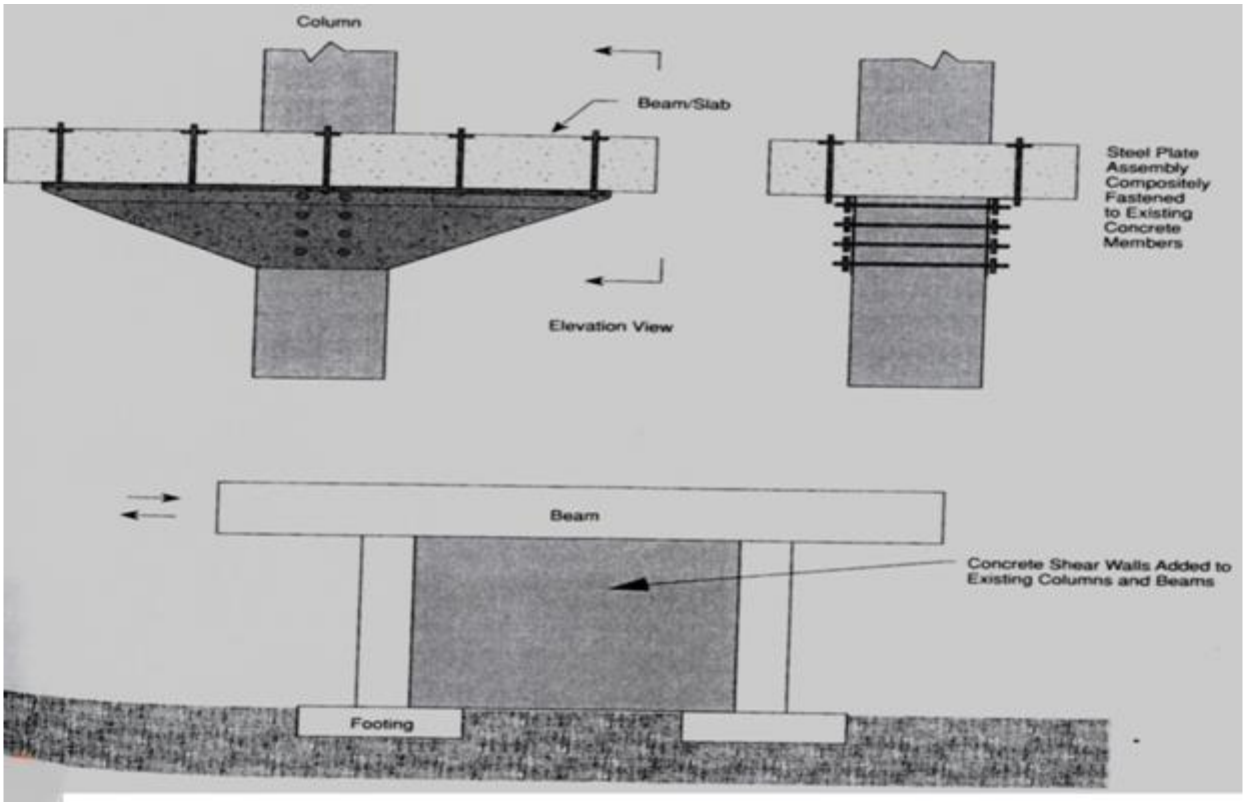
- Column section enlargement
- Composite bonded steel shear collars



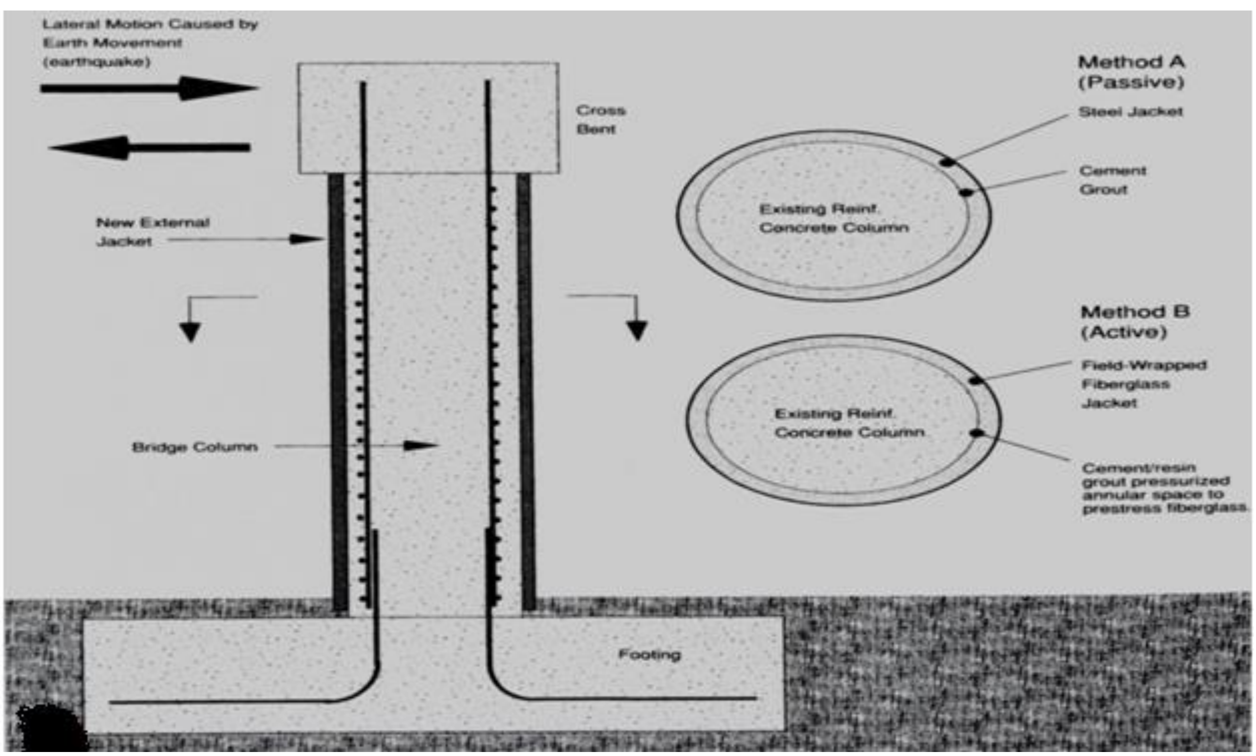
3. Beam-Column Moment Capacity Strengthening:

Beam-column connections can be strengthened using various techniques including:

- Bonded steel members
- Concrete overlay
- Continuous external column confinement
- Shear wall construction



4. Confinement Strengthening:



FLEXURAL STRENGTHENING

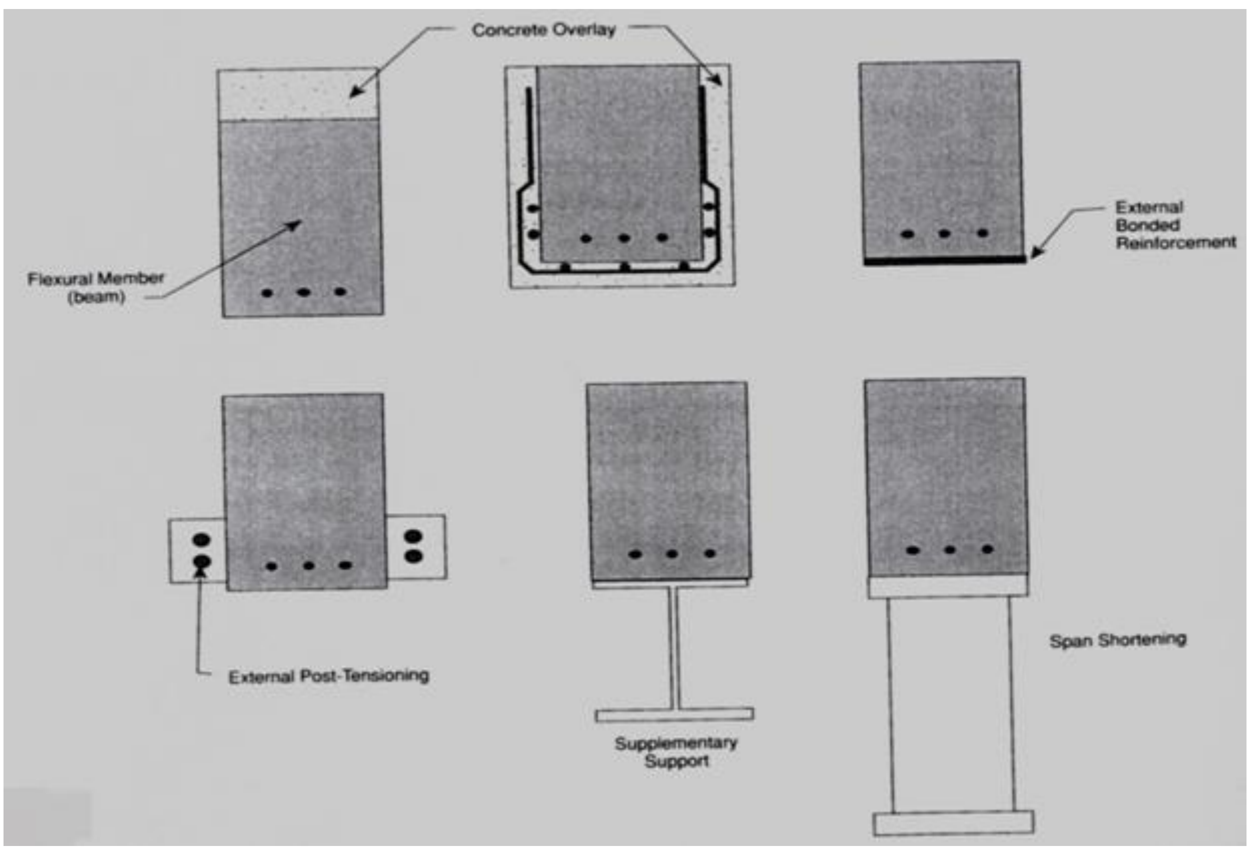
1. Summary of Methods
2. External Post-Tensioned Reinforcement
3. Span Shortening Techniques
4. Bonded Steel Plate Reinforcement
5. Correction of Deflected Member with Bonded Steel Plate
6. Concrete Overlay and Section Enlargement
7. Wall Strengthening

1. Summary of Methods

Beam and Slab Flexural Strengthening

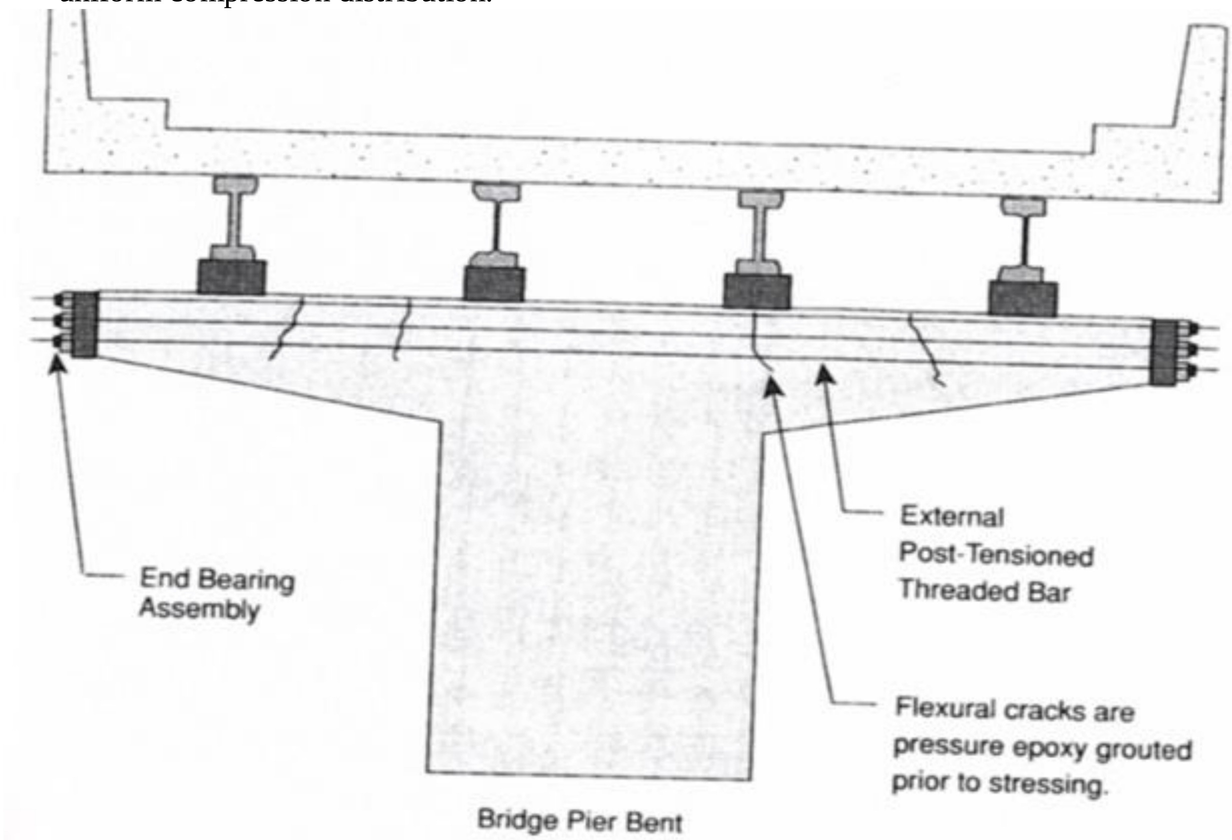
The flexural capacity of concrete members requires an increase when either a design deficiency is uncovered, excessive deflection occurs, or additional loads are anticipated.

- Various techniques used to increase flexural capacity include:
- Concrete encasement
- External post-tensioning
- Externally bonded reinforcement
- Concrete overlays
- Span length shortening
- Supplemental support



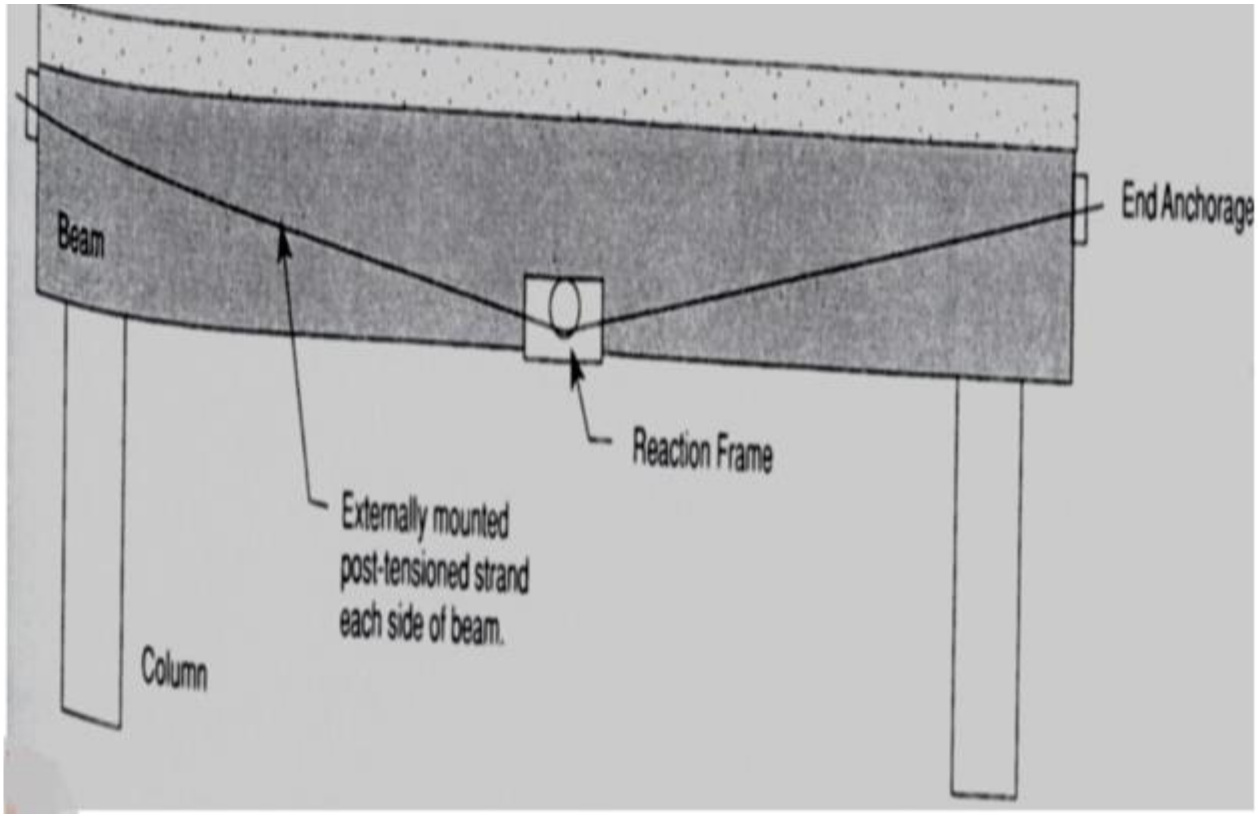
2. External Post-Tensioned Reinforcement:

- The use of external post-tensioned reinforcement is an excellent method of **increasing flexural capacity or replacing damaged prestressed strands.**
- **High strength thread bar** is commonly used for straight lengths, and strand is generally used where drape is required.
- External post-tensioning provides for immediate and active participation in both dead and live load distribution.
- Prior to the prestressing, any flexural cracks should be **pressure grouted** with epoxy for uniform compression distribution.



- Attachment of external post-tensioning hardware to the existing structure requires either a **shear transfer mechanism** or an **end bearing assembly.**

- Protection of externally mounted strands and bars against fire and aggressive agents is provided by either **precast concrete or shotcrete encasement, or by large grouted strand ducts.**

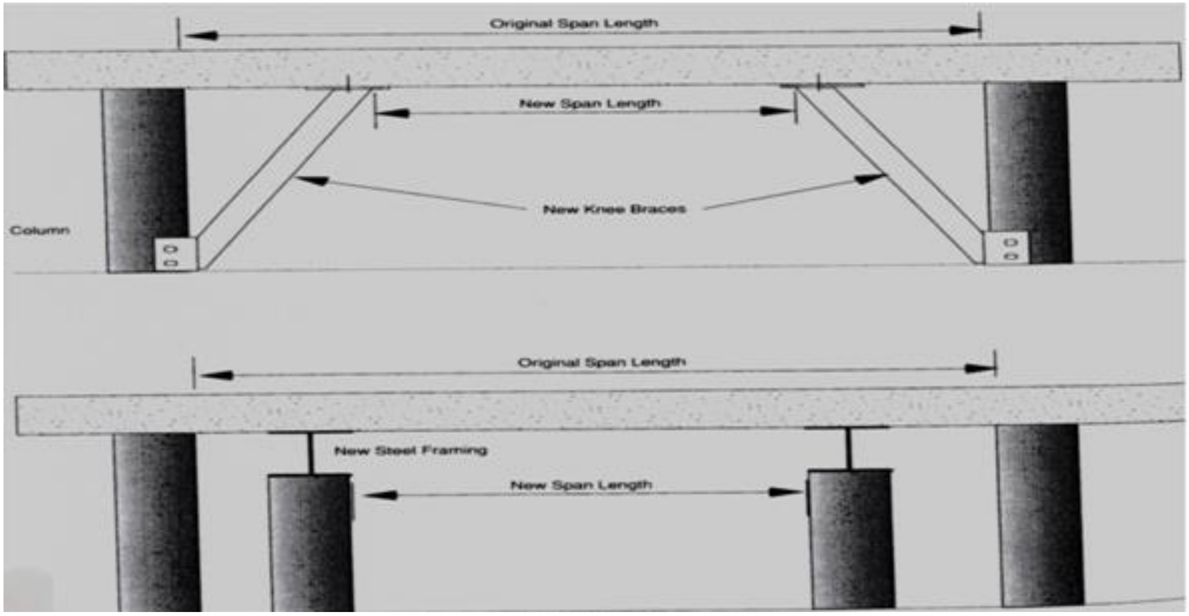


3. Span Shortening Techniques

- Span length shortening, adding additional flexural capacity or stiffness, can be very cost effective.

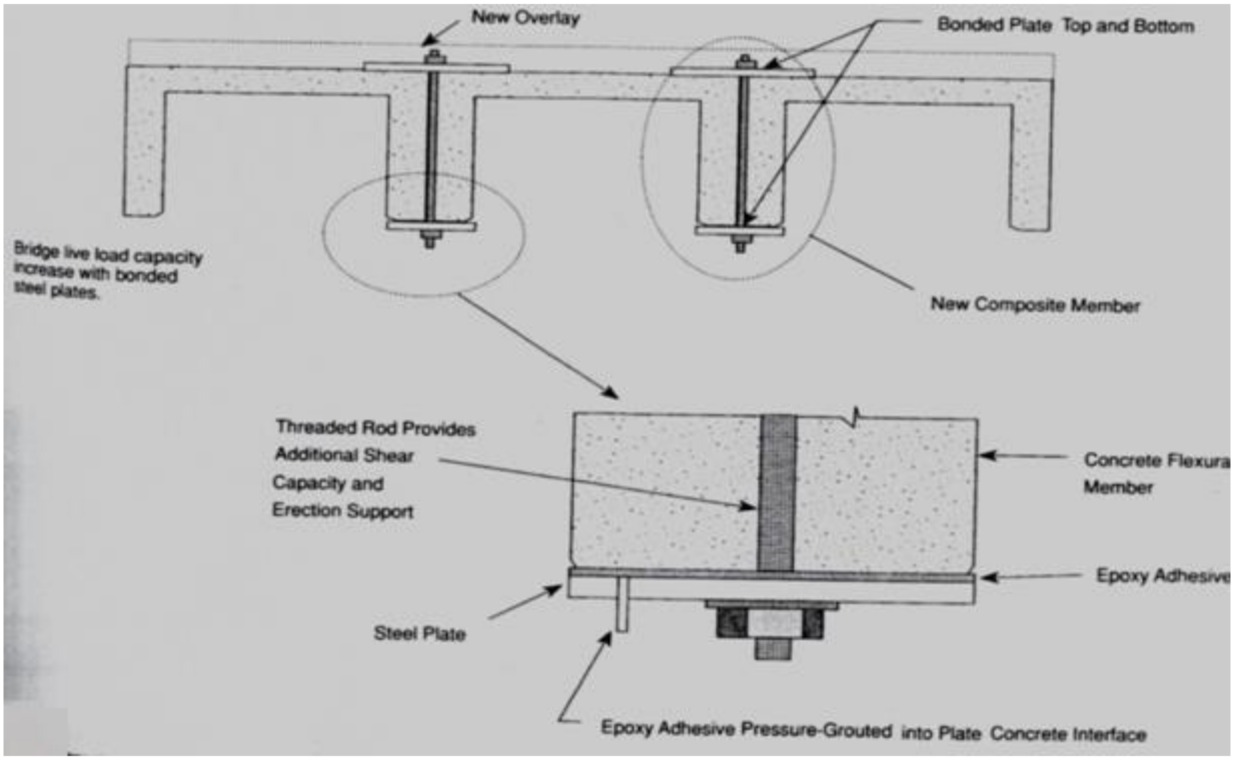
Span shortening for slabs and beams is accomplished by various methods, including:

- Enlarging the column capitals,
- Adding steel or concrete diagonal braces, or
- Placing sub framing within the span



4. Bonded Steel Plate Reinforcement

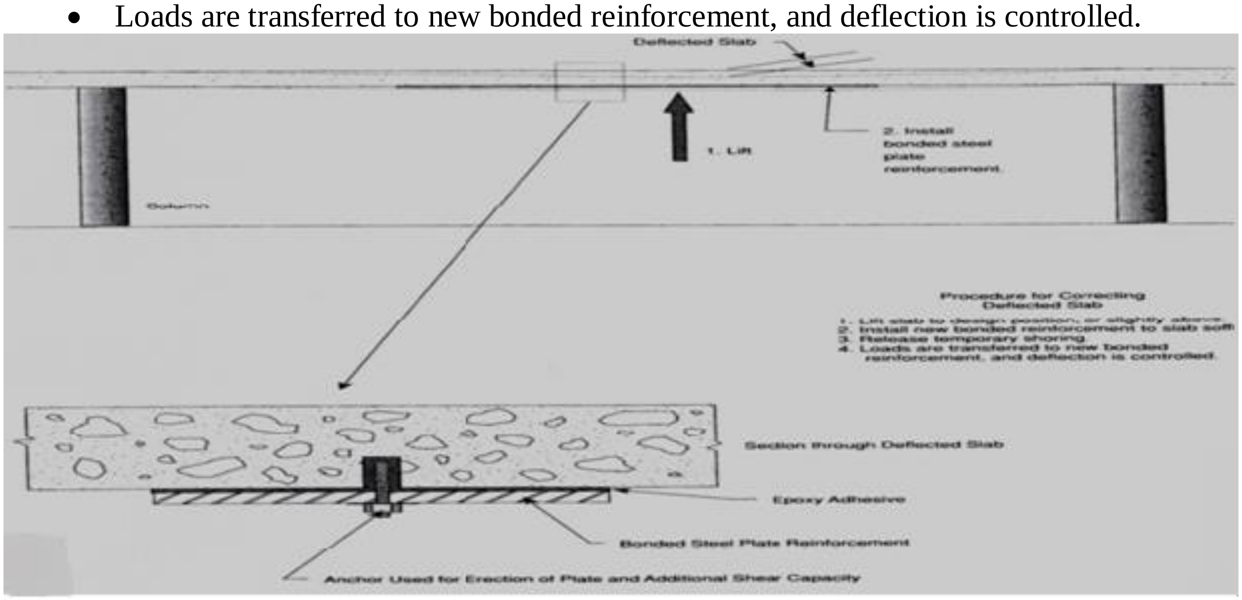
- Externally bonded reinforcement is an effective method of increasing **live load capacity** or removing **unwanted deflection**.
- In most cases, steel plates are bonded, using epoxy, to the soffit or sides of flexural members.
- An **advantage** of this technique is that repair results in only a small increase in dimensions, which may be important for vertical traffic clearance or aesthetics.
- Externally bonded reinforcement is an effective method of increasing live load capacity or removing unwanted deflection.
- In most cases, steel plates are bonded, using epoxy, to the soffit or sides of flexural members.
- An advantage of this technique is that repair results in only a small increase in dimensions, which may be important for vertical traffic clearance or aesthetics.
- When using steel plates, removal of mill scale and any bond-inhibiting materials is required.
- Shot blasting or heavy abrasive blasting produces a rough surface on the steel, which improves the adhesive bond and shear transfer.
- Effective bonding has been achieved using either pressure-injected flowable epoxy resin or epoxy gel applied to the mating surfaces prior to final erection of the steel plates.
- In some applications, expansion anchors are used in combination with the epoxy adhesive to develop adequate shear transfer between the concrete and steel.



5. Correction of Deflected Member with Bonded Steel Plate

Procedure for Correcting Deflected Slab

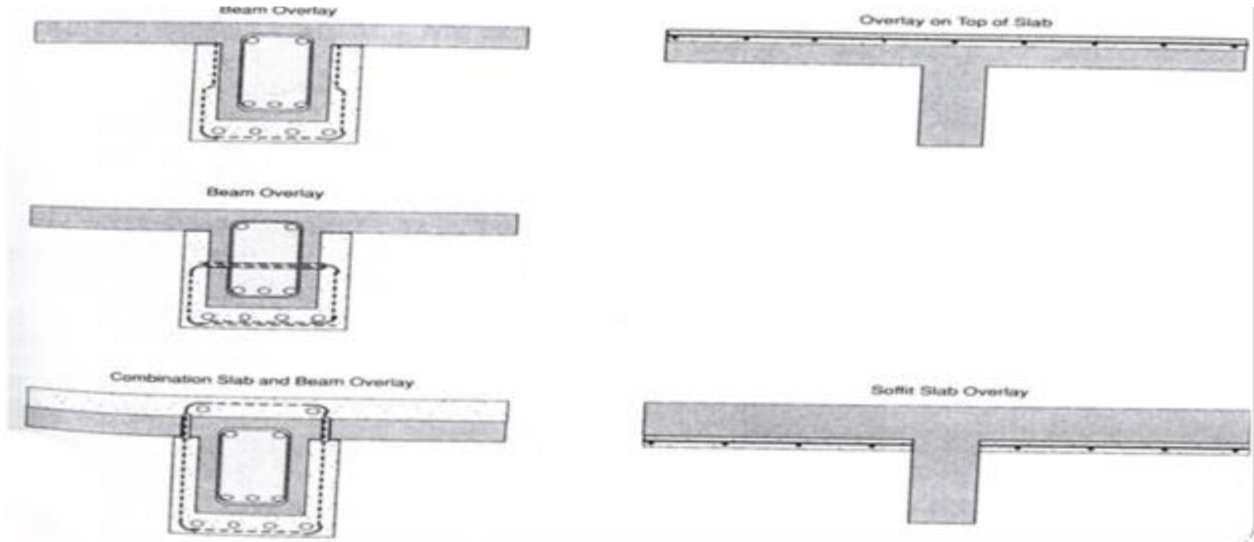
- Lift slab to design position, or slightly above.
- Install new bonded reinforcement to slab soffit.
- Release temporary shoring.
- Loads are transferred to new bonded reinforcement, and deflection is controlled.



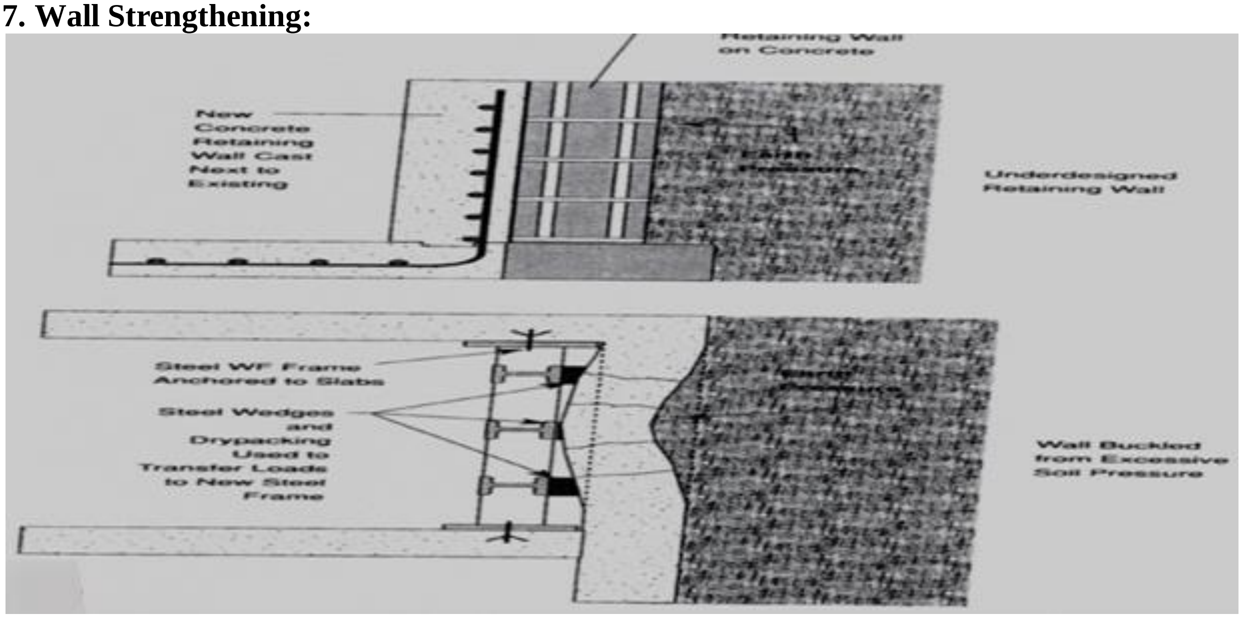
6. Concrete Overlay and Section Enlargement:

Concrete overlaying techniques have been effective when used to increase both flexural capacity and the stiffness of concrete floor slabs and beams.

- This technique involves: addition of considerable dead load, thus requiring careful analysis of its effects on the supporting structural components.
- Slabs can be overlayed from the top side or soffit.
- When soffit overlays are constructed, shotcrete or form and pump techniques must be used.



7. Wall Strengthening:



CONNECTION STABILIZATION AND STRENGTHENING

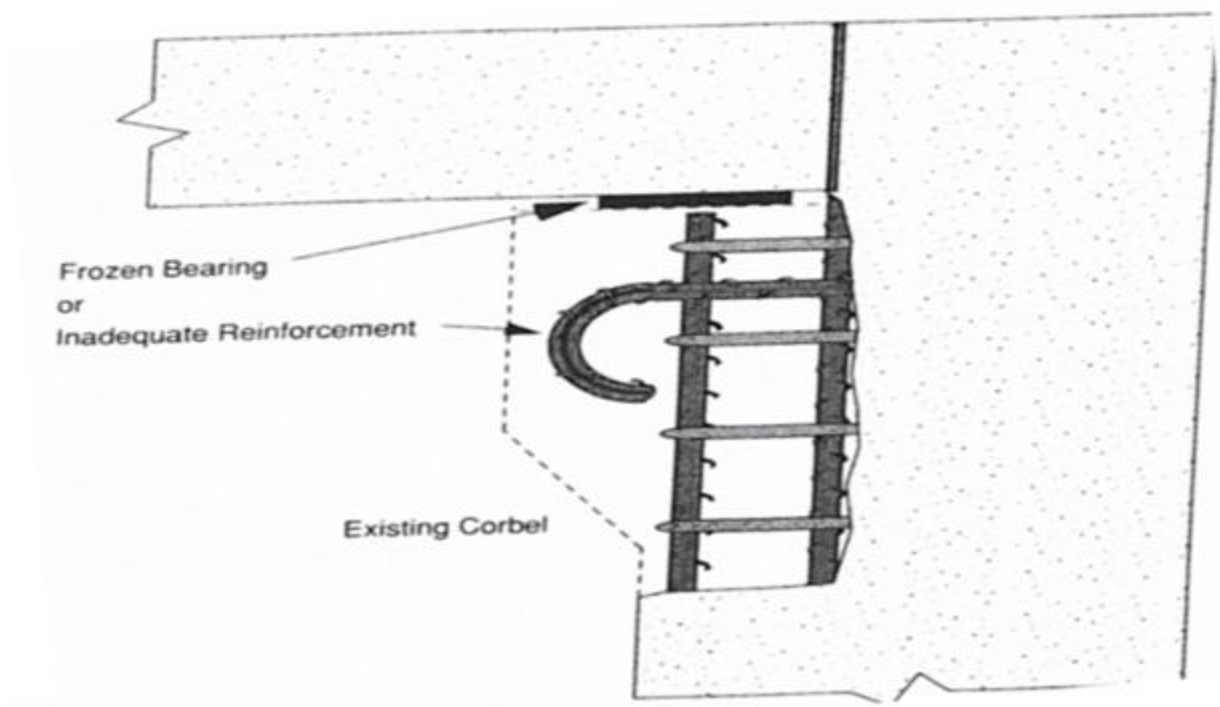
1. Reconstruction of Corbel Bearing
2. Externally Mounted Compression Struts

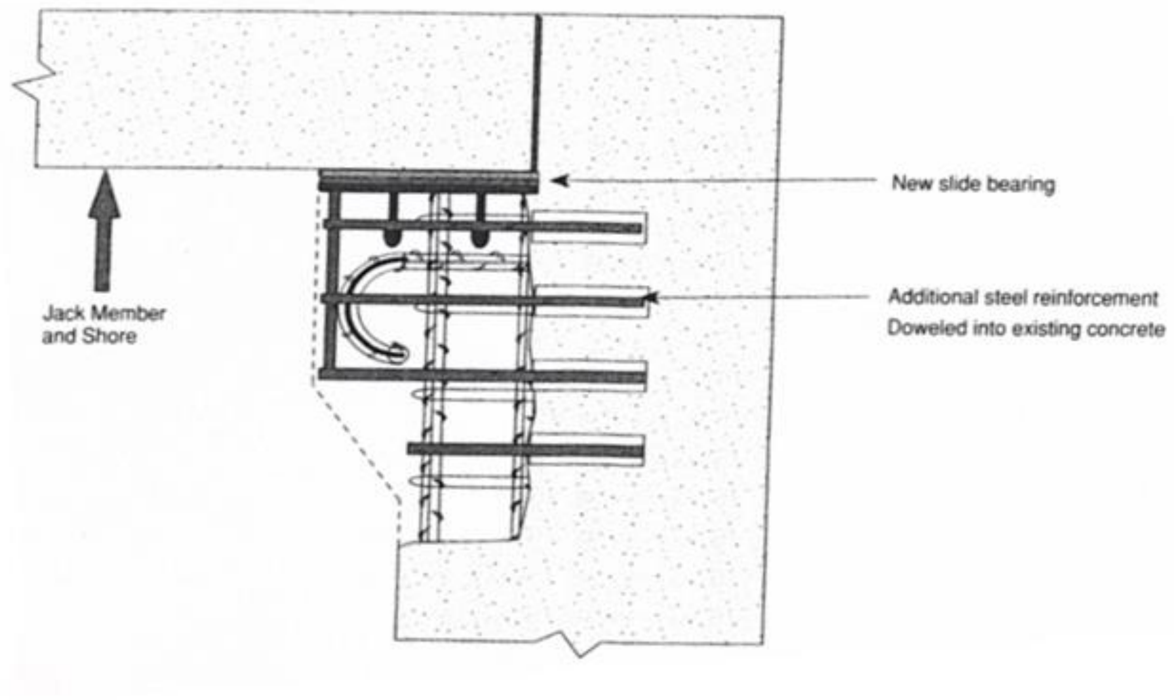
1. Reconstruction of under designed or Nonfunctioning Corbel

Several joints exist within structures, including those at beam-column connections. These connections must be free to rotate, expand, and contract. If the connection fails to allow for these movements, or the structural support elements become overstressed, reconstruction becomes necessary.

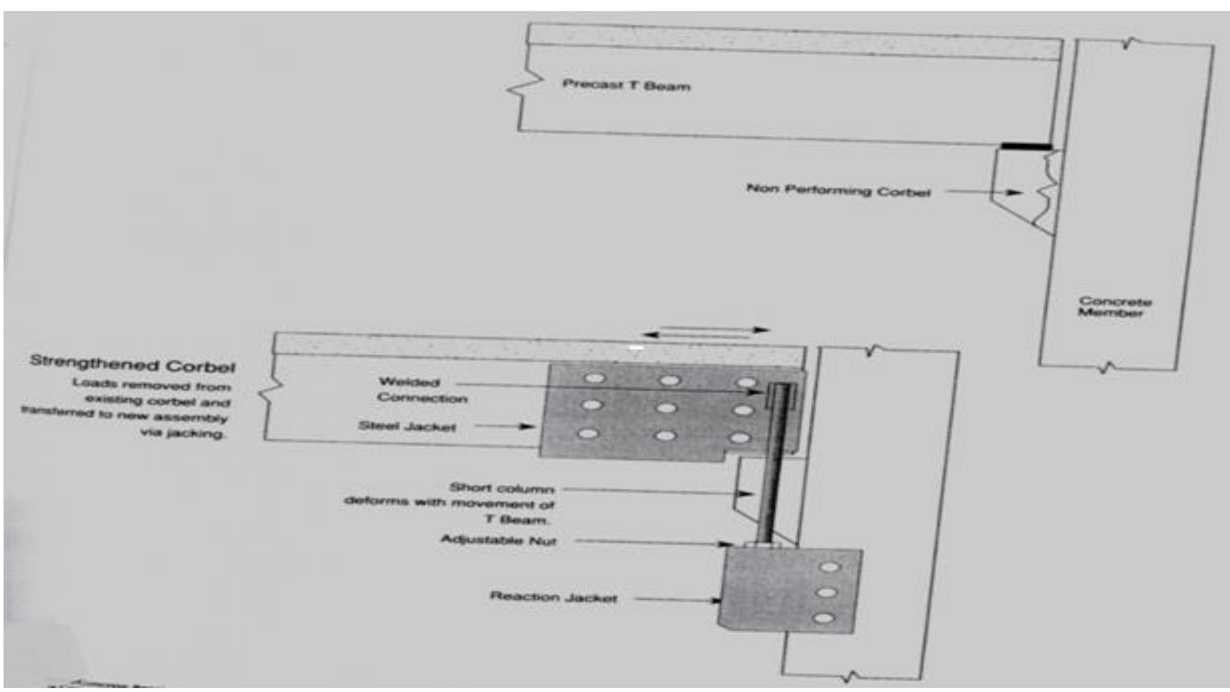
Various techniques are available for this reconstruction, including:

- Corbel reconstruction
- Short compression column (pedestal)
- Tension strut hanger
- Shear shelf





2. Externally Mounted Compression Struts:



SHOTCRETE

Shotcrete is mortar or very fine concrete deposited by jetting it with high velocity(pneumatically projected or sprayed) on to a prepared surface as shown in figure the system has different proprietory names in different countries such as Blastcrete,Blowcrete,Guncrete,Jet-crete,Nucrete,pneukrete,Spraycrete,Torkrete,etc. though the principle is essentially the same. Shotcrete offers advantages over conventional concrete in a variety of new construction and repair works. Shotcrete is frequently more economical than conventional concrete because of less formwork requirements, requiring only a small portable plant for manufacture and placement. It is capable of excellent bonding with a number of materials and this may be an important consideration

Typical shotcreting machine

swimming in pool construction

Sculptured shotcreting

slope stabilization

Shotcrete has wide applications in different constructions, such as thin over-head vertical or horizontal surfaces, particularly the curved or folded sections; canal, reservoir and tunnel lining; swimming pools and other water-retaining structures and prestressed tanks. Shotcrete is very useful for the restoration and repair of concrete structures, fire damaged structures and waterproofing of walls.

shortcrete has been successfully used in the stabilization of rock slopes and temporary protection of freshly excavated rock surfaces. Its utility has been proved for protection against long-term corrosion of piling, coal bunkers, oil tanks, steel building frames and other structures, as well as in encasing structural steel for fire proofing.

Special shotcrete has been developed for high temperature applications, such as refractory lining of kilns, chimneys, furnaces, ladles, etc.

TYPES OF SHOTCRETING;

There are two basic types of shortcreting processes which are described here.

1. Dry mix process
2. Wet mix process

Dry mix process

In the dry mix process the mixture of cement and damp sand is conveyed through a delivery hose pipe to a special mechanical feeder or gun called delivery equipment. The mixture is metered in to the delivery hose by a feed wheel or distributor. This material is carried by compressed air through delivery hose to a special nozzle. The nozzle is perforated mainfold through which water is introduced under pressure and intimately mixed with other ingredients. The mortar is jetted from the nozzle at high velocity to the surface to be shortcreted. In this process any alteration in the quantity of water can be easily accomplished by the nozzleman (i.e, the worker in charge of the nozzle). If the water content is more, then concrete tends to slump when jetted on to vertical surface. On the other hand in case of deficiency of water the material which will rebound from the surface will be excessive. Alteration of water content done accordingly. The amount of water should be so adjusted that wastage of material by rebounding is minimum. The water-cement ratio should be between 0.33 and 0.50

Several forms of equipment are available for shotcreting by this technique. A common layout includes an air-compressor, a material hose, air and water hoses, a nozzle gun and a pressure tank or pump for water supply, and transporting equipment. The equipment ensuring continuous supply of the mortar can convey the material to a distance of 300 to 500 m horizontally and 45 to100 m vertically.

WET MIX PROCESS

In this process, all the ingredients, i.e. cement, sand, small-sized course aggregate and water, are mixed before entering the chamber of delivery equipment. The ready-mixed concrete is metered into the feeding chamber and conveyed by compressed air at a pressure of 5.5 to 7 atmosphere to a nozzle. Additional air is injected at the nozzle to increase the velocity and improve the gunning pattern. Equipment capable of placing concrete at the rate of 3 to 9 cubic meters per hour is available.

The phenomenon of falling back of a part of mortar or concrete jetted on to surface to be treated, due to high velocity of jet, is called rebound and depends up on the water-cement ratio, and the nature and position of the surface treated. The rebound decreases with higher water-cement ratio, and has higher values for vertical and overhead surfaces. The approximate range of rebound is 5 to 15 percent for horizontal slabs, 15 to 30 percent for sloping and vertical surfaces and 20 to 50 percent for the treatment of overhead surfaces and corners. The rebounding material mostly consists of sand or/ and course particles and very little quantity of cement falls back. The rebound material falling on surface is cleaned before being treated by shotcreting. The vertical surfaces should be treated from bottom to top. The rebound also depends upon the angle of jetting with respect to the surface being treated; it is minimum when the nozzle is held at right angles to the surface. The nozzle should be kept at a distance of 900 mm from the surface. Addition of pozzolanic material to the mix reduces the rebound by improving its plasticity. Since rebounded material is wastage, it is economical to reduce the rebound by adding as much water at the nozzle as conditions permit.

The dry-mix process is preferred in case the light-weight concrete is used. The lower water-cement ratio used results in higher strengths, less creep and drying shrinkage and higher durability. Whereas in the wet process the higher durability can easily be achieved by using air-entraining agents. The water-cement ratio can be very accurately controlled in the wet process. Further, the wet process does not cause dust problems. The larger capacity available in wet mix process results in higher rates of placing of concrete. The procedure of shotcreting a surface invoves the following steps:

(i) Preparation of surface to receive shotcrete: Where the shotcrete is to be placed against earth surfaces as in canal linings, the surfaces should first be thoroughly compacted and trimmed to line and grade. Shotcrete should not be placed on any surface which is frozen, spongy, or where there is free water. The surface should be kept damp for several hours before applying shotcreting.

For repairing deteriorated concrete it is essential to remove all unsound material. Chipping should be done to remove all the offsets in the cavity which may cause abrupt change in thickness of the repair work. No square shoulders should be left at the perimeter of the cavity, and all edges should be tapered .After ensuring that the surface to which the shotcrete is to be bounded is sound, it should be sand-blasted .The nozzleman usually scours clean the area before applying the shotcrete with an air-water jet, and then the water is shut off and all free water is blown away by compressed air.

(ii)Construction of forms: The forms are usually of ply-wood sheeting, true to line and dimension .They are adequately braced to ensure protection against excessive vibration. The form should be constructed to permit the escape of air and rebound during the gunning operation. They should also be oiled or dampened .Adequate and safe scaffolding is necessary so that the nozzleman can hold the nozzle at a distance of 1 to 1.5 m from the surface.

(iii)Placement or Reinforcement: Sufficient clearance should be provided around the reinforcement to permit complete encasement with the shotcrete .The minimum clearance between the reinforcement and the form may vary between 12mm for the case of mortar mix and wire mesh reinforcement to 50mm for the case of concrete and reinforcing bars.

(iv)Preparation for succeeding layers: The receiving layer should be allowed to take its initial set before applying a fresh layer of shotcrete .All laitance ,use material and rebound should be removed brooming .Any laitance which has been allowed to take final set should be removed by sand -blasting and the surface cleaned with an air-water jet.

(v)Finishing of the surface: Natural gun finish is preferred from both structural and durability stand points. There is a possibility that further finishing may disturb the section, harming the bond between the shotcrete and underlying material, and creating cracks in the shotcrete. Where greater smoothness or better appearance is required special finishes must be applied .Sometimes, for finer finish, a flash coat consisting of finer sand when normal, and with the nozzle held well back from the surface,is applied to the shotcrete surface as soon as possible after the screeding.

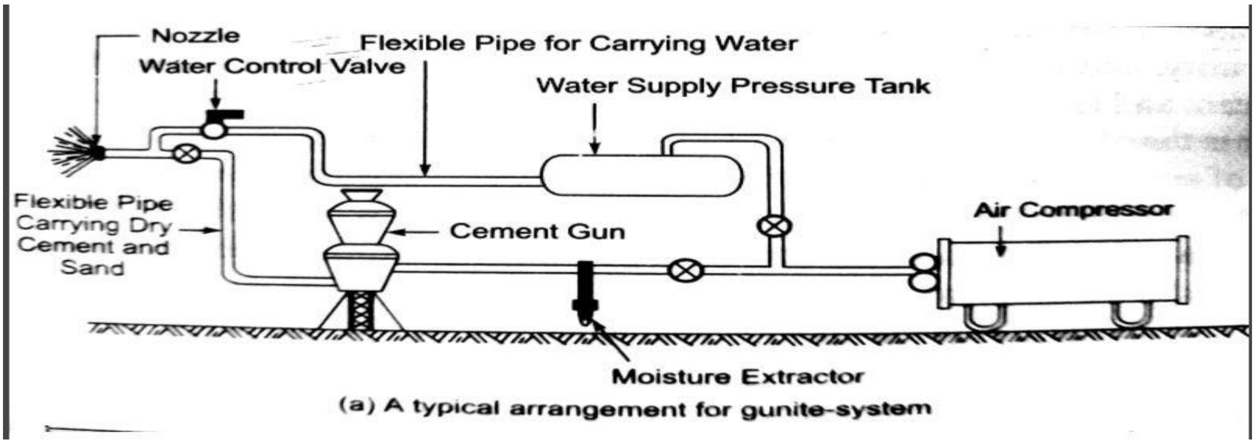
Disadvantages with Shotcretes:

The method in which raw materials, aggregate and cement are handled may be objectionable to environmentalists. Dust from either the fine aggregate and/or cement can settle on the ground around the application area .This potential hazard must be considered when designing or applying a shotcrete coating. Sometimes special type of enclosures may be necessary to confine the area design for batching, mixing or charging the gun .In addition to the dusting problem, rebound also has to be cleaned up and hauled to an approved waste area.

The high cost of shotcrete combined with wastage due to rebound has to be weighted with the difficulties involved with other techniques before shotcreting is adopted for any particular situation. Inspite of all these problems, shotcrete has its own merits, such as the need of form work only on one side of the work, its suitability for concreting thin sections and in sites where access is difficult .Moreover, shotcrete bonds perfectly with the existing old concrete masonry, exposed rock or suitably prepared steel surface and hence is very effective in the repair of the structures concerned.

2. GUNITING:

Gunite also known as a dry process shotcrete, uses air pressure to convey dry material from machine through hose to nozzle where water is added. The technique of depositing very thin layers of mortar in each pass of the nozzle than that available with the shotcrete, is termed guniting. A typical arrangement in the gunite system is shown in figure. In addition to the general requirements for quality control of



(a) A typical arrangement for gunite-system


Gunite machine


Guniting the prepared surface

normal concrete, guniting requires careful and skilful handling of nozzle for high quality finished work. The surface to be gunited should be cleaned thoroughly of grease or oil or any other loose or defective material by applying either air blast or high pressure water jet. If necessary the surface can even be sand-blasted by omitting the cement using the same gun and reducing the velocity of jet. The sand blasting can also help in removing the loose rust on the reinforcement. The surfaces likely to absorb water should be kept wet up six hours before guniting. The mix generally used for guniting is 1:3 to1:4:5 with a water-cement ratio of about 0.30. The maximum size of sand is limited to 10mm. A 7-day strength of the order of 70 Mpa can be achieved with a 1:3 mix. This high- quality mortar with low water-cement ratio results in low permeability, good resistance to weathering and chemical attack, etc. The resistance to the chemical attack can be increased by using sulphate-resisting Portland cement or high-alumina cement. Addition of Pozzolana up to 5 percent by a mass of cement can improve plasticity and reduce the rebound. Due to good bonding between reinforcement and gunite, the gunite acts as a part of the structure and not merely as an added cover. Each layer of the gunite is usually provided with a spot-welded steel-wire-mesh fabric of 5mm diameter wires, to reduce initial shrinkage and to prevent cracks in the freshly placed material. The meshes should overlap each other by one mesh to maintain continuity whenever the meshes are joined. The reinforcing fabric should be maintained at a distance of 6 to 10 mm from the original concrete surface during guniting. The guniting can effectively be used for the repair of dams, spillways, bridges piers, sewerage pipes and water mains, and for protection of canal banks. It has been extensively used for the protection of steel girders from corrosion, etc. and waterproofing of reservoirs and tunnel. Another important application is the repair of all types of concrete structures where the concrete has spalled off due to corrosion of reinforcement.

EPOXY

Epoxy Grouting

Epoxy grouting has been used in the recent past with a high degree of success especially in treating deep-rooted cracks.

Epoxy Coating

Epoxy coating is highly effective against corrosion of concrete, used advantageously as a rehabilitation or repair technique in conjunction with other methods of repair suiting the damaged structure. It can be applied with brushes or specially designed spray guns. Whenever epoxy coating is used in conjunction with guniting (or) new concreting, the epoxy-treated surface should be properly roughened with emery paper to improve the bond of the coat, or the concrete should be deposited while the epoxy coating is still tacky.

Epoxy Mortar Coating

Epoxy mortar coating can be used to fill cracks in concrete if the damage is not widespread. If the damage is extensive, then the concrete in the friable stage has to be chipped off and epoxy mortar coating applied to reinstate the integrity of the structure. Care should, however, be taken to apply a tack coat of epoxy resin before applying the epoxy or cement mortar. It is necessary to clean the surface to be treated thoroughly and no loose or unsound material should be allowed to remain before applying epoxy mortar. The tack coat should be tacky while applying epoxy or cement mortar.

CRACK CELLING

Cracks may be an indication of a damaged or distressed structure. However, all types of cracks are not to be treated alike. Basically, the cracks have to be repaired for two reasons, namely, for structural purpose and for durability purposes. One of the most prevalent techniques of repairing cracks is injection of different types of materials (depending up on the nature of the defect). The selection of material for injection requires thorough understanding properties of the material and functions that such a repair has to perform. In all the cases, it is imperative that the cause of cracking is properly determined, so that the selection of material is appropriate. Basically, material injection can be used for three purposes. Firstly, injection materials that are used to restore the structural stability of the structures. Secondly, injection materials that are used to protect the reinforcement against moisture and air entering the concrete, thereby lowering the rate of corrosion. Thirdly, injection materials which are used to stop the water from entering the structure.

The selection of material for injecting into cracks largely depends on the following factors:

- Pattern of cracks
- Width of the crack
- Movement in the crack faces

  - due to temperature

  - due to dynamic loading

- moisture in the crack
- dirt in the crack

The pattern of cracking helps in ascertaining the reason for cracking, which in turn helps in the selection of base material. The width of crack has direct bearing on viscosity of the material required it depends on the movements in the crack, which reflects on the type of material required, i.e., whether it should act as structural injection or just an elastic seal. In case the injection is used for structural purpose, it should be able to transfer the stresses from one crack face to the other and should have adequate compressive and flexural strengths, at least 10-15% higher than the neighbouring concrete. The moisture in the crack calls for a water-compatible system of injection. Presence of dirt in the crack will affect the choice of the crack preparation system Table shows the chart for selection of materials.

The newly developed repair materials owing their improved state-of-the art properties have provided opportunity to rehabilitate structures. This chapter described various properties of repair materials with respect to their strength and applicability under various situations. These materials have proved to be effective if chosen properly and applied using correct techniques. We discussed in this chapter, the properties of repair materials and the method of selecting them for various applications.

Table 21.7 Selection of materials

Type of crack	Width (mm)	Movement	Water	Type of material	Mode of application and/or principle
Shrinkage cracks in concrete	0.2	No	No	Two-component epoxy injection	Surface treatment which works through capillary action
Shrinkage cracks in plastic state	0.2	No	No	One-component flexible paint on acrylic base	Coat with roller or brush
Shrinkage cracks in concrete, brickwork	0.2–1	No	No	Two-component epoxy low viscosity	Low pressure injection, smaller cracks with high pressure injection
Shrinkage cracks in concrete, brickwork	1–2	No	No	Two-component epoxy injection and solvent-free epoxy	Low pressure injection
Shrinkage cracks in concrete, brickwork	2–5	No	No	Solvent-free epoxy thicotropic	Low pressure injection, with hand pump
Shrinkage cracks in concrete, brickwork	5	No	Dry/wet	Polymer-modified cement-based grout	Grout with injection grout by gravity or hand pump
Shrinkage cracks in concrete, brickwork	15	No	Dry/wet	Non-shrink grout	Cut and fill non-shrink mortar
Moving cracks in concrete, brickwork	0.2–1	Due to temperature changes	Dry/wet	Two-component polyurethane injection and flexible paints when wet joints, primary injection with polymer gel forming	Higher pressure injection with (low pressure injection also possible) then coat with roller/brush
Joints in prestressed concrete (coupling joints)	0.2–2	Vibration	Dry/wet	Two-component polyurethane injection and joint sealant, when wet joint primary injection with polyurethane gel forming	Higher pressure injection with (low pressure injection also possible) then coat with roller/brush

UNIT-VI
SEISMIC RETROFITTING OF REINFORCED CONCERTE BUILDINGS

Seismic Retrofitting Techniques are required for concrete constructions which are vulnerable to damage and failures by seismic forces. In the past thirty years, moderate to severe earthquakes occurs around the world every year. Such events lead to damage to the concrete structures as well as failures.

Thus the aim is to Focus on a few specific procedures which may improve the practice for the evaluation of seismic vulnerability of existing reinforced concrete buildings of more importance and for their seismic retrofitting by means of various innovative techniques such as base isolation and mass reduction.

So Seismic Retrofitting is a collection of mitigation technique for Earthquake engineering. It is of utmost importance for historic monuments, areas prone to severe earthquakes and tall or expensive structures.

Keywords: Retrofitting, Base Isolation, Retrofitting Techniques, Jacketing, Earthquake Resistance

1. Introduction to Seismic Retrofitting Techniques:

- Earthquake creates great devastation in terms of life, money and failures of structures.
- Upgrading of certain building systems (existing structures) to make them more resistant to seismic activity (earthquake resistance) is really of more importance.
- Structures can be (a) Earthquake damaged, (b) Earthquake vulnerable
- Retrofitting proves to be a better economic consideration and immediate shelter to problems rather than replacement of building.

1.1 Seismic Retrofitting of Concrete Structures:

Definition:

It is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes.

The retrofit techniques are also applicable for other natural hazards such as tropical cyclones, tornadoes, and severe winds from thunderstorms.

1.2 Need for Seismic Retrofitting:

- To ensure the safety and security of a building, employees, structure functionality, machinery and inventory
- Essential to reduce hazard and losses from non-structural elements.
- predominantly concerned with structural improvement to reduce seismic hazard.
- Important buildings must be strengthened whose services are assumed to be essential just after an earthquake like hospitals.

1.3 Problems faced by Structural Engineers are:

Lack of standards for retrofitting methods – Effectiveness of each methods varies a lot depending upon parameters like type of structures, material condition, amount of damage etc.,

1.4 Basic Concept of Retrofitting:

The aim is at:

- Upgradation of lateral strength of the structure
- Increase in the ductility of the structure
- Increase in strength and ductility

2. Classification of Retrofitting Techniques:

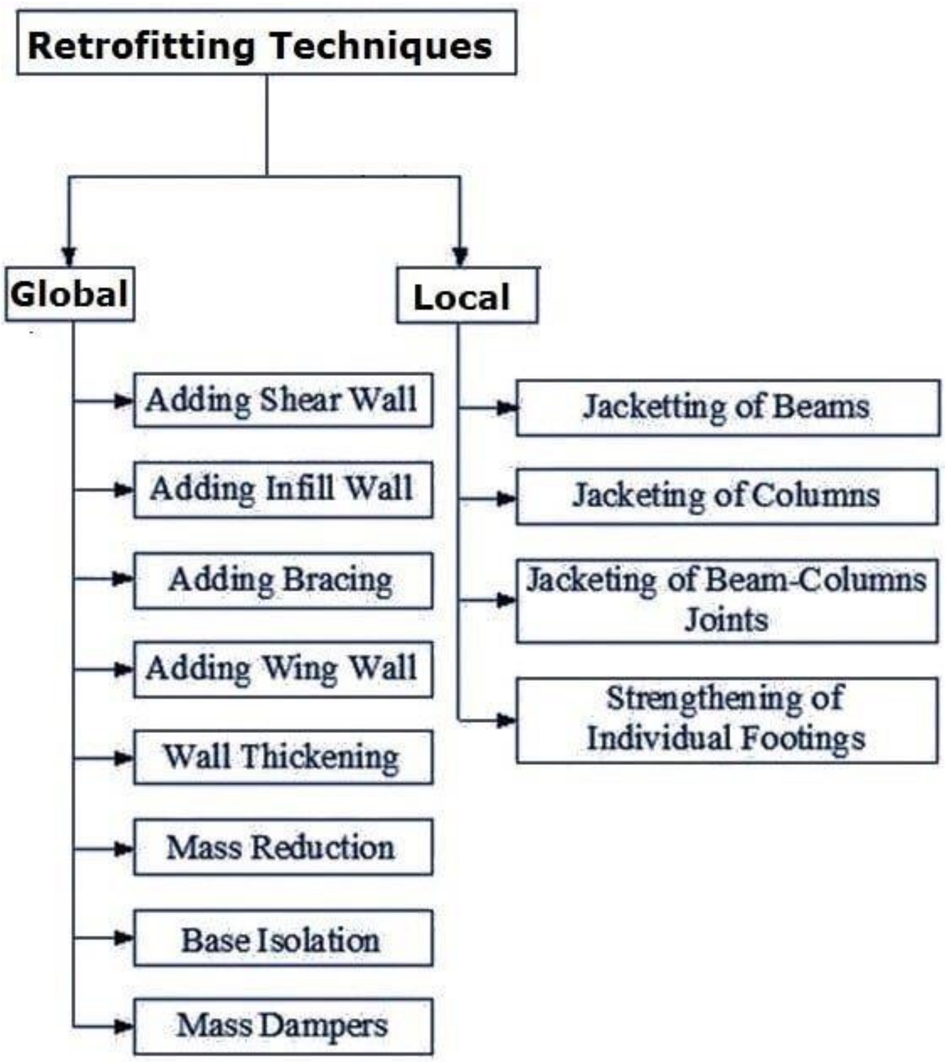


Fig 1: Retrofitting Techniques for Reinforced Concrete Structures

2.1 Adding New Shear Walls:

- Frequently used for retrofitting of non ductile reinforced concrete frame buildings.
- The added elements can be either cast?in?place or precast concrete elements.
- New elements preferably be placed at the exterior of the building.
- Not preferred in the interior of the structure to avoid interior mouldings.

Fig 2: Additional Shear Wall

2.2 Adding Steel Bracings

- An effective solution when large openings are required.
- Potential advantages due to higher strength and stiffness, opening for natural light can be provided, amount of work is less since foundation cost may be minimized and adds much less weight to the existing structure.

Adding STEEL Bracings:

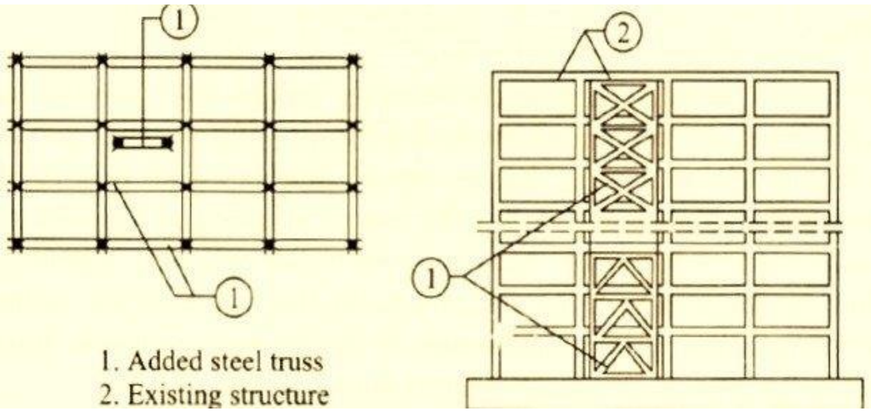


Fig 3: RC Building retrofitted by steel bracing

2.3 Jacketing (Local Retrofitting Technique):

This is the most popular method for strengthening of building columns.

Types of Jacketing:

1. 1.Steel jacket,
2. Reinforced Concrete jacket,
3. Fibre Reinforced Polymer Composite (FRPC) jacket

Purpose for jacketing:

- To increase concrete confinement
- To increase shear strength
- To increase flexural strength

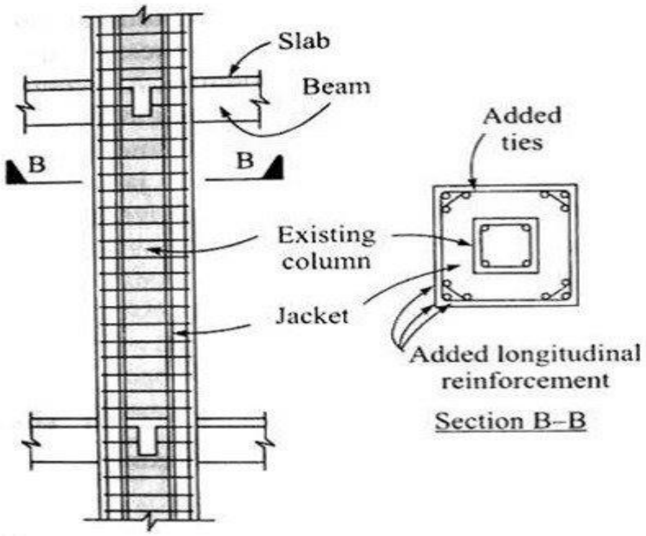


Fig 4: Column Jacketing

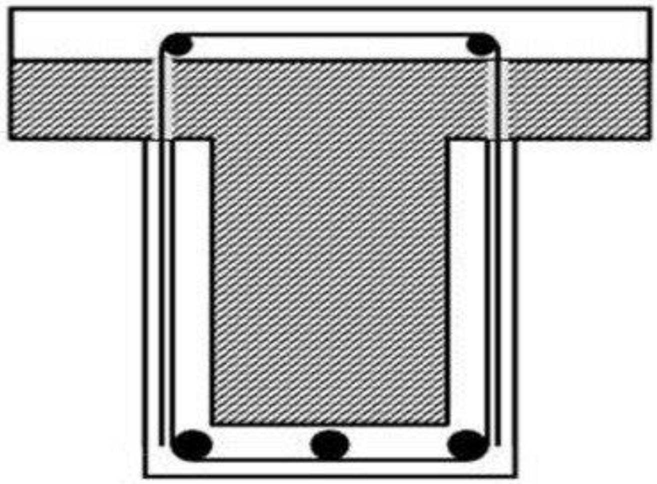


Fig 5: Beam Jacketing

2.4 Base Isolation (or Seismic Isolation):

Isolation of superstructure from the foundation is known as base isolation. It is the most powerful tool for passive structural vibration control technique.

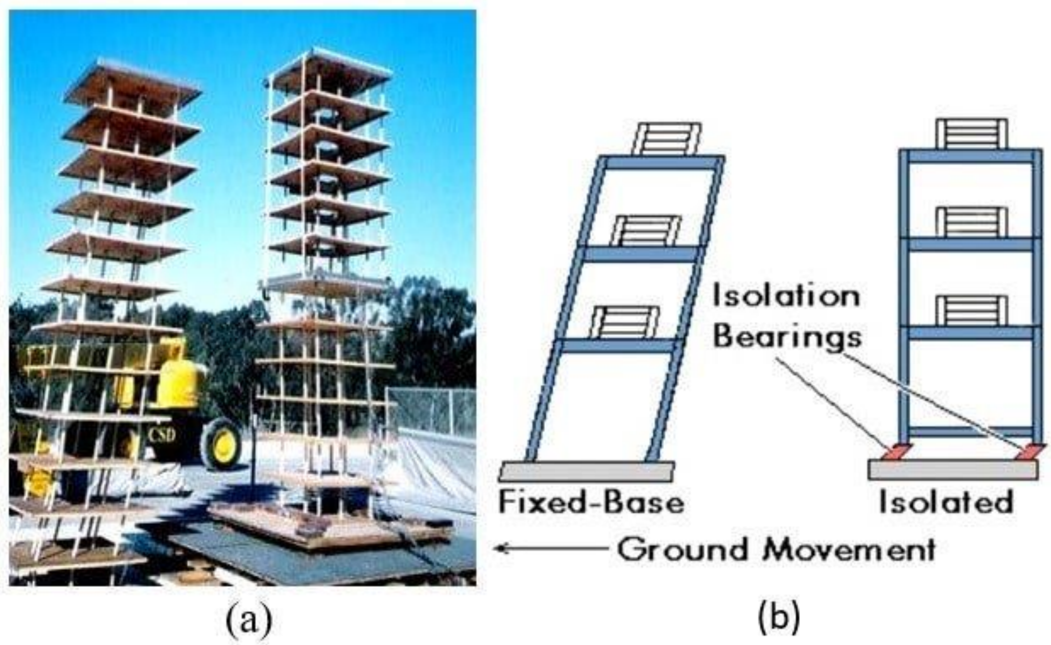


Fig 6: Base Isolated Structures (a)Model Under Test, (b) Diagrammatical Representation

2.4.1 Advantages of Base Isolation

- Isolates Building from ground motion – Lesser seismic loads, hence lesser damage to the structure, -Minimal repair of superstructure.
- Building can remain serviceable throughout construction.
- Does not involve major intrusion upon existing superstructure

2.4.2 Disadvantages of Base Isolation

- Expensive
- Cannot be applied partially to structures unlike other retrofitting
- Challenging to implement in an efficient manner

2.5 Mass Reduction Technique of Retrofitting:

This may be achieved, for instance, by removal of one or more storey's as shown in Figure. In this case it is evident that the removal of the mass will lead to a decrease in the period, which will lead to an increase in the required strength.

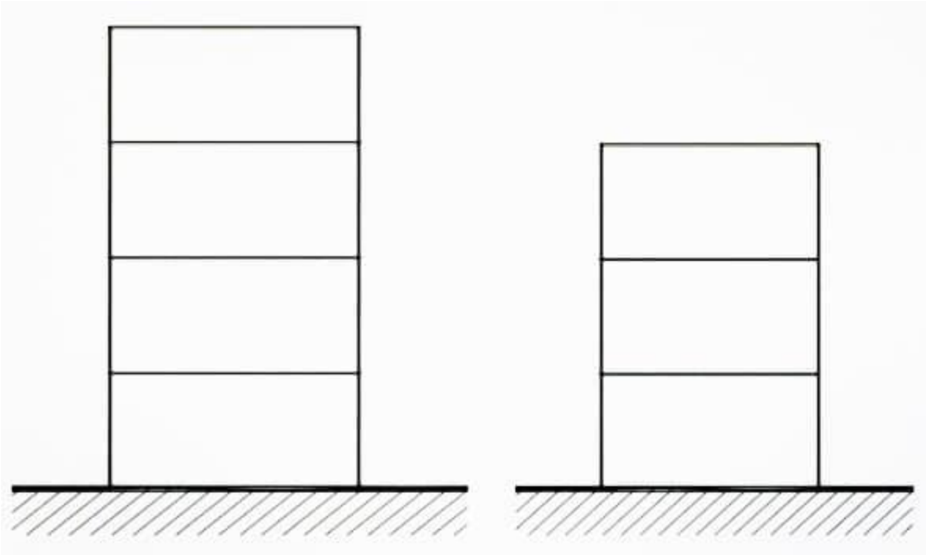


Fig 7: Seismic Retrofitting by Mass reduction (removal of Storey)

2.6 Wall Thickening Technique of Retrofitting:

The existing walls of a building are added certain thickness by adding bricks, concrete and steel aligned at certain places as reinforcement, such that the weight of wall increases and it can bear more vertical and horizontal loads, and also its designed under special conditions that the transverse loads does not cause sudden failure of the wall.

3. Indian Standard Codes for Earthquake Design of Structures:

- IS: 1893-2002 (part-1) Criteria for Earthquake Resistant Design of Structures (Part 1 : General Provision and Buildings) – Code of Practice
- IS: 4326-1993 Earthquake Resistant Design and Construction of Buildings – Code of Practice
- IS: 13920-1993 Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces – Code of Practice
- IS: 13935-1993 Repair and Seismic Strengthening of Buildings – Guidelines
- IS: 13828-1993 Improving Earthquake Resistance of Low Strength Masonry Buildings – Guidelines
- IS: 13827-1993 Improving Earthquake Resistance of Earthen Buildings – Guidelines

4. Conclusion – Seismic Retrofitting Techniques for concrete structures:

- Seismic Retrofitting is a suitable technology for protection of a variety of structures.
- It has matured in the recent years to a highly reliable technology.
- But, the expertise needed is not available in the basic level.
- The main challenge is to achieve a desired performance level at a minimum cost, which can be achieved through a detailed nonlinear analysis.
- Optimization techniques are needed to know the most efficient retrofit for a particular structure.
- Proper Design Codes are needed to be published as code of practice for professionals related to this field.