5. A wall section between two openings above each other is a weak point of the wall under lateral in-plane forces. Cracking in this zone occurs before diagonal cracking of piers (Figure 7.1-2). In order to prevent it and to enable the full distribution of shear among all the piers, either a rigid slab or R.C band must exist between them.

Failure of Non-bearing Walls

The common modes of failures of infilled wall or partition wall are the following:

1 Overturning of wall due to out-of-plane inertia forces
2 Local crushing of the corners.
3 Sliding on bed joints
4 Diagonal cracking through the bedding joints.
5 Diagonal cracking through the units.

Failure of Wall Connections

1 Walls can be damaged due to the seismic force of the roof, which can cause tension cracks and separation of supporting walls (Figure 7.1-3). This failure is characterisitc of heavy flat roofs (or floors) on joists which in turn are supported by bearing walls, but without proper connection with them. Also if the connection with the foundation is not adequate, walls crack there and slide. This may also cause failure of plumbing pipes.

2. Failure due to Torsion and Warping: The damage in an unsymmetrical building occurs due to torsion and warping in an earthquake. This mode of failure causes excessive cracking due to shear in all the walls. Larger damage occurs near the corner of the building.

Failure of Frame Elements

1 Failure of columns due to excessive bending: The columns of a frame may be damaged (by cracking or buckling) due to excessive bending combined with heavy gravity loads, or due to large secondary moments resulting from eccen tricity (see Figure 7 1-4). The latter behavior occurs when storey height is big, columns are slender and vertical loads are heavy.

2 Failure of rigid joints of frame elements. Severe cracking occurs near the rigid joints of frame elements due to shearing action, which can even cause collapse of the frame by complete failure of columns or beams

3 Unequal settlement of individual footings. The unequal settlement of individual column footings may result in excessive deformation in the frame and can cause its collapse.

4.Failure of gable frames, as may be used for assembly halls, cinema houses, school auditoriums etc., is likely if connections are inadequate, since the frames have a tendency of spreading out and there is no secondary resistance available once a joint fails (see Figure 7 1-5).

Failure of Roofs and Floors

1. Dislodging of roofing material: Improperly tied roofing material is dislodged by inertia forces acting on the roof. This failure is typical of sloping roofs, particularly when slates, clay, tiles etc are used as roofing material. Brittle material like asbestos cement may be broken if trusses and sheeting purlins are not braced together.

2. Weak roof-support connection is the cause of separation of roof trusses from supports. Complete roof collapse mostly occurs due to collapse of the supporting struc ture. The rupture of the bottom chord of the roof

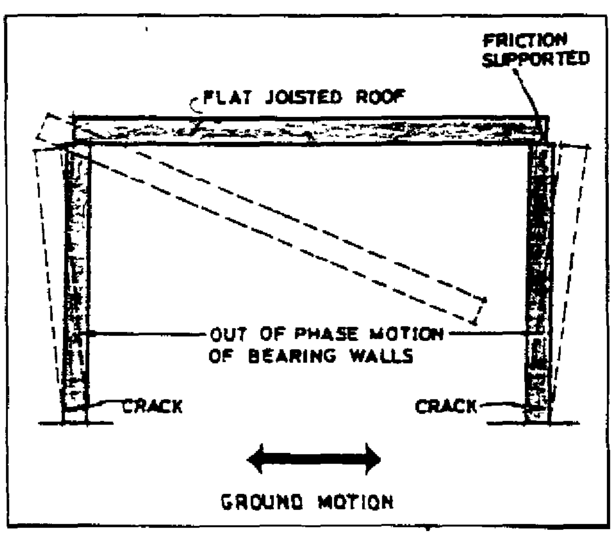

Figure 7.1-3 Fall of Roof because of Inadequate Connection between Roof of Wall [1]

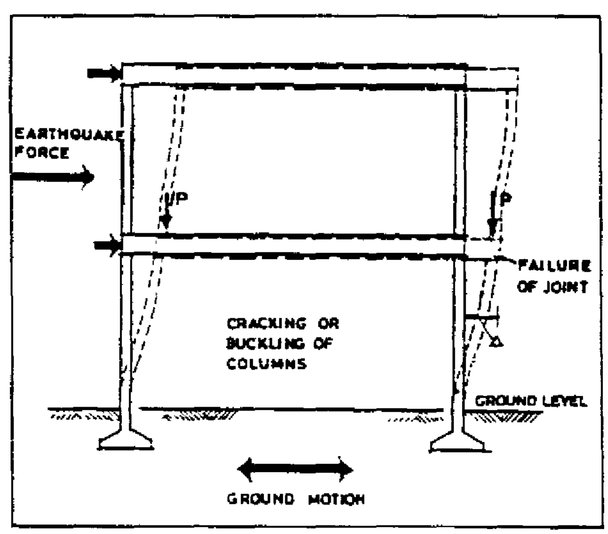

Figure 7.1-4 Failure of Columns due to Excessive Bending [1]

truss may cause a complete collapse of the truss as well as that of the walls (Figure 7.1-6).

3 Heavy roofs, as used in rural areas, with thick earth cover on round timbers, give large forces on the walls and lead to complete collapse.

4. Lean-to roofs can cause instability in the lower supporting walls or piers. From lack of ties, collapse easily occurs.

Chimneys and Flue-Pipes

Brick or block chimneys have a very bad record in earthquakes. They often break off at roof level (Figure 7.1-7) It is always cheaper, safer to use a simple flue pipe. Where a brick chimney is to be used, it should be bonded to a wall and be reinforced.

Failure of Ground

1. Inadequate depth of foundation: shallow foundations deteriorate as a result of weathering and consequently become weak to earthquakes.

2. Differential settlement of foundation: during severe ground shaking, liquefaction of loose water-saturated sands, and differential compaction of weak, loose soils occurs leading to excessive cracking and tilting of building, which may even collapse completely

3 Sliding of Slopes: Earthquakes cause sliding failures in man-made as well as natural hill slopes, and buildings resting on such slopes have a danger of complete

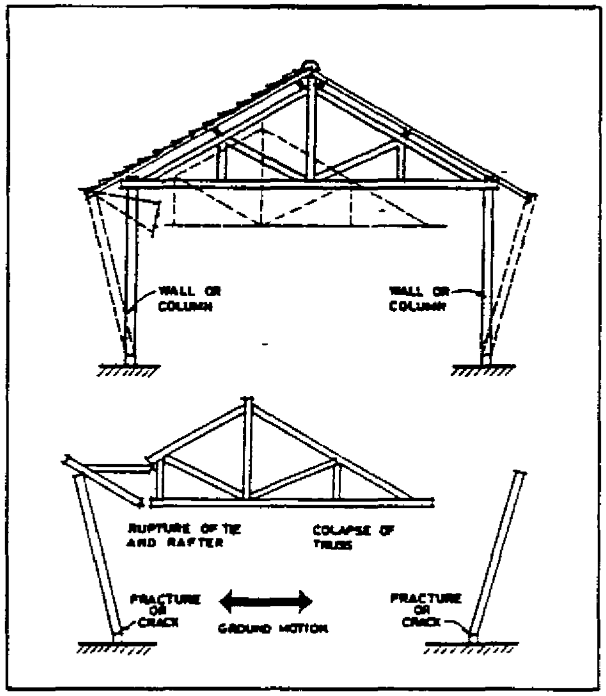

Figure 7.1-6 Failure due to Rupture of Bottom Chord of Roof Truss

disastrous disintegration.

Lessons Learned from Past Earthquakes

The study of damage and failures after earthquakes is one of the main sources of design criteria for earthquake-resistant buildings and structures These design criteria and methods

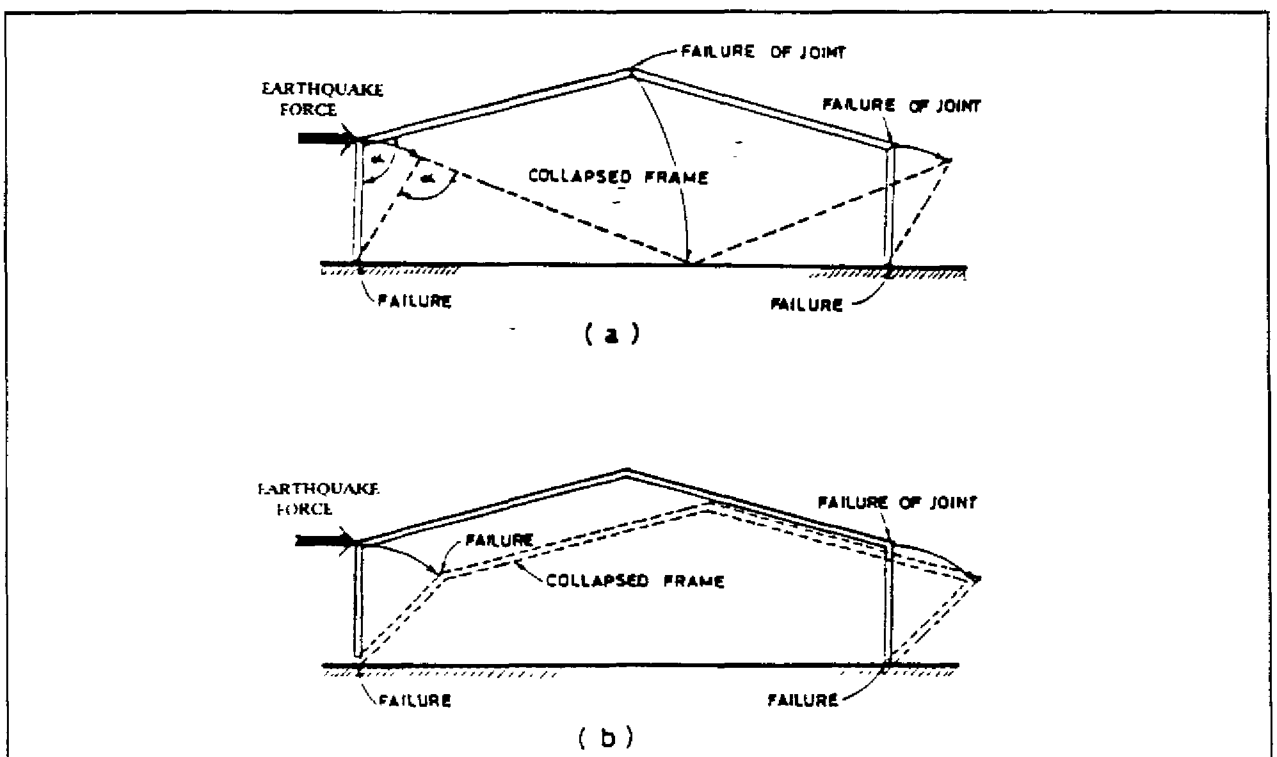

Figure 7.1-5 Failure Modes of Gable Frame [1]

for reinforcing or strengthening buildings can be briefly described on the following lines:

1. Improvement in design by good structural planning,
2 Need of integral action to make the building behave as a unit,
3. Adequate structural members and strong, ductile connections between walls, roof elements and foundation,
4. Reinforcing or strengthening of weaker sections by steel, timber or reinforced concrete,
5 High quality of construction and insertion of special bonding elements.

seismic failure, wall, frame, truss, roof, connection, ground.

SESSION 8: MATERIALS

Topic 8.1: Materials

Masonry, timber, reinforced concrete and steel are the main materials used for the construction of houses and buildings For high-rise buildings, steel and *in situ* reinforced concrete are used For medium-rise buildings, precast reinforced concrete and reinforced masonry can also be used. Timber and unreinforced masonry are used for low-rise buildings. The following table shows the suitability and applicability of the major structural materials for earthquake resistant buildings

Type of Building		
High - rise	**Medium - rise**	**Low - rise**
1. Steel 2 In situ reinforced concrete	1. Steel 2. In situ reinforced concrete 3 Precast concrete 4. Prestressed concrete 5. Reinforced masonry	1. Masonry 2. Timber 3. In situ Reinforced concrete 4 Precast concrete 5. Steel

Table 8 1-1 Structural Materials in Approximate Order of Suitability/Applicability

This chapter includes a brief account of the properties of common materials for the structural elements of non-engineered buildings. Typical numerical values of the properties are also presented for use where local standards are not available

In terms of earthquake resistance, materials must have the following properties

- High strength/weight ratio
- High ductility
- Ease in making full strength connections and bracing
- Homogeneity

Generally, the higher the structure the more important the above properties are Some materials, such as masonry, are not suitable for flexible structures On the other hand steel is used essentially to obtain flexible structures, although if greater stiffness is desired. diagonal bracing or reinforced concrete shear panels may be incorporated in steel frames. Concrete can readily be used to achieve almost any degree of stiffness

Timber is in itself an excellent material for earthquake resistance It is light, strong, easily braced and capable of absorbing energy It is in the connections where its strength or weakness lie Timber floors do not function as rigid diaphragms and do not transmit forces between stiff vertical elements as effectively as, for example, in situ reinforced concrete slabs.

Failure of unreinforced masonry is common. Many earthquake codes ban the use of unreinforced masonry altogether. However, economic reasons still ensure that it is widely used for low-rise buildings and as infill walls to framed structures On the contrary, low-rise houses of reinforced masonry have shown satisfactory performance during earthquakes

Quality of materials and workmanship are important factors for a durable and strong structure All countries, especially developing countries. have problems in finding good quality materials at reasonable prices.

Natural sand and gravel may contain a lot of deleterious substances such as chlorides and sulphates, which accelerate the corrosion of the reinforcement because sulphate reacts with cement and leads to deterioration of concrete.

Crushed aggregates from acid rocks, such as granite, are good. Weathered rock should not be used Some basic materials (gabbro, diabase) are also good, but one must be very careful with serpentine and other ultra basic rocks, which contain a great amount of ferromagnesium minerals These minerals deteriorate very quickly under the presence of water and at high temperature Amorphous silica should not be used since this material reacts with cement (alkali-silica reaction or cancer of concrete) and leads to deterioration of concrete.

Limestone, dolomite and especially marble are good materials for concrete. They do not usually contain any potentially active minerals but limestone has a high water absorption

Mild steel or hot-rolled high yield steel with strength not exceeding 400 N/mm2 is recommended for earthquake resistant structures For reinforced concrete structures good quality of concrete and adequate cover to reinforcement is needed, in order to avoid corrosion of reinforcement

Timber must also be preserved and protected from moisture to avoid deterioration of its strength through decay or other attack The presence of knots and of other defects make timber a non-homogeneous material and its quality has a considerable effect on its performance during earthquakes

In many cases the failure of buildings in earthquakes has been attributed to poor quality of materials and workmanship Each country should take the necessary measures and actions, so that proper materials are available at reasonable prices

The properties of commonly used materials for the construction of low-rise buildings are briefly described.

Masonry

The strength of masonry walls depends on many factors such as the following:

1. Compressive strength of the masonry unit. The common masonry units are.

Bricks
-Common burnt clay bricks - solid or perforated
-Sand-lime bricks
-Lime-pozzolana bricks
-Adobe or unburnt clay brick or clay mud
Stones
-Regular sized
-Random rubble
Concrete blocks
-Solid blocks
-Hollow blocks

2. Mix of the mortar used and age at which tested. The mortar used for different wall constructions varies in quality as well as strength. It is generally described on the basis of the main binding material such as cement mortar, lime mortar, cement lime mortar, lime-pozzolana or hydraulic lime mortar. Clay mud mortar is also used in many countries particularly in rural areas.

3. Slenderness ratio of the wall, that is the ratio of effective height of the wall to its thickness. Larger is the slenderness ratio, smaller the strength.

4. Eccentricity of the vertical load on the wall - Larger the eccentricity, smaller the strength.

5. Percentage of opening in the wall - the larger the openings, the lower the strength.

The tensile and shear strength of masonry depends upon the bond or adhesion between the masonry unit and the mortar; the values are only a small percentage of the crushing strength. The richer a mortar is in cement or lime content, the higher is the tensile and shear strength in relation to the crushing strength. Tests carried out on brick-couplets in cement mortar give values as in Table 8.1-2

Brick couplet tests under combined tension-shear and compression-shear stresses show that the shear strength decreases when acting with tension and increases when acting with compression. Figure 8.1-1 shows the combined strengths.

Mortar Mix		Tensile Strenght N/MM2	Shearing strenght N/mm2	Compressive Strenght in N/mm2 corresponding to crushing strength of unit			
Cement	Sand			3 5	7 0	10 5	14 0
1	12	0 04	0.22	1 5	2 4	3 3	3 9
1	6	0.25	0 35	2 1	3 3	5 1	6 0
1	3	0 71	1.04	2.4	4 2	6 3	7 5

Table 8.1.-2 Typical Strenght of Masonry

The tensile strength of masonry is not generally used for design purposes under normal loads and the area subjected to tension is assumed cracked. However, under seismic conditions, the permissible tensile and shear stresses in Table 8.1-3, acting on the area of horizontal mortar bed joint in masonry, may be adopted

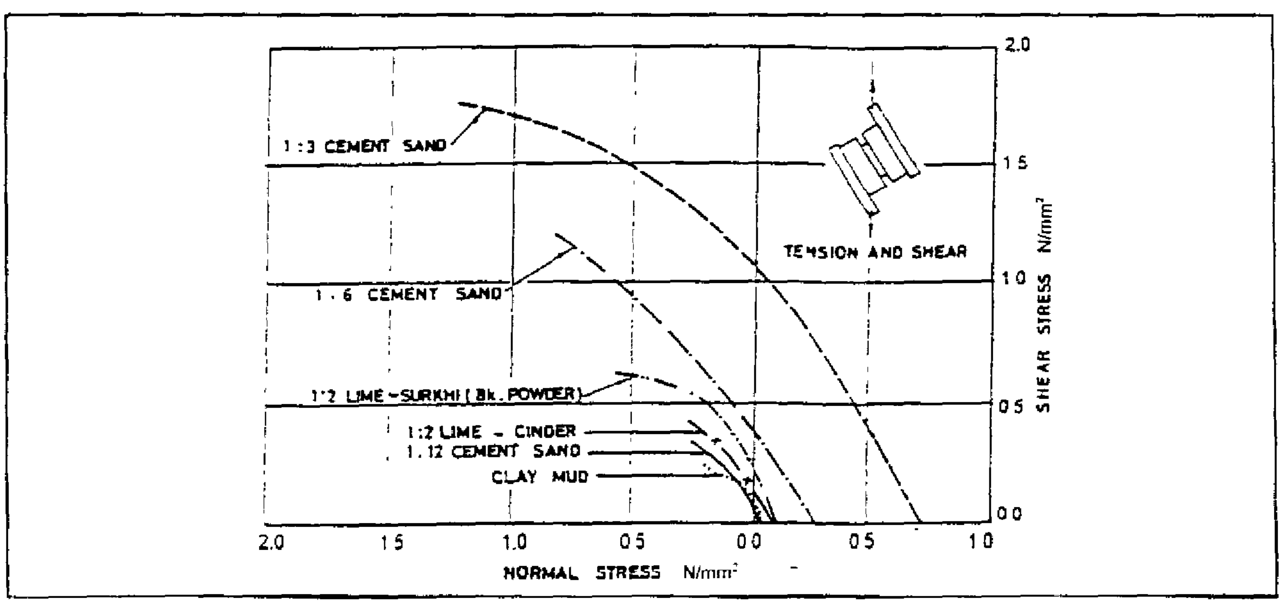

Figure 8.1-1 Combined Strenght Masonry

Mortar Mix			**Permissible Stress**		**Compressive Strenght in N/mm2 for strenght of unit**			
Cement	Lime	Sand	Tensile Strenght N/mm2	Shearing Strenght N/mm2	3.5	7.0	10.5	14.0
1		6	0 05	0 08	0.35	0.55	0.85	1 0
1	1	6	0.13	0 20	0.35	0 70	1.0	1 1
1		3	0.13	0.20	0.35	0.70	1 1	1.3

Table 8.1-3 Typical Permissible Stresses.

The unit weight of masonry mainly depends on the type of masonry unit. For example brickwork will have a unit weight of about 1900 kg/m3 and dressed stone masonry 2400 kg/m3.

Adobe

The earth used in mud houses and adobe (sun dried bricks or blocks) should be of good quality as follows:

1. A mud paste made with a small quantity of water so that the mud does not stick to hands, should be capable of being rolled in the form of a thin thread between 5 and 15 cm long without cracking. If it cracks below 5 cm, clay is to be added, if it does not crack above 15 cm, sand is to be added.

2. In particular for soils with higher clay contents, it is necessary that a sufficient quantity of fibrous materials (straw, cane bagasse, horse hair, etc.) be added to the mix before making adobes

3. After 4 weeks of drying in the sun the adobe should be strong enough to support, in bending, the weight of a man (Figure 8.1-2) If it breaks, more clay and fibrous material are to be added.

Structural timber

Timber finds extensive use in buildings both for structural as well as nonstructural purposes It is light in weight, nearly equally strong in compression and tension along its grain, and very resilient under impact and vibrations. These qualities make it eminently suitable for construction under severe seismic conditions Unfortunately, there are several shortcomings too, which inhibit its universal use for structural purposes. Unless thoroughly preserved and carefully protected, it decays and rots with time, is liable to insect attack and is vulnerable to fire hazards

Timber is in short supply everywhere and hence its cost is increasing rapidly. In view of its lightness, very easy workability such as cutting, nailing and safe transportability, timber makes an excellent material for post-earthquake relief and rehabilitation construction.

Material Properties

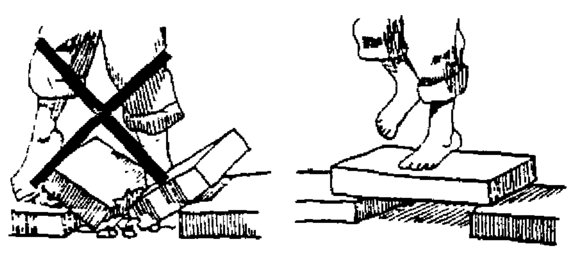

Figure 8.1-2 Testing Strenght of Adobe

Due to the large varieties of timber in use in various countries, it will not be practicable to present their strength properties here But it will be useful to mention that these depend on a number of factors as follows:

- Wood species,
- Direction of loading relative to grain of wood,
- Defects like knots, checks, cracks, splits, shakes and wanes,
- Moisture content or seasoning,
- Sapwood, pith, wood from dead trees and dried wood conditions,
- Location of use, viz. inside protected, outside, alternate wetting and drying.

The permissible stresses must be determined taking all these factors into account. Table 8.1-4 in the text gives typical basic stresses for timber placed in three groups A, B and C, classified on the basis of strength. It is reasonable to increase the normal permissible stress by a factor of 1.33 to 1.5 when earthquake stresses are superimposed.

Characteristics of Elements

Timber is non-homogeneous and anisotropic material showing different characteristics not only in different directions but also in tension and compression.

Plain and reinforced concrete

Concrete is used in building construction in several ways Plain concrete is used as base course, as flooring etc. For such purposes both cement with stone aggregate or lime with under fired brick aggregate are used Since plain concrete is quite strong in compression but weak in tension, it is reinforced with steel reinforcement so that concrete takes the compression and steel takes the tension. Where stresses are reversible, as in columns subjected to bending moments due to earthquake, steel reinforcement is used on both faces. Other variations are cast-in-situ concrete and pre-cast concrete components The latter can vary from simple joists and small panels to complete wall panels, footings, columns, roof beams and slabs; depending on the level of technology, handling equipment and transportation facilities. In most developing countries, it does not appear feasible to adopt large scale pre-casting for use in building construction in widely dispersed towns and villages Although concrete is a heavy material, reinforced concrete has been found to be a very suitable material for construction in earthquake areas due to its strength, stiffness and energy absorption.

Types of Stress	Location	Permissible StressN/mm2, for		
		Group A	Group B	Group C
Bending and Tension along grain	Inside	18.2	12.3	8.4
	Outside	15.2	10.2	7.0
	Wet	12.0	0.9	6.0
Shear in Beams	All	1.2	0.9	0.6
Shear along Grain	All	1.7	1.3	0.9
Compression parallel to Grain	Inside	12.0	7.0	6.4
	Outside	10.6	6.2	5.6
	Wet	8.8	5.8	4.6
Compression perpendicular to grain	Inside	6.0	2.2	2.2
	Outside	4.6	1.8	1.7
	Wet	3.8	1.5	1.4

Table 8.1-4 Basic Permissible Stresses for Timber Groups.

Material Properties

Concrete strength is defined on the basis of 28 days cube compressive strength or cylinder compressive strength. For use in buildings, the cube strength Fc between 20 to 25 N/mm^2 will be adequate for R.C. work. The unit weight of R.C. is about 2400 kg/m3 and modulus of elasticity is variously related with the concrete strength. Each country has its own standards for allowable stresses and load factors which may be referred to in this regard.

Under seismic condition these allowable values may be increased by 33 percent or the load factors may be decreased by 25 percent unless specified otherwise in national standards. It is important to know that the tensile strength of concrete is only about one-tenth of the compressive strength. The diagonal tension caused by seismic shear forces, if not thoroughly taken by well designed stirrups or ties, can lead to wide cracking and failure.

Concrete is a brittle material and weak against impact, shock and vibrations. Ductility is imparted to it by the reinforcing steel reinforcement.

Steel

Steel is used in different shapes and sizes in building construction and mostly for structural purposes. Recently increased use is being made for non-structural purposes such as in door and window frames, but this is mostly in the affluent countries. Angles, channels and I-joists are the most common shapes used for trusses, columns and beams. Use of steel in structural forms is limited, due to its high cost. But it may become competitive if used in light gauge forms for columns and beams and in tubular form for roof trusses.

The methods of jointing steel sections are bolting, riveting and welding. Welding is the most economical in terms of material but it needs careful design and construction to achieve desired strength, ductility and stiffness in the joint. Bolting is the simplest form which could be used in the remotest village without electricity or high skill of workmanship. Stiffness of bolted structures is generally less than others unless high-strength grip bolts are used.

The more common use of steel in buildings is in the form of reinforcing bars in reinforced concrete. The various forms used are plain mild steel bars, high-strength deformed bars, welded wire fabric, expanded metal meshes. The diameters and sizes vary across a wide range to suit various requirements.

Material Properties

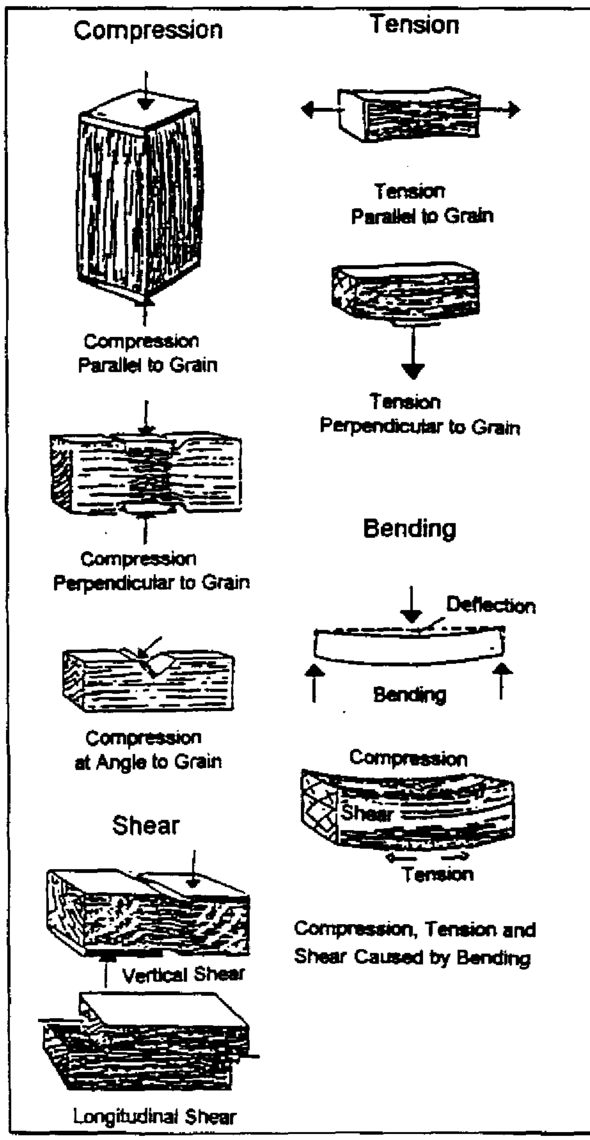

Figure 8.1-3 Characteristics of Timber

Steel is a heavy, strong, stiff and ductile material, quite strong in tension and compression with high strength shear as well. Its resilience to impacts and shocks is also very high. Thus it is one of the most suitable materials for earthquake resistant construction.

The mechanical properties of steel depend upon its chemical composition and amount of hot and cold working. As an illustration, the chemical composition and mechanical properties of some steels are shown in Table 8.1-5.

Type of Steel and percentage of Chemicals	**Class of Steel Products**	**Normal Size or Thickness (mm)**	**Guaranteed Minimum Yield Stress (N/mm2)**	**Tensile Strenght Minimum (N/mm2)**	**Minimum Elongation Percent**
Mild C = 0 25 S = 0 06 P = 0 06	Plates, Sections and Flats	6 to 40 over 40	260	420	23
Mild C = 0 25 S = 0 06 P = 0 06	Bars (round, square, hexagonal)	10 to 20 over 20	260 240	420 420	23 23
High Strenght C = 0.30 S = 0 06 P = 0 06	Plates, Sections and Flats and Bars	6 to 28 29 to 45 46 to 63 over 63	360 350 330 300	580 580 580 580	20 20 20 20
High Strenght - weldable C = 0.22 S = 0 06 P = 0 06 Si = 0 10	Plates, Sections, Flats and Bars	6 to 16 17 to 32 33 to 63 over 63	360 350 340 290	550 550 520 500	20 20 20 20

Notes

C=Carbon, S=Sulphur, P=Phosporus, Si=Silicon

Table 8.1-5 Chemical Composition and Mechanical Properties of Structural Steels

material, applicability, property, masonry, timber, concrete, steel.

Topic 8.2: Strengthening and Repair Materials

The most common materials for damage repair works of various types are cement and steel. In many situations non-shrinking cement or an admixture like aluminum powder in ordinary portland cement is admissible.

Steel may be required in many forms from bolts, rods, and angles to channels, expanded metal and welded wire fabric. Wood and bamboo are the most common materials for providing temporary supports and scaffolding etc., and will be required in the form of rounds, sleepers, planks, etc.

Besides the above, special materials are available for best results in repair and strengthening.

Shot-Crete.

Shot-crete is a method of applying a combination of sand and portland cement which is mixed pneumatically and conveyed in dry state to the nozzle of a pressure gun, where water is mixed and cement hydration starts just prior to expulsion. The material bonds perfectly to properly prepared surfaces of masonry and steel. In versatility of application to curved or irregular surfaces, its high strength after application and good physical characteristics, make for an ideal means to achieve added structural capability in walls and other elements There are some minor restrictions of clearance, thickness, direction of application etc.

Epoxy Resins:

Epoxy resins are excellent binding agents with high tensile strength. There are chemical preparations the compositions of which can be changed as per requirements The epoxy components are mixed just prior to application. The product is of low viscosity and can be injected in small cracks too.

The higher viscosity epoxy resin can be used for surface coating or filling larger cracks or holes. The epoxy mixture strength is dependent upon the temperature of curing (lower strength for higher temp) and method of application.

Epoxy Mortar:

For larger void spaces, it is possible to combine the epoxy resins of either low viscosity or higher viscosity, with sand aggregate to form epoxy mortar. Epoxy mortar mixture has higher compressive strength, higher tensile strength and a lower modulus of elasticity than Portland cement concrete Thus the mortar is not a stiff material for replacing reinforced concrete. It is also reported that epoxy is a combustible material.

Therefore it is not used alone. The sand aggregate mixed to form the epoxy mortar provides a heat sink for heat that is generated and it provides increased modulus of elasticity too

Gypsum Cement Mortar

It has rather limited use for structural application It has lowest strength at failure among these three materials

Quick-setting Cement Mortar:
This material is patented and was originally developed for the use as a repair material for reinforced concrete floors adjacent to steel blast furnaces. It is a non-hydrous magnesium phosphate cement with two components, a liquid and a dry, which can be mixed in a manner similar to portland concrete.

Mechanical Anchors:
Mechanical type of anchors employ wedging action to provide anchorage. Some of the anchors provide both shear and tension resistance. Such anchors are manufactured to give sufficient strength.
Alternatively chemical anchors bonded in drilled holes with polymer adhesives can be used.

Material, repair, strengthening.

SESSION 9: SOILS AND FOUNDATIONS

Topic 9.1: Soils and Foundations

The vertical and lateral loads of structures are transmitted to the soil through the foundations. The design of foundations depends upon the structural system of the superstructure, the bearing capacity of the soil and the intensity of load transmitted from above These factors are much less critical for low height buildings than for tall heavy structures

The most important factor for good behavior of low buildings is the behavior of the soil itself. If the soil consists of loose sandy soil and the water table is high, the soil loses much of its shear strength when shaken. Under severe shaking, it may even liquefy Then the building will have unequal settlement and suffer damage Also, when separate individual footings are used under load bearing columns in soft soils, they could be displaced relative to each other This aspect must be explored in alluvial soils where the water table is high, say within 6 to 7 m below ground level, and particularly in severe to cata strophic seismic zones. Determination of standard cone penetration test values (N-values) will be quite indicative of the density and bearing of the soil. If the N-values are less than 15, there is room for concern and for N<10, liquefaction is definitely indicated It will be best to avoid such a site Otherwise, deep foundations in the form of piles will have to be used since compaction of soil for individual buildings may not be feasible. Inter-connection of individual footings at foundation or plinth-level beams will be useful where the bearing capacity of the soil is less than about 10 t/m^2 (0 1 MPa).

Steep slopes liable to landslides during earthquakes or sites subject to the danger of rock fall should also be avoided

Choice of Site

The choice of site for buildings, from the seismic point of view, is mainly concerned with the stability of the soil. The following aspects are to be considered,

Stability of Slope

Earthquake-induced landslides differs from conventional landslides by their geometry, failure mechanism and type of sliding. Conventional landslides are caused by rainfall infiltrating a slope. Water tends to reduce the shear strength of soil deposits, and increases their weight. When the shear strength of the material is exceeded, a mass of soil shaped like a wedge with a roughly circular bottom moves downward in response to gravity

Earthquake-induced landslides are triggered by the energy of the ground shaking This shaking, depending on its intensity and duration, weakens and eventually loosens rock and soil materials, ultimately forcing them down the slope. These landslides appear to be confined to surface failures, and result in rock falls, rock slides, and soil or debris slides

All of the factors that play a role in static slope stabil ity also affect dynamic slope stability. The safety factor for dynamic conditions is lower than that for static condi tions The main factors controlling the triggering of land slides are the intensity and duration of ground shaking, and the inclination of the slope The potential for landslides is increased when steep slopes are underlain by low-density, weathered, weakly cohesive soils or highly fractured material Earthquake-induced landslides normally occur with the initial shock, but in some cases this only serves as the weakening agent, and subsequent aftershocks actually cause the failure. Heavy rain following a major earthquake usually compounds the problem Steep slopes devoid of vegetation, steep road cuts where blocks of unconsolidated materials are detached are particularly susceptible to slides. Debris slides usually occur on moderate-to-steep natural slopes and include loose soils or colluvial materials above the bedrock. A conservative rule-of-thumb gives slopes of about 35 degrees prone to landslides, and 25 degrees prone to debris slides.

Hillslides liable to slide during an earthquake should be avoided and only stable slopes should be chosen to locate the buildings It is preferable to have several separated blocks on terraces than to have one large block Sites sub ject to the danger of rock falls also have to be avoided

Very Loose Sands or Sensitive Clays

These two types of soils are liable to be disturbed by the earthquake so much as to lose their original structure and thereby undergo compaction. This would result in large unequal settlements and damage buildings. If the loose co hesionless soils are saturated with water they are apt to lose their shear resistance altogether during shaking and liquefy. Three major factors are conducive to liquefaction. These are ground shaking, shallow water table, and sandy material. Generally, low-lying areas covered by young, un consolidated, well-sorted sand and/or silty sand materials are more susceptible to liquefy. Some minor topographic re liefs, such as stream banks or gentle to steep slopes, are also prone to liquefaction ground failure. However, ground failure can also occur on flat ground if the liquefiable materials are not evenly loaded, such as in the case of road fills Such soils can be compacted, but for small buildings the operation may be too costly and should better be avoided For large building complexes, such as entire neighborhoods, this factor should be thoroughly investigated and addressed.

Foundations

For the purpose of making a building truly earthquake resistant, it will be necessary to choose an appropriate foundation type for it. Since the loads from low height buildings are light, providing the required bearing area will not usually be a problem. The depth of footing in the soil should go below the zone of deep freezing in cold countries and below the level that undergoes considerable volume changes in clayey soils. Choosing the type of foundation for earthquakes, the soil may be grouped as follows

1. Firm soil having allowable bearing capacity of more than 10 t/m2 (0.1MPa).
2. Soft soil having allowable bearing capacity of less than or equal to 10 t/m2 (0.1MPa)
3. Weak soils which are liable to large differential settlement, or liquefaction during an earthquake

Note: Appropriate soil investigation should be made to establish the allowable bearing capacity wherever possible.

Firm Soil

In firm soil conditions, any type of footing, individual or strip type, could be used. It will be desirable to connect the individual column footings in zone A by means of R.C. beams just below plinth level intersecting at right angles and capable of resisting 10 percent of the larger column load as a strut or tie.

Soft Soil

In soft soil it will be desirable to use plinth band in all walls and necessary to connect to the individual column footings by means of plinth beams as suggested above.

It may be mentioned that continuous reinforced concrete footings are considered to be most effective from earthquake considerations as well as to avoid differential settlements under normal vertical loads. These should ordinarily be pro vided continuously under all the walls, continuous footing should be reinforced both in the top and bottom faces, width of the footing should be wide enough to make the contact pressures small and uniform, and the depth of footing should be below the lowest level of weathering. The height of continuous footings should be equal to or more than 1/18 of the building height but not less than 60 cm, except for one storey buildings in which it should not be less than 50 cm from the ground level.

Weak Soil

Such soils must be compacted before constructing the build ing or special types of foundations must be used, such as piles

General Rules for Foundations

The siting and foundations are extremely important factors for the safety not only of an earthquake resistant building, but of any other type of building. It is essential to have the advice of a qualified engineer for the siting and foundations of the building, especially with soft soils.

However, the following are very important recommendations for the design and construction of foundations:

1. The minimum depth of the shallow foundations must be determined by a number of conditions. In the first place, it must be such that the base of the foundation lies beneath the surface layer of soil, which undergoes cycles of humidity and dryness and variations in volume owing to seasonal changes. In addition, the depth must be greater than that of the vegetation layer, in which the soil is weakened by the presence of roots and decaying vegetable matter. In very cold regions the minimum depth of the foundation depends also on the depth of the freezing process during the winter
2. The loads which act on foundations are transmitted to the soil and produce deformations in it. This deformation increases with the load, and if the latter is sufficient ly large, the deformations are so great that the result is regarded as a fracture of the soil. The load transmit ted through the foundation to the soil is expressed in terms of the "contact pressure", the average pressure calculated as the total load divided by the area of the foundation
3. Foundations should be designed as continuous in order to avoid relative horizontal and vertical displacements
4. Where circumstances require the use of separate foundations, they should be joined to each other and to the rest of the structure by means of foundation beams. Such foundation beams may or may not be designed to withstand seismic moments. Where simple ties are used, they should be designed to take compression and tension forces of the order of one tenth of the maximum vertical load supported by the footings being joined. Foundation beams connecting separate footings or foundations, can be designed only as ties if there are other beams on top of them able to resist moments
5. It is recommended that parts of building foundations which rest on soils of different types or are sunk to different depths should be designed as separate units. In such cases there should also be structural independence in the superstructure. It is also recommended that if different parts of a building are to be structurally independent because of the shape of their ground plan, their foundations should also be independent
6. The design of water pipes and drains requires special care in the case of buildings in earthquake zones. Im proper design of such installations can cause breakage of pipes during an earthquake, so that water escapes and filters down into the foundation soil, where it may change the soil structure and partially alter its bearing capacity. Proper design of such installations and correct placement of pipes in relation to foundations will prevent these problems
7. It is important, in designing the foundations of a build ing, to know the ground-water level and its usual variations. The ground-water level should be at least one meter below the foundation level

8. Foundations to be preferably at the same level.
9. Questionable soils prone to liquefaction, settlements, landslides, rocksliding, faulting and others during ea rthquakes, should be investigated by field and laboratory testing to determine the possibilities and conditions for construction of structures.

? a. Are weak foundations of the types described common in your country?
b. Is it common that in later years additional floors were added to buildings?
c. What can be done to reduce vulnerability?

soil, foundation design, slope stability, bearing capacity.

SESSION 10: STRENGTHENING OF FOUNDATIONS

Topic 10.1: Strengthening of Foundations

Masonry walls can be damaged due to differential settlement of foundations or sliding caused by an earthquake. Foundation strengthening can also be required to increase the bearing area when reconstruction increases building weight. It may also be desired to provide structural ties at the foundation to help the building behave as a single unit.

Seismic strengthening of foundations is the most complicated task, and may require careful underpinning. To avoid disturbance to the integrity of the building during the foundation strengthening process, proper investigation and the advice of an engineer is called for. Some guidance is given for the strengthening scheme.

1. Introducing new load bearing members to relieve the already loaded members. Jacking operations may be needed in this process.

2. Improving the drainage of the area and preventing saturation of foundation soil to obviate liquefaction which may occur because of poor drainage.

3. Providing aprons around the building to prevent soaking of the foundation and providing for draining off of the water.

4. Adding reinforced concrete strips attached to the existing foundations of the building. These will also bind footings on one side, if not both sides, of the wall. The reinforced concrete strips have to be linked with the walls or foundations by keys inserted between them.

Stage-by-stage underpinning is possible by means of placing concrete in blocks of about 50 to 100 cm length, in a spacing equal or greater than twice their length (Figure 10.1-3). Another method, mentioned before, is to build a reinforced con crete belt all around the building at the foundation level. This reinforced concrete belt can be constructed on the outside of the building only or can be constructed on both sides (Figure 10.1-1 and Figure 10.1-2). Potential sliding of

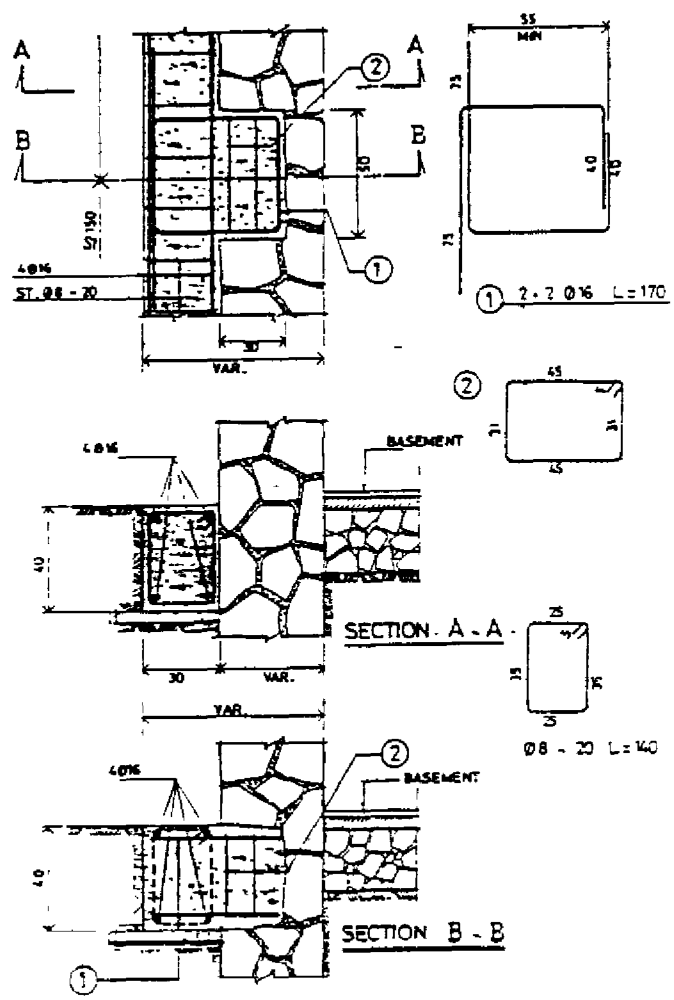

Figure 10.1-1 Strenghtening Existing Foundation (R.C. Strip on Outside only)

a foundation can be prevented by constructing reinforced concrete "briddles", especially in sloping ground. These "briddles" are extended deep into the soil, on the down side of the foundation and run parallel to ground contours (Figure 10 1-4)

foundation, strengthening.

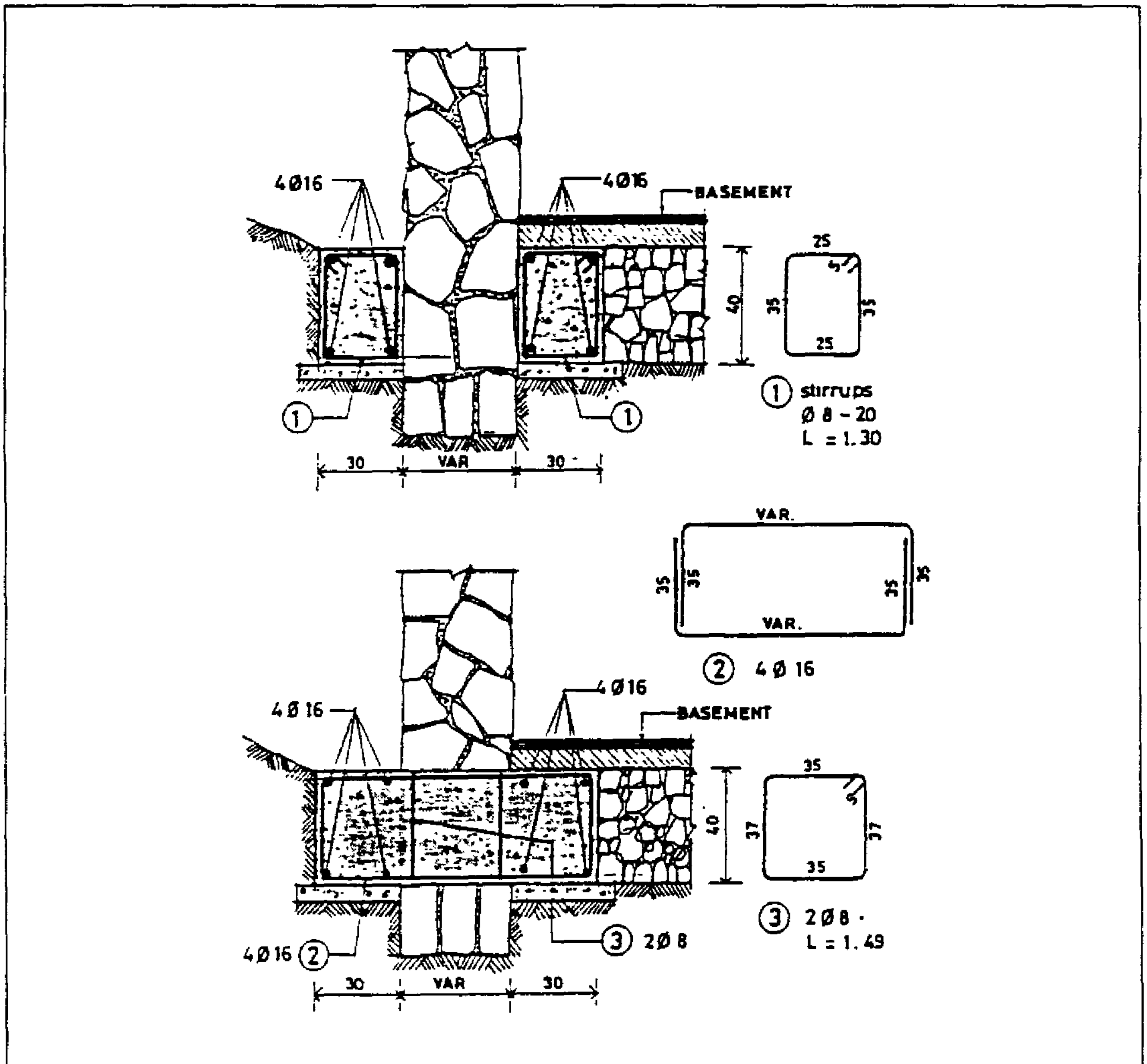

Figure 10.1-2 Strenghtening Existing Foundation (R C. Strip on Both Side)

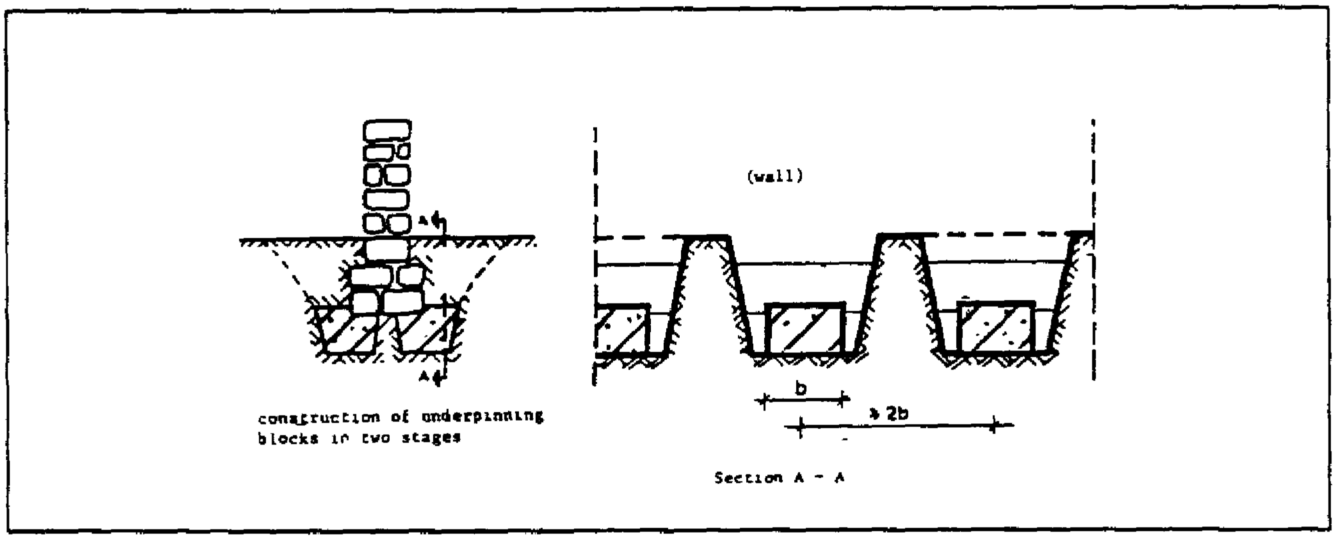

Figure 10.1-3 Construction of Underpinning Blocks Two Stages

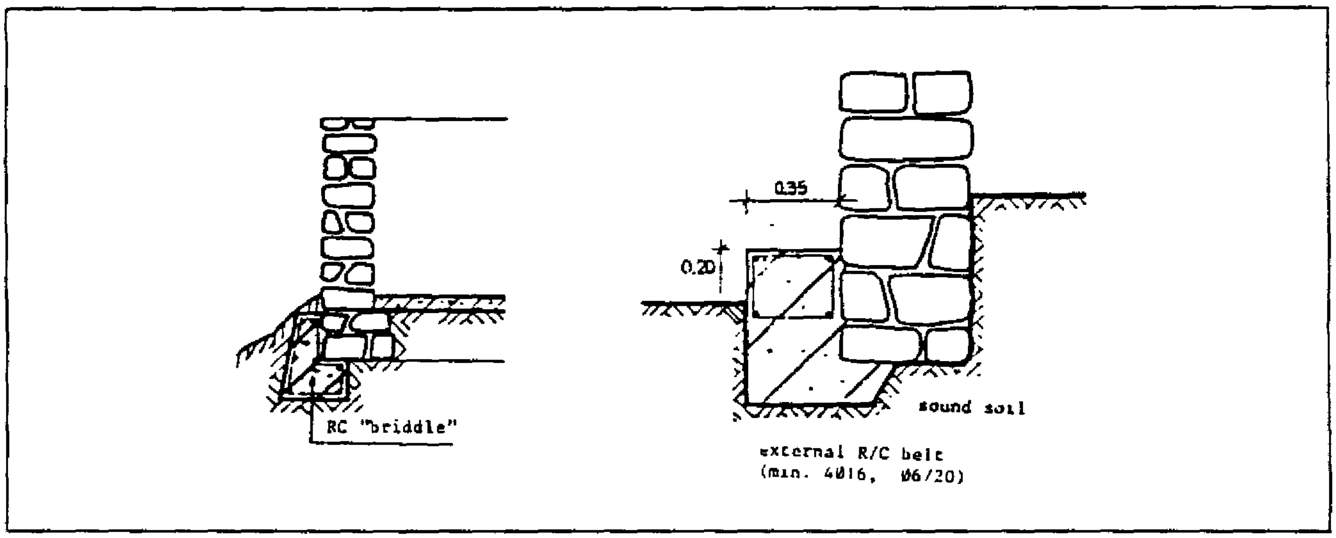

Figure 10.1-4 Reinforced Concrete Briddles

SESSION 11 : REINFORCED CONCRETE FRAMES AND WALLS

Topic 11.1: Reinforced Concrete Frames and Walls

Design codes for reinforced concrete buildings in seismic zones are well established and when properly applied provide a sound basis for design and detailing. Concrete is strong in compressive forces but is very weak in tensile forces; therefore, steel reinforcement must be used in structures subjected to tension and shear. The dimensions and reinforcement of the reinforced concrete members should be appropriately calculated by an engineer. Good detailing and workmanship are also very important factors in the behavior of reinforced concrete structures in earthquakes.

Reinforced Concrete Frames

The construction considered here is that in which the R.C. frame is rigidly jointed and is supposed to carry all vertical and lateral loads. The wall panels are only for cladding and partitions and not relied to provide structural strength.

For the stability of the infill panels, the measures as outlined in an earlier stage will be adequate. The sections of the R.C. beams and columns will have to be appropriately calculated by rational analysis using the design value of seismic coefficients. For achieving good performance of R.C. frames, suitable details for the steel reinforcement must be adopted so that adequate ductility is obtained under a severe shock (Figure 11.1-1). The following recommendations should be followed for beams, columns, and connections.

Beams

1. Longitudinal Steel: Beams should be reinforced on both top and bottom face, throughout. Where reinforcement is required by calculation, the percentage should correspond to ductile behavior. Where it is not required, theoretically a minimum of about 0.35 percent of cross-sectional area must be used.
2. Splicing of Steel. All longitudinal bars should be anchored and spliced for full strength development. All splices should be contained within at least two stirrups so as to avoid spalling of the cover of concrete. The splicing is 45 to 50 diameters the bar size.

3. Transverse Steel. Vertical shear stirrups should be closely spaced at not more than half of effective depth at the two ends of the beam, for a distance of two times the depth of the beam. The ultimate shear strength of the beam should be designed to be more than its ultimate flexural strength.

Columns

Vertical reinforcement should be distributed on all the faces of the columns. Spirally reinforced columns are superior to columns with ties. Concrete confined within the spirals is stronger and much more ductile as compared to plain concrete or that containing widely spaced stirrups. The behavior of tied columns can be much

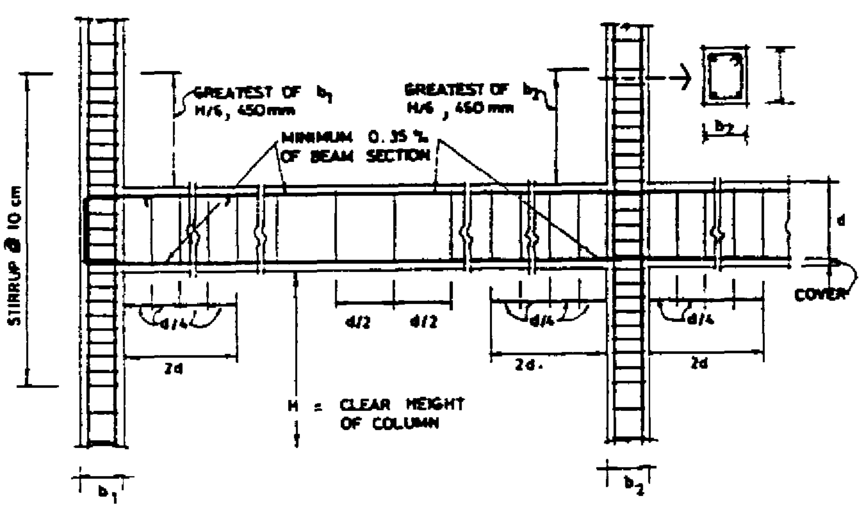

Figure 11.1-1 Details of Reinforcement in Reinforced Concrete Construction [1]

improved by using the ties with adequate anchorage at ends in the form of suitable hooks and spacing closely so that the longitudinal bars cannot buckle In a length of about 45 cm near the ends of columns, a spacing not more than 10 cm may be adopted for achieving ductility. The corner columns of buildings are stressed more than any other column due to bi-axial bending and torsion, and should therefore be made stronger.

If they are constructed conforming to the above mentioned considerations, columns have good structural performance against seismic forces When infill walls with wide openings are attached to columns (See Figure 11 1-2), the portion of the columns that will deform when they are subjected to lateral forces become very short and attract large shear forces. It is anticipated that shear failure of this short column portion may occur and it may cause partial or total failure of the building. Therefore, spacing of hoops should be at least the same as the ends of columns

Connections

The beam/column connections are the critical sections for transfer of forces and need great attention in design. Where the joint is not confined by beams on all four sides, it will be necessary to place the closely spaced ties in the column throughout the height of the joint as well The beam and column bars must be well anchored in the compression zone so as to achieve their full strength.

Shear Wall Buildings

Shear Walls with Frames

The system considered here is a composite one in which the R.C. frame members mainly transmit the vertical loads, but for lateral loads the shear resistance of walls is relied upon. Bounded wall panels can resist very large lateral loads. Depending on the loads to be carried, the wall panel can be in masonry or concrete, plain or reinforced. But in each case, a necessary condition for the composite behavior is the adequate shear transfer at the contacts of panels and frames. Therefore, these wall panels must be located at per manent positions and should be anchored into the bounding columns (Figure 13 1-7, Figure 13.1.10). It will be quite reasonable to build the walls and columns together Alternatively, dowels can be left projecting from the columns and beams which are built into the walls

In this case, the connections between the bounding members of reinforced concrete are loaded quite heavily and must be made extra strong. The suggestions given before for connec tions will be appropriate here also, besides providing full anchorage to beam and column reinforcement across the con nection.

Shear Walls without Frames

Reinforced concrete shear walls without frames can be used as one of the construction methods especially for apartment houses. This type of construction behaves well against seismic actions during severe earthquakes, if carried out up to 3 storeys and conforming to the following requirements

1 Shear wall ratio, which is the total length of the shear

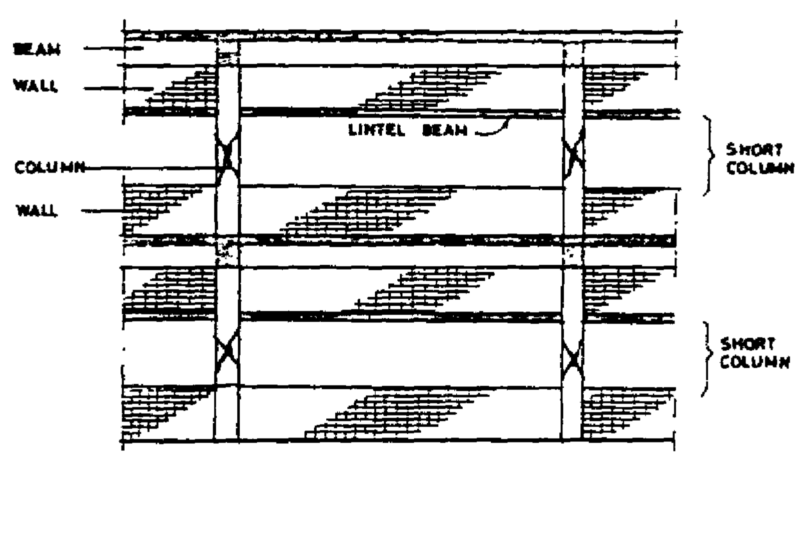

Figure 11.1-2 Shear Failure of Short Column [1]

wall divided by the floor area, should not be less than 15 cm/m^2 at the first floor

2. Floor area enclosed by shear walls should not be more than 30 m^2

3. Shear wall should not be less than 15 cm in thickness and should be adequately reinforced by vertical and horizontal reinforcing bars

4. Corners, junctions and openings on the shear wall should be adequately reinforced.

? a. Are engineers and contractors familiar with the described strengthening techniques ?

b Would distribution of simple leaflets be enough ?

c. Would you propose to establish comprehensive training programs?

reinforced concrete, frame, wall, column, connection.

SESSION 12: STRENGTHENING OF REINFORCED CONCRETE STRUCTURES

Topic 12.1: Strengthening of Reinforced Concrete Structures

Repairing of reinforced concrete elements is required after damage. Strengthening such elements is a method to increase earthquake resistance. Thus, the strength of the structures can be moderately or significantly increased and the ductility can be improved.

Depending on the desired earthquake resistance, the level of the damage, the type of the elements and their connections, members can be repaired and/or strengthened by injection, removal and replacement of damaged parts or jacketing. For repair of concrete structures the advice of engineers is required.

Establishing bonds between old and new concrete is of importance. It can be done by chipping away the concrete cover of the original member and roughening its surface, by preparing the surfaces with glue (for instance, with epoxy prior to concreting), by additional welding of reinforcement or by formation of reinforced concrete or steel dowels.

Perfect confinement by close, adequate and appropriately shaped stirrups and ties contributes to the improvement of the ductility of the strengthened members. Redistribution of the internal forces in structures due to member stiffness changes is very important.

Jacketing with steel profiles (angles and straps) is used for the strengthening of columns. The beam-to-column joint is difficult to be strengthened in this way.

Jacketing by steel encasement is implemented by gluing of steel plates on the external surfaces of the original members. Steel plates as reinforcement are glued to the concrete by epoxy resin. This does not require any demolition, it is easy to implement and hardly increases the cross section of the members. Trained technicians are required for this work.

Jacketing by steel profiles or encasement requires special measures for fire and corrosion protection of the new steel profiles. Reinforced concrete jacketing does not need such a protection but the construction procedure is more difficult.

🔑 strengthening, reinforced concrete, jacketing.

Topic 12.2: Strengthening Columns

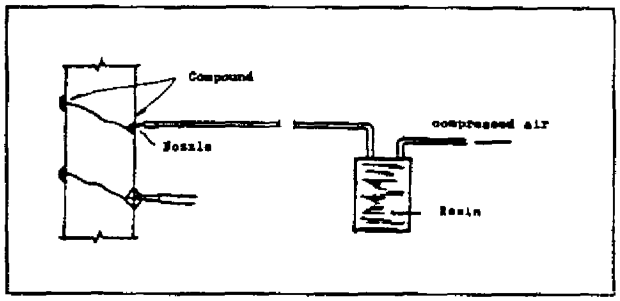

Figure 12.2-1 Epoxy Injection [8]

Increasing flexural and shear strength, improving column ductility and rearrangement of column stiffness can be achieved by repairing techniques.

Column flexural strength increases with the enlargement of the concrete area and by adding reinforcement. Shear strength, especially ductility, is improved by closely placed reinforce ment ties or steel strips.

Damage to reinforced concrete columns may include slight cracks (horizontal or diagonal) without damage to reinforcement, superficial damage in the concrete without damage to reinforcement, crushing of the concrete, buckling of reinforce ment or rupture of ties. Based on the degree of damage, techniques such as injections, removal and replacement or jacketing can be applied.

Local Repairs

Resin injections are applied only for damaged columns with slight cracks without damaged concrete or reinforcement. Epoxy resin injection is suitable for cracks with width from 0.1 to 5 mm (Figure 12.2-1). Cement grout injections can be applied for larger cracks (widths from 2 to 5 mm).

Removal and replacement is necessary for heavily damaged columns with crushed concrete, buckled longitudinal bars or ruptured ties.

When the concrete is slightly damaged, the loose concrete is removed, the surfaces are roughened and dust removed. Depending on the amount of concrete removed, some additional ties or reinforcement may be added and local jacketing is carried out (Figure 12.2-2).

When the vertical reinforcement is buckled, the ties are ruptured and the concrete is crushed, total removal and replacement of the damaged parts must be carried out (Figure 12.2-3). If only repair is required, the original cross sections size will be maintained. If strengthening is necessary, the area of the column must be increased. Damaged and loose concrete should be removed, new vertical reinforcement inserted and welded to the existing reinforcement and new ties placed. Non-shrinkage concrete or concrete with low shrinkage properties should be used. Special attention must be paid to achieve a good bond between new and old concrete.

Reinforced Concrete Jacketing

Jacketing should be applied in cases of heavily damaged columns or in cases of insufficient column strength. This is really a strengthening procedure although it can also be used for repairing. Jacketing can be performed by adding reinforced concrete, steel profiles or steel encasement.

Reinforced concrete jacketing, depending on the space around the column, can accomplished by adding jacketing to one, two, three or four sides of the column (Figure 12.2-4). It is recommended that columns be jacketed on all four sides. In order to achieve the best bond between new and existing concrete, four-sided jacketing is best. In case one, two or three sided jacketing is all that is possible, the concrete cover in the jacketed parts of the existing column must be chipped away so that new ties can be welded to existing ties. In case of a four-sided jacketing, only roughening of the surface of the existing column may be required. Four-sided jacketing results in the lowest increase of cross sectional area.

Jacketing only within one floor does not improve seismic response unless shear walls are also added. Adequate column strength can be achieved by passing the new vertical reinforcement through holes drilled in the slab and adding new concrete in the beam-column joint region. Special attention should be paid to the good confinement of the vertical reinforcement near the floor beams. It must be noted that the interconnection of columns from floor to floor may cause a considerable increase of column cross section.Reinforced concrete jacketing of columns should conform to the following provisions:

- The strength of the new materials must be greater than those of the column.
- The thickness of the jacket should be at least 4 cm for shotcrete application or 10 cm for cast-in-situ concrete.
- The reinforcement should not be less than four bars for four-sided jacketing and bar diameter should be at least 14 mm.
- Every corner and alternate longitudinal bar should have lateral ties with an angle of bend of 135 degrees minimum. No intermediate bar should be farther than 10 cm from corner of the ties. In some cases, it will be necessary to drill into the core of the column to place epoxy hooked ties into the hole or drill completely through the existing column core to install new ties.
- The ties should be minimum 8 mm, and at least 1/3 of the vertical bar diameter.
- Vertical spacing of ties is at most 20 cm Close to the joints the spacing should not exceed 10 cm, within a length of 1/4 the clear height. In addition, the spacing of ties should not exceed the thickness of the jacket.

Jackets can be made either with conventional or special cast-in-situ concrete or by shotcrete (gunite). For both methods, the existing concrete must be thoroughly roughened by chipping or heavy sandblasting and cleaned of all loose material, dust and grease The surface shouldbethoroughly moistened before placing the concreteorshotcrete

Steel Profile Jacketing

Steel profile jacketing consists of four vertical angle profiles one at each corner of the column, connected together with steel straps (Figure 12.2-6). They are welded to the angle profiles and can be either round bars (minimum diameter of 12 mm) or steel straps (minimum size of 25/4 mm). The angle pro file should be no less than L 50/50/5 Gaps and voids between the angle profiles and the surface of the existing column must be filled with non-shrinking grout or resin grout. A covering with concrete or shotcrete reinforced with welded fabrics is efficient for corrosion or fire protection. Tight bearing between profiles and floor is achieved by an angle profile collar around the column, directly in contact with the floor structures

strengthening, jacketing, column, local repair

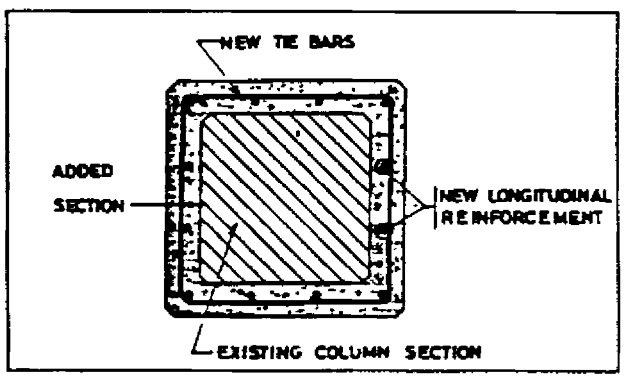

Figure 12.2-5 Four-sided Jacketing [1]

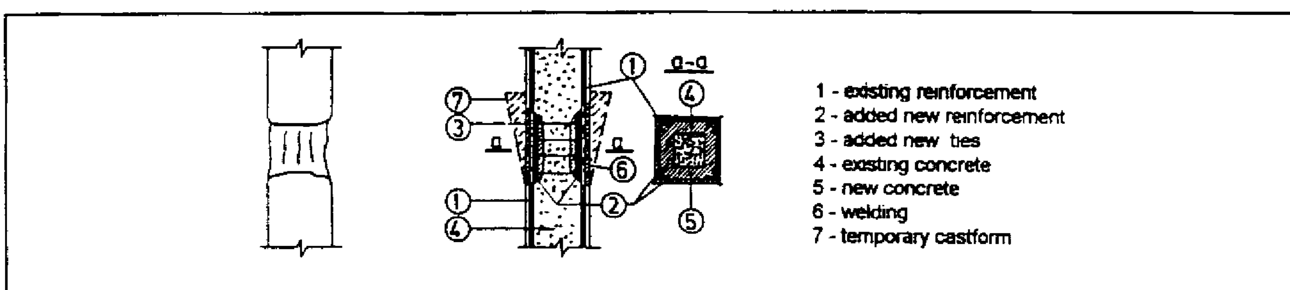

Figure 12.2-2 Local Jacketing [3]