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SEISMIC EVALUATION OF EXISTING BUILDING

Project Report submitted in partial fulfillment of the degree of

Bachelor of Technology

In

Civil Engineering

Under the Supervision of

Mrs. Poonam Dhiman

By

Naman kumar [111665]

To

विद्या तत्व ज्योतिसम

Department of Civil Engineering

Jaypee University of Information Technology

Waknaghat, Solan – 173234, Himachal Pradesh.

Learning Resource Center
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Waknaghat Solan (H.P.)

CERTIFICATE

This is to certify that project report entitled "Seismic Evaluation of existing buildings", submitted by Naman Kumar [111665] on partial fulfillment for the award of degree of Bachelor of Technology in Civil Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

This work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

Date: 30/5/15

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I am sincerely grateful to Dr. Ashok Kumar Gupta, Professor and Head of Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat for providing all the necessities for the successful completion of my project.

I would also like to thank the laboratory staff of Department of Civil Engineering for their timely help and assistance.

Date: 30th May '15

Naman Kumar [111665]

Abstract

"Seismic evaluation of existing building" In this project evaluation of existing building on the basis of earthquake has been done. Evaluation of the building tells us about the building that it will sustain earthquake or not and if not than what kind of methods we can use to make it more sustainable. This project work have covered framed structure as well as masonry buildings located near Jaypee University of Information technology.

Index – Tables

Index – Figures

CONTENTS

Chapter 1: Overview

1.1 Introduction

Occurrences of recent earthquakes in India and in different parts of the world and the resulting losses, especially human lives, have highlighted the structural inadequacy of buildings to carry seismic loads. There is an urgent need for assessment of existing buildings in terms of seismic resistance. In view of this various organizations in the earthquake threatened countries have come up with documents, which serve as guidelines for the assessment of the strength, expected performance and safety of existing buildings as well as for carrying out the necessary rehabilitation, if required.

In this project work some of the methods are explained which will help to better understand various factors causing earthquake, testing methods (destructive and non-destructive) as well as analysis of results.

Retrofitting refers to the addition of new technology or features to older systems.

Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. With better understanding of seismic demand on structures and with our recent experiences with large earthquakes.

2.2 Objectives

The seismic evaluation process consists of investigating if the structure meets the defined target structural performance levels. The main goal during earthquakes is to assure that building collapse doesn't occur and the risk of death or injury to people is minimized and beyond that to satisfy post-earthquake performance level for defined range of seismic hazards. Also seismic evaluation will determine which are the most vulnerable and weak components and deficiencies of a building during an expected earthquake.

My objective is to evaluate seismic vulnerability of buildings around Jaypee University of Information technology, Waknaghat and to have a better understanding towards structural properties and their behavior before, after and at the time of earthquake.

Chapter 2: Literature

2.1 Earthquake tips

2.1.1 What causes Earthquake?

The Earth and its Interior:

Long time ago, a large collection of material masses coalesced to form the Earth. Large amount of heat was generated by this fusion, and slowly as the Earth cooled down, the heavier and denser materials sank to the center and the lighter ones rose to the top. The differentiated Earth consists of the Inner Core (radius ~1290 Km), the Outer Core (thickness ~2200 Km), the Mantle (thickness -2900 Km) and the Crust (thickness ~5 to 40 Km).

Figure 1 shows these layers.

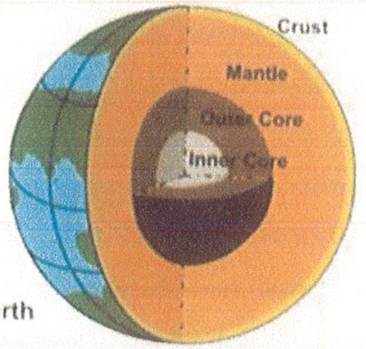

Figure 1:
Inside the Earth

Convection currents develop in the viscous Mantle, because of prevailing high temperature and pressure gradients between the Crust and the Core. These convection currents result in a circulation of the earth's mass; hot molten lava comes out and the cold rock mass goes into the Earth. The mass absorbed eventually melts under high temperature and pressure and becomes a part of the Mantle, only to come out again from another location, someday. Many such local circulations are taking place at different regions underneath the Earth's surface, leading to different portions of the Earth undergoing different directions of movements along the surface.

Plate Tectonics:

The convective flows of Mantle material cause the Crust and some portion of the Mantle, to slide on the hot molten outer core. This sliding of Earth's mass takes place in pieces called Tectonic Plates. The surface of the Earth consists of seven major tectonic plates and many smaller ones (Figure 2).

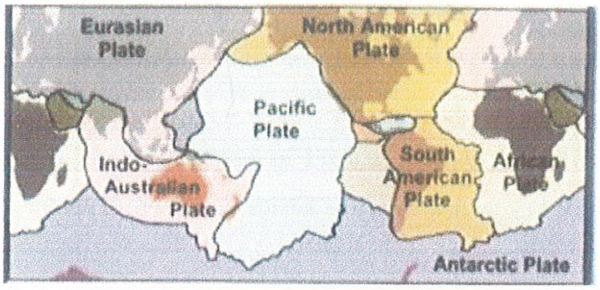

Figure 2:7 major tectonic plates

The Earthquake:

Rocks are made of elastic material, and so elastic strain energy is stored in them during the deformations that occur due to the gigantic tectonic plate actions that occur in the Earth. But, the material contained in rocks is also very brittle. Thus, when the rocks along a weak region in the Earth's Crust reach their strength, a sudden movement takes place there; opposite sides of the fault (a crack in the rocks where movement has taken place) suddenly slip and release the large elastic strain energy stored in the interface rocks. The sudden slip at the fault causes the earthquake a violent shaking of the Earth when large elastic strain energy released spreads out through seismic waves that travel through the body and along the surface of the Earth. And, after the earthquake is over, the process of strain buildup at this modified interface between the rocks starts all over again.

Types of Earthquakes and Faults

Most earthquakes in the world occur along the boundaries of the tectonic plates and are called Inter- plate Earthquakes (e.g., 1897 Assam (India) earthquake). A number of earthquakes also occur within the plate itself away from the plate boundaries (e.g., 1993 Latur (India) earthquake); these are called Intra-plate Earthquakes. In both types of earthquakes, the slip generated at the fault during earthquakes is along both vertical and horizontal directions (called Dip Slip) and lateral directions (called Strike Slip).

2.1.2 How the ground shakes?

Seismic Waves:

Large strain energy released during an earthquake travels as seismic waves in all directions through the Earth's layers, reflecting and refracting at each interface. These waves are of two types - body waves and surface waves; the latter are restricted to near the Earth's surface. Body waves consist of Primary Waves (P-waves) and Secondary Waves (S- waves), and surface waves consist of Love waves and Rayleigh waves.

Measuring Instruments:

The instrument that measures earthquake shaking, a seismograph, has three components - the sensor, the recorder and the timer. A pen attached at the tip of an oscillating simple pendulum (a mass hung by a string from a support) marks on a chart paper that is held on a drum rotating at a constant speed. A magnet around the string provides required damping to control the amplitude of oscillations. The pendulum mass, string, magnet and support together constitute the sensor; the drum, pen and chart paper constitute the recorder; and the motor that rotates the drum at constant speed forms the timer as shown in figure 3.

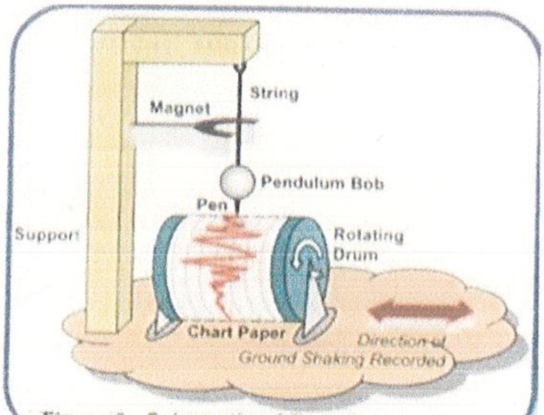

Figure 3: Schematic of Early Seismograph

2.1.3 What are magnitude and Intensity?

Magnitude:

Magnitude is a quantitative measure of the actual size of the earthquake. An increase in magnitude (M) by 1.0 implies 10 times higher waveform amplitude and about 31 time's higher energy released.

Intensity:

Intensity is a qualitative measure of the actual shaking at a location during an earthquake, and is assigned as Roman Capital Numerals. There are many intensity scales. Two commonly used ones are the Modified Mercalli Intensity (MM!) Scale and the MSK Scale. Both scales are quite similar and range from I (least perceptive) to XII (most severe).

2.1.4 Where are the seismic zone in India?

Seismic Zones of India The varying geology at different locations in the country implies that the likelihood of damaging earthquakes taking place at different locations is different. Thus, a seismic zone map is required to identify these regions. Based on the levels of intensities sustained during damaging past earthquakes, it now has four seismic zones - II, III, IV and V. The areas falling in seismic zone I in the 1970 version of the map are merged with those of seismic zone II. You can see various seismic zone in map below (figure 4).

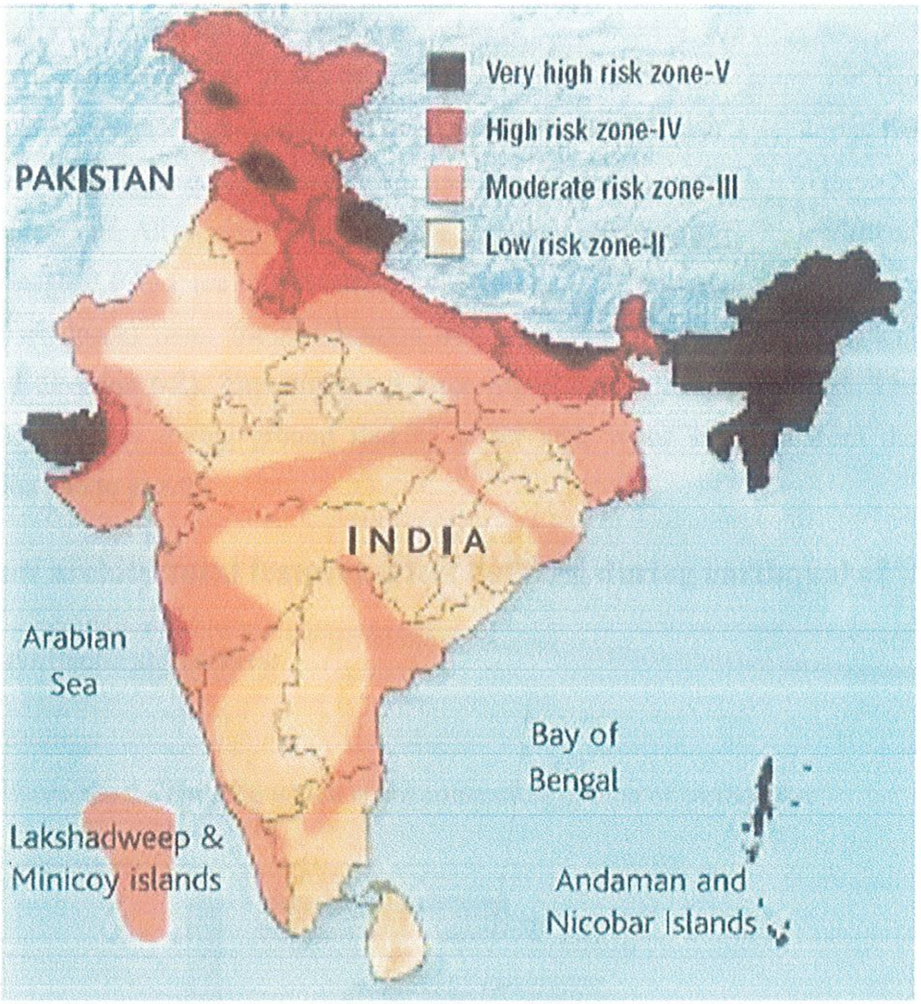

Figure 4: seismic zone in India

2.1.5 What are the seismic effect on structure?

Inertia Forces in Structures:

Earthquake causes shaking of the ground. So a building resting on it will experience motion at its base. From Newton's First Line of Motion, even though the base of the building moves with the ground, the roof has a tendency to stay in its original position. But since the walls and columns are connected to it, they drag the roof along with them.

Horizontal and Vertical Shaking:

Earthquake causes shaking of the ground in all three directions - along the two horizontal directions (X and Y, say), and the vertical direction (Z, say) Also, during the earthquake, the ground shakes randomly back and forth (-and +) along each of these X, Y and Z directions. All structures are primarily designed to carry the gravity loads, i.e., they are designed for a force equal to the mass M (this includes mass due to own weight and imposed loads) times the acceleration due to gravity g acting in the vertical downward direction (-Z). The downward force Mg is called the gravity load. The vertical acceleration during ground shaking either adds to or subtracts from the acceleration due to gravity.

2.1.6 How architectural features affect building during earthquake?

Architectural Features:

1. Size of Buildings:

   Figure 5 illustrates the building which is not compatible at time of earthquake.

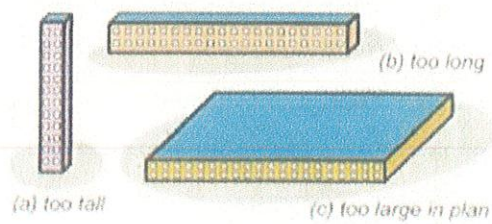

Figure 5: Buildings with one of their overall sizes much larger or much smaller than the other two, do not perform well in earth quake.

2. Horizontal Layout of Buildings:

Figure 6 illustrates plan shape of buildings.

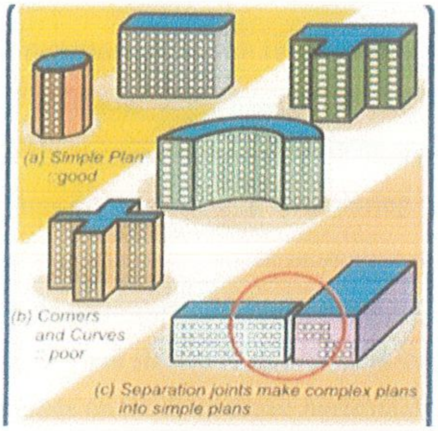

Figure 6: Simple plan shape building do well during earthquakes.

3. Vertical Layout of Buildings:

The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path; any deviation or discontinuity in this load transfer path results in poor performance of the building. Buildings with vertical setbacks cause a sudden jump in earthquake forces at the level of discontinuity. Buildings that have fewer columns or walls in a particular storey or with unusually tall storey, tend to damage or collapse which is initiated in that storey. Buildings on sloppy ground have unequal height columns along the slope, which causes ill effects like twisting and damage in shorter columns. Buildings with columns that hang or float on beams at an intermediate storey and do not go all the way to the foundation, have discontinuities in the load transfer path. Some buildings have reinforced concrete walls to carry the earthquake loads to the foundation. Buildings, in which these walls do not go all the way to the ground but stop at an upper level, are liable to get severely damaged during earthquakes.

3. Adjacency of Buildings:

When two buildings are too close to each other, they may pound on each other during strong shaking. With increase in building height, this collision can be a greater problem.

2.1.7 How buildings twist during earthquake?

Why a building twists:

Consider a rope swing that is tied identically with two equal ropes. It swings equally, when you sit in the middle of the cradle. Buildings too are like these rope swings; just that they are inverted swings. The vertical walls and columns are like the ropes, and the floor is like the cradle. Buildings vibrate back and forth during earthquakes. Buildings with more than one storey are like rope swings with more than one cradle. Thus, if you see from sky, a building with identical vertical members and that are uniformly placed in the two horizontal directions, when shaken at its base in a certain direction, swings back and forth such that all points on the floor move horizontally by the same amount in the direction in which it is shaken.

Again, let us go back to the rope swings on the tree: if you sit at one end of the cradle, it hoists. This also happens sometimes when more of your friends bunch together and sit on one side of the swing. Likewise, if the mass on the floor of a building is more on one side, then that side of the building moves more underground movement. This building moves such that its floors displace horizontally as well as rotate.

Once more, let us consider the rope swing on the tree. This time let the two ropes with which the cradle is tied to the branch of the tree be different in length. Such a swing also twists even if you sit in the middle. Similarly, in buildings with unequal structural members (i.e., frames and/or walls) also the floors twist about a vertical axis and displace horizontally. Likewise, buildings, which have walls only on two sides (or one side) and flexible frames along the other, twist when shaken at the ground level.

2.1.8 What is the seismic design philosophy of buildings?

Earthquake Design Philosophy

The earthquake design philosophy may be summarized as follows:

(a) Under minor but frequent shaking, the main members of the building that carry vertical and horizontal forces should not be damaged; however building parts that do not carry load may sustain repairable damage.

(b) Under moderate but occasional shaking, the main members may sustain repairable damage, while the other parts of the building may be damaged such that they may even have to be replaced after the earthquake; and

(c) Under strong but rare shaking, the main members may sustain sever (even irreparable) damage, but the building should not collapse.

Damage in Buildings:

Unavoidable Design of buildings to resist earthquakes involves controlling the damage to acceptable levels at a reasonable cost. Contrary to the common thinking that any crack in the building after an earthquake means the building is unsafe for habitation,

Acceptable Damage: Ductility

Earthquake-resistant buildings, particularly their main elements, need to be built with ductility in them. Such buildings have the ability to sway back-and-forth during an earthquake, and to withstand earthquake effects with some damage, but without collapse.

2.1.9 How to make building ductile for good seismic performance?

Construction materials:

Steel is used in masonry and concrete buildings as reinforcement bars of diameter ranging from 6mm to 40mm. Reinforcing steel can carry both tensile and compressive' loads. Moreover, steel is a ductile material. This important property of ductility enables steel bars to undergo large elongation before breaking.

Earthquake-Resistant Design of Building:

By using the routine design codes (meant for design against non-earthquake effects), designers may not be able to achieve a ductile structure. Special design provisions are required to help designers improve the ductility of the structure.
Such provisions are usually put together in the form of a special seismic design code, e.g., IS:13920-1993 for RC structures. These codes also ensure that adequate ductility is provided in the members where damage is expected.

2.1.10 How flexibility of buildings affects their earthquake response?

Oscillations of Flexible Buildings:

When the ground shakes, the base of a building moves with the ground, and the building swings back- and-forth. If the building were rigid, then every point in it would move by the same amount as the ground. But, most buildings are flexible, and different parts move back-and-forth by different amounts.

Importance of Flexibility:

In a typical city, there are buildings of many different sizes and shapes. One way of categorizing them is by their fundamental natural period T. The ground motion under these buildings varies across the city. If the ground is shaken back and-forth by earthquake waves that have short periods, then short period buildings will have large response. Similarly, if the earthquake ground motion has long period waves, then long period buildings will have larger response. Thus, depending on the value of T of the buildings and on the characteristics of earthquake ground motion (i.e., the periods and amplitude of the earthquake waves), some buildings will be shakes more than the others. Flexible buildings undergo larger relative horizontal displacements, which may result in damage to various nonstructural building components and the contents.

2.2 Seismic Evaluation:

2.2.1 IS CODE 1893:2002

IS CODE 1893:2002 tells us about the standard provisions for earthquake resistant design of buildings. With rapid strides in earthquake engineering in the last several decades, the seismic codes are becoming increasingly sophisticated. The first Indian seismic code (IS 1893) was published in 1962 and it has since been revised in 1966, 1970, 1975 and 19841. More recently, it was decided to split this code into a number of parts, and Part 1 of the code containing general provisions (applicable to all structures) and specific provisions for buildings has been published.

IS CODE 1893:2002 tells us about important factors to consider while constructing a structure in various earthquake zones.

2.2.2 Destructive test:

In destructive testing tests are carried out to the specimen's failure, in order to understand a specimen's structural performance or material behavior under different loads. These tests are generally much easier to carry out, yield more information, and are easier to interpret than nondestructive testing but It is usually not economical to do as it harm the structure.

Some important points on doing lab test:

1. It may neither be feasible nor is the practice to conduct field/laboratory testing on every structural member in an existing distressed building.

2. The field/laboratory testing of structural concrete and reinforcement is to be undertaken, basically for validating the findings of visual inspection.

3. These may be undertaken on selective basis on representative structural members from each of the various groups based on exposure conditions as explained in the preceding sections.

4. The programme of such testing has to be chalked out based on the record of visual inspection.

Table 1 on the next page shows some test which we can perform in destructive testing.

Property under investigation	Test	Equipment type
Corrosion of embedded Steel	Half Cell potential	Electrochemical
	Resistivity	Electrical
	Linear polarization resistance	Electrochemical
	A.C. Impedance	Electrochemical
	Cover depth	Electromagnetic
	Carbonation depth	Chemical/microscopic
	Chloride concentration	Chemical/electrical
Concrete quality, durability and deterioration	Surface hardness	Mechanical
	Ultrasonic pulse velocity	Electromechanical
	Radiography	Radioactive
	Radiometry	Radioactive
	Neutron absorption	Radioactive
	Relative humidity	Chemical/electronic
	Permeability	Hydraulic
	Absorption	Hydraulic
	Petrographic	Microscopic
	Sulphate content	Chemical
	Expansion	Mechanical
	Air Content	Microscopic
	Cement type and content	Chemical/microscopic
	Abrasion resistance	Mechanical
Concrete strength	Cores	Mechanical
	Pull-out	Mechanical
	Pull – off	Mechanical
	Break-off	Mechanical
	Internal fracture	Mechanical
	Penetration resistance	Mechanical
	Maturity	Chemical/electrical
	Temperature-matched Curing	Electrical/electronic
Integrity and Performance	Tapping	Mechanical
	Pulse-echo	Mechanical/electronic
	Dynamic response	Mechanical/electronic
	Acoustic emission	Electronic
	Thermoluminescence	Chemical
	Thermography	Infra-red
	Radar	Electromagnetic
	Reinforcement location	Electromagnetic
	Strain or crack measurement	Optical/mechanical/electrical
	Load test	Mechanical/electronic/electrical

Table 1: Some of the destructive method are shown above [principal test methods]

2.2.3 Non Destructive test:

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. The term 'nondestructive' is used to indicate that it does not impair the intended performance of the structural member being tested/investigated. Commonly used NDE test are shown below [table 2]

Sl No	Test Method	Details
A.	**Insitu Concrete Strength:**	
1	Rebound Hammer Test	A qualitative field test method to measure surface hardnessof concrete
2	Ultrasonic Pulse Velocity	A qualitative field test by measurement of Ultrasonic Pulse Velocity (UPV)
3	Windsor Probe	A qualitative field test for assessment of near surface strength of concrete
4	Capo/Pull out test	-do-
5	a. Core cutting/ sampling b. Lab Testing of Cores	Field cum lab test method for assessing quality of concrete as under: - strength - density - texture - permeability
6	Load Test	A field test for assessing the load carrying capacity within the limits of elastic deformations
B.	**Chemical Attack**	
1	Carbonation Test	A field/lab test for assessment of pH of concrete and depth of carbonation
2	Chloride Test	A field/lab Test for assessment of total water/acid soluble chloride contents
3	Sulphate Test	A Lab Test for assessment of total acid/water soluble sulphate contents of concrete
C.	**Corrosion Potential Assessment**	
1	Cover-Meter / Profo-meter measurement (In-situ Test)	A field method for measuring -thickness of cover concrete -reinforcement diameter -reinforcement spacing.
2	Half Cell Method	A field method for Measuring/ plotting corrosion potential for assessing probability of corrosion
3	Resistivity Meter	A field method for assessing electrical resistivity of concrete to determine its corrosion resistance
4	Permeability a. Water b. Air	A field/Lab method for assessment of in-situ permeability of concrete due to water and air.
D. Fire Damage Assessment		
1	Thermo-Gravimetric Analysis (TGA)	A laboratory test for assessment of temperature range to which concrete was subjected to
2	Differential Thermal Analysis (DTA)	A laboratory Test for assessment of qualitative & quantitative composition of sample of concrete
3	X-ray Diffraction (XRD)	To determine the extent of deterioration in concrete subjected to fire

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3	X-ray Diffraction (XRD)	To determine the extent of deterioration in concrete subjected to fire

Table 2: General NDE test

Some of the non-destructive tests are explained below:

Rebound Hammer Test:

The operation of Rebound Hammer (also called Schmidt's Hammer) is illustrated in figure 7. When the plunger of rebound hammer is pressed against the surface of concrete, a spring controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale. This measured value is designated as Rebound Number (a rebound index). A concrete with low strength and low stiffness will absorb more energy to yield in a lower rebound value.

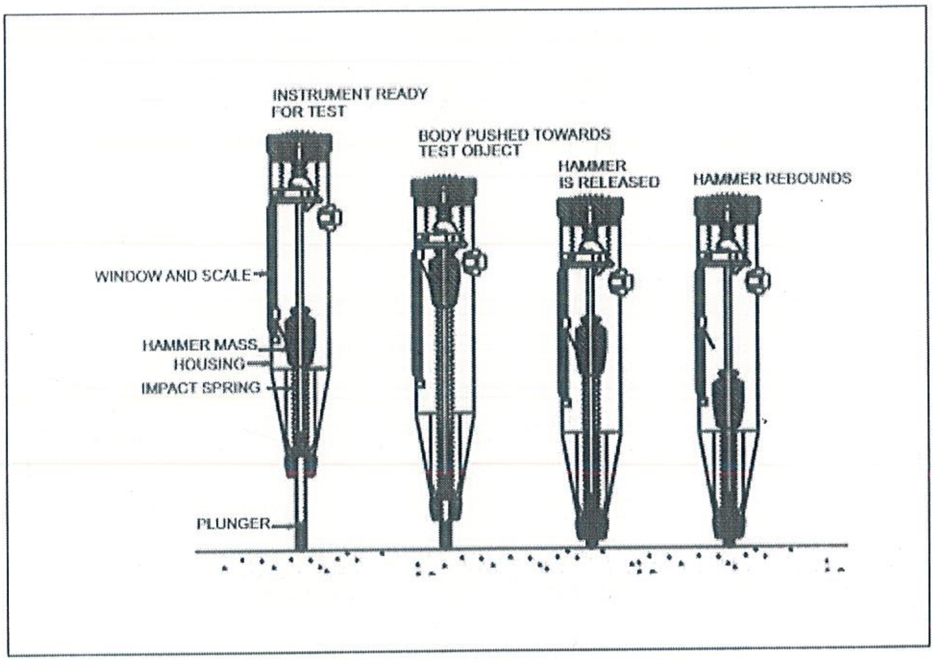

Figure 7: Working of rebound hammer.

Ultrasonic Pulse Velocity (UPV) test

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 endlength, 'L' (i.e. the distance between the two probes) and time of travel, T the pulse velocity (V = L/T) is calculated. 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.

Penetration Resistance ('Windsor Probe' and 'PNR Tester')

This technique offers a means of determining relative strengths of concrete in the same structure or relative strength of different structures. Because of the nature of equipment, it cannot, and should not be expected to yield absolute values of strength. ASTM C-803 gives this standard test method titled, "penetration resistance of hardened concrete". 'Windsor Probe', as commercially known, is penetration resistance measurement equipment, which consists of a gun powder actuated driver, hardened alloy rod probe, loaded cartridges, a depth gauge and other related accessories. In this technique, a gunpowder-actuated driver is used to fire a hardened alloy probe into the concrete. During testing, it is the exposed length of probe, which is measured

By a calibration depth gauge. But, it is preferable to express the coefficient of variation in terms of the depth of penetration as the fundamental relation is between concrete strength and penetration depth. Windsor probe is shown in figure 8.

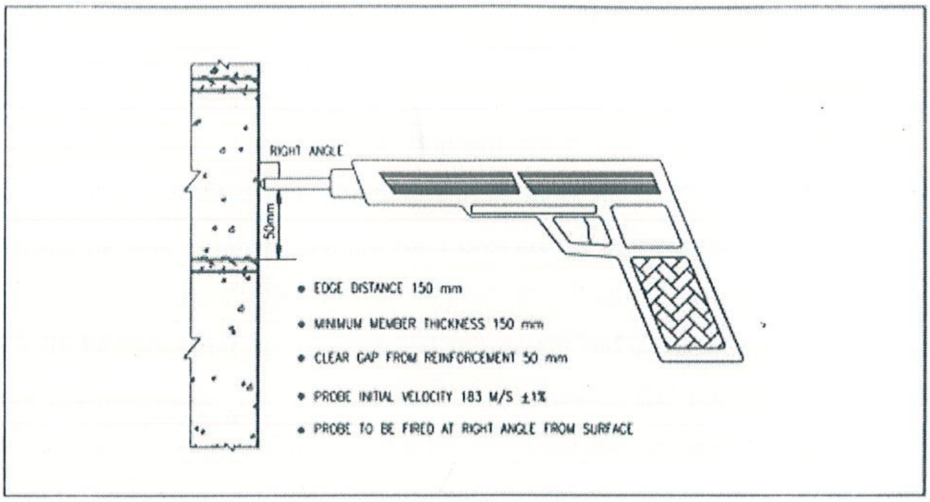

Figure 8: Windsor probe

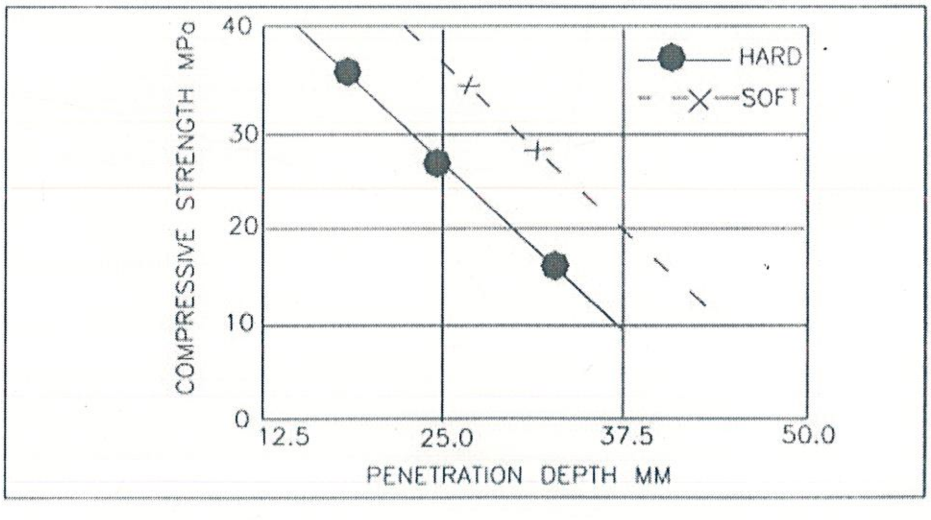

Figure 9: PNR tester

A pin penetration test device (PNR Tester), which requires less energy than the Windsor Probe System is shown in figure 9. Being a low energy device, sensitivity is reduced at higher strengths. Hence, it is not recommended for testing concrete having strength above 28 N/sq mm. In this, a spring-loaded device, having energy of about 1.3% of that of Windsor Probe, is used to drive 3.56 mm diameter, a pointed, hardened steel pin in to the concrete. The penetration of pin creates a small indentation (or hole) on the surface of concrete. The pin is removed from the hole, the hole is cleaned with an air jet and the hole depth is measured with a suitable depth gauge. Each time a new pin is required as the pin gets blunted after use.

Core Sampling and Testing

While rebound hammer, Capo/Pullout, Windsor probe and ultrasonic pulse velocity tests give indirect evidence of concrete quality, a more direct assessment on strength can be made by core sampling and testing. Cores are usually cut by means of a rotary cutting tool with diamond bits. In this manner, a cylindrical specimen is obtained, usually with its ends being uneven, parallel and square and sometimes with embedded pieces of reinforcement. The cores are visually described and photographed, giving specific attention to compaction, distribution of aggregate, presence of steel etc. The core should then be soaked in water, capped with molten sulphur to make its ends plane, parallel, at right angle and then tested in compression in a moist condition as per BS 1881: Part 4: 1970 or ASTM C 42-77. The core samples can also be used for the following:

- Strength and density determination
- Depth of carbonation of concrete
- Chemical analysis
- Water/gas permeability
- Petrographic analysis
- ASHTO Chloride permeability test

Chapter 3: Seismic Evaluation of Existing Building: Framed structure

3.1 Introduction:

Hill Point

Use of building:

- Residential
- Commercial

Location: JUIT Road, Waknaghat (District Solan) Himachal Pradesh, 173234
Earthquake zone: 4

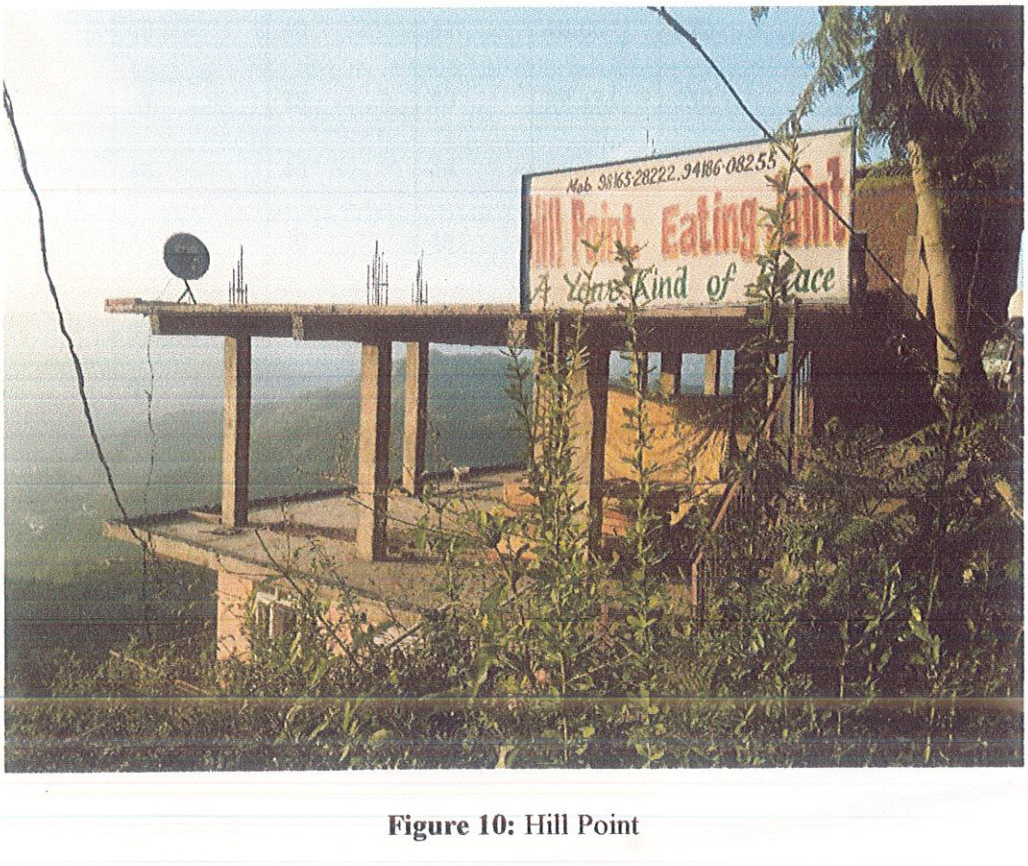

Figure 10: Hill Point

3.2 Data Collection

- All the dimensions of structure are measured by metric tape (30 mts).

Measurement are shown in floor map (figure 11).

- Compressive strength is calculated by using rebound hammer or known as "Schmidt hammer". Reading of beams and columns are shown below:

Beam no.	Rebound Number, R			R_{avg}	Compressive Strength (kg/cm^2)	Compressive Strength (N/mm^2)
	R_1	R_2	R_3			
1	48	42	38	42.66	380	38
2	44	46	42	44	420	42
3	42	44	40	42	380	38
4	40	40	42	40.66	340	34
5	44	38	40	39.33	330	33
6	44	44	44	44	420	42
7	44	40	46	43.33	400	40
8	44	46	48	46	460	46
9	42	44	48	44	420	42

Table 3: Readings of rebound hammer test on beams.

Column no.	Rebound Number, R				Compressive Strength (kg/cm^2)	Compressive Strength (N/mm^2)
	R_1	R_2	R_3	R_{avg}		
1	32	32	34	32.66	280	28
2	38	36	38	37.33	360	36
3	38	40	42	40	420	42
4	28	30	30	29.33	230	23
5	40	36	34	36.66	340	34
6	42	40	48	43.33	470	47
7	34	34	36	34.66	310	31
8	32	32	34	32.66	280	28
9	34	40	44	39.33	400	40
10	32	34	32	32	280	28
11	30	30	30	30	250	25
12	30	30	32	30.66	250	25
13	28	30	28	29.31	230	23
14	30	32	28	30	250	25
15	32	30	32	31.33	260	26
16	36	34	34	34.66	310	31
17	28	26	26	27.33	200	20
18	28	28	28	28	220	22

Table 4: Readings of rebound hammer test on columns

3.3 Data Analysis:

3.3.1 Evaluation of collected data

Above data shows that reading of rebound hammer varies at different locations it can happen because:

- Surface on which the readings were taken is rough
- Reinforcement is near or far away from surface
- Pores or voids are present near the surface
- Aggregate is more close to the surface
- Some kind of defect has been occurred in concrete ex: segregation Reading shown above are comparatively less then what it should be for zone 4.

3.3.2 Staad Pro:

Modelling:

Properties:

R1: 0.31 X 0.23 R2: 0.31 X 0.27

R3: 0.31 X 0.23 R4: 0.23 X 0.32

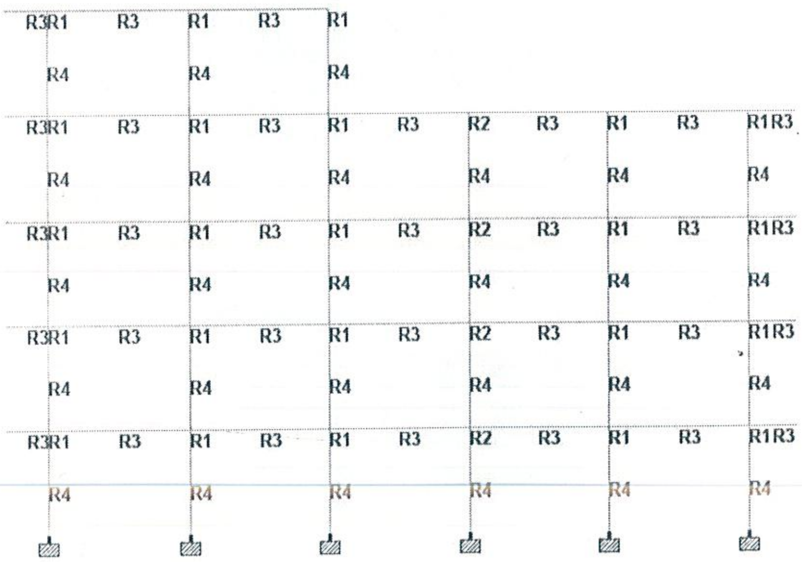

Figure 11: Showing all the properties applied

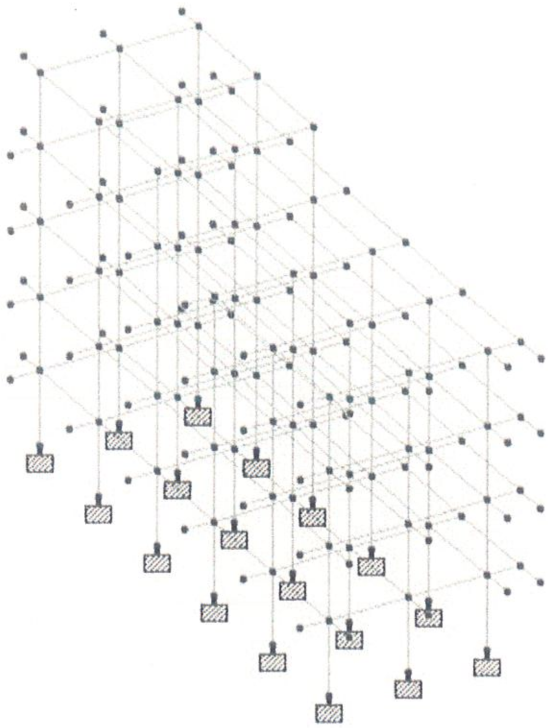

Figure 12: Basic structure showing fixed joint

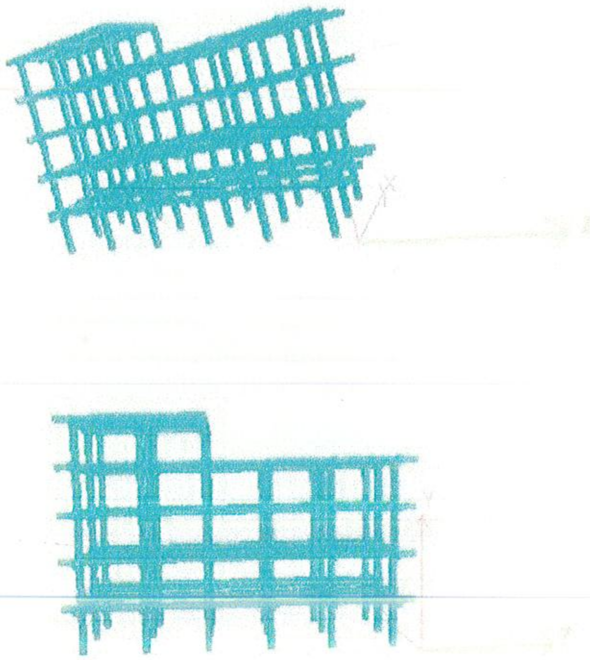

Figure 13: View of model structure

□ Analysis done: Dynamic

According to clause no. 7.8.1 of IS 1893:2002

If a building is of irregular shape with total height more than 12mts we have to do dynamic analysis.

Method applied:

Response pattern: - support at all joints (pinned)-To calculate Modal Mass

□ Loadings:

Dead load

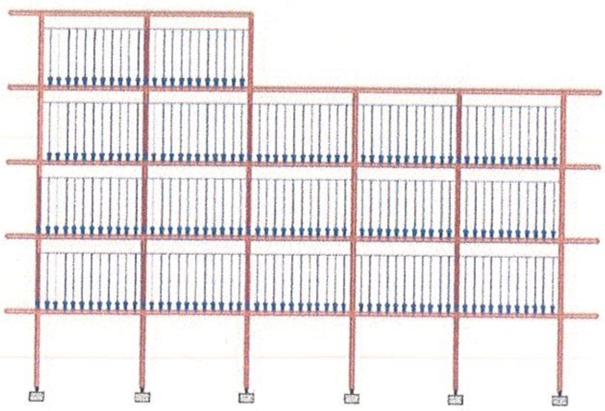

Figure 14: Dead load of wall

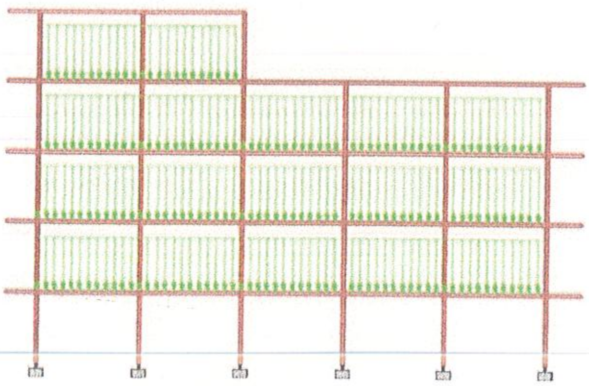

Figure 15: self-weight

Calculation of dead load:

DL of wall= thickness of wall x weight of masonry x height

=12.88 KN/m

Live Load:

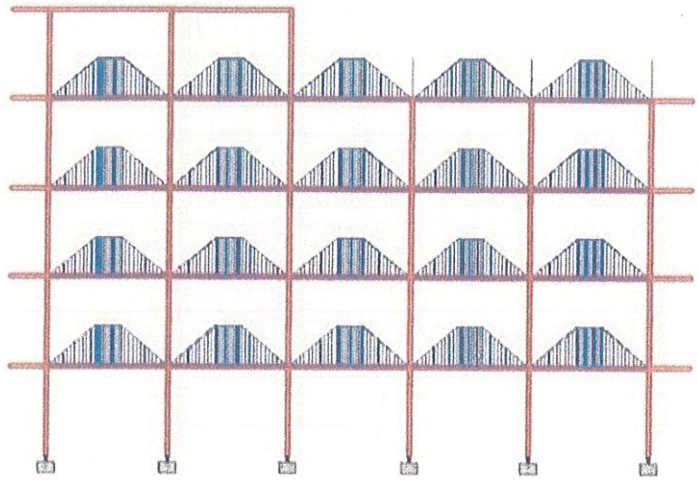

Figure 16: Live load on building

Seismic parameters taken (IS 1893:2002)

Zone 4: value 0.24

Damping ratio: 0.05

Period in x direction: 0.41

Period in y direction: 0.272

Live load: 50% of value

Live load on roof: neglected

Results:

Structure pattern at various modes (Different response pattern):

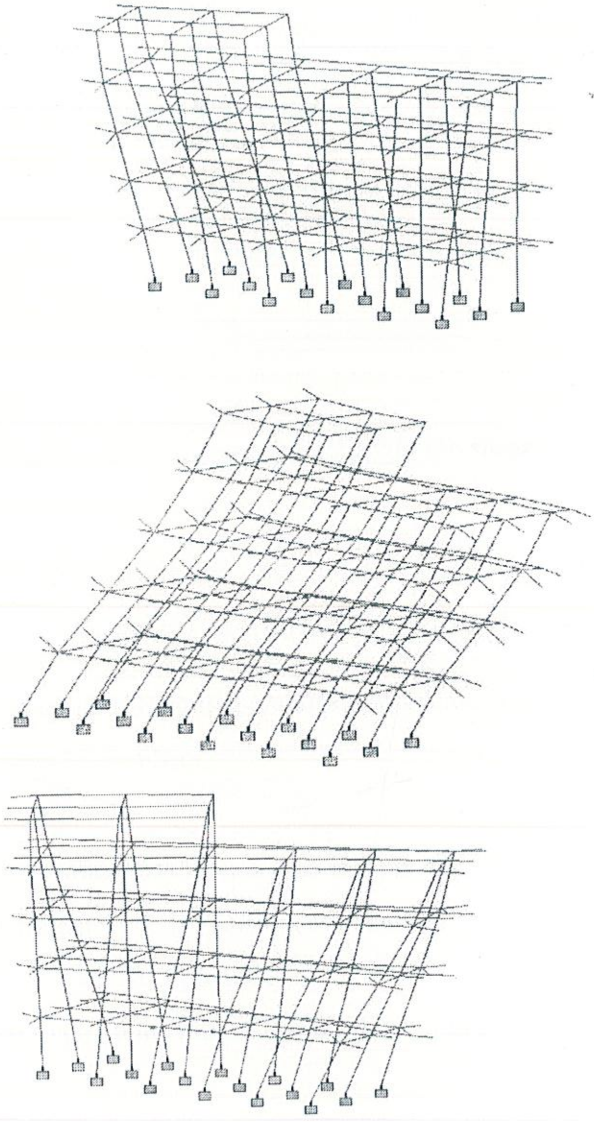

Figure 17 Structural behavior at different modes.

Mass participation (%) and base shear in different directions:

	MASS PARTICIPATION FACTORS IN PERCENT						BASE SHEAR IN KN		
MODE	X	Y	Z	SUMM-X	SUMM-Y	SUMM-Z	X	Y	Z
1	43.76	0.00	7.50	43.763	0.000	7.500	76.71	0.00	18.86
2	6.03	0.00	69.85	49.794	0.000	77.431	10.57	0.00	173.77
3	24.71	0.00	0.22	74.509	0.001	77.654	43.32	0.00	0.56
4	0.00	26.40	0.00	74.509	26.404	77.656	0.00	0.00	0.00
5	0.00	4.16	0.03	74.509	30.560	77.686	0.00	0.00	0.07
6	1.05	0.06	0.00	75.563	30.621	77.686	1.54	0.00	0.00
				TOTAL SRSS		SHEAR	88.75	0.00	174.79
				TOTAL 10PCT		SHEAR	97.46	0.00	192.63
				TOTAL ABS		SHEAR	132.15	0.00	193.25
				TOTAL CSM		SHEAR	98.83	0.00	192.70
				TOTAL CQC		SHEAR	111.08	0.00	192.54

```
* TIME PERIOD FOR X 1893 LOADING =     0.41000 SEC
* SA/G PER 1893=     2.439, LOAD FACTOR= 1.000
*       FACTOR V  PER 1893=     0.0976 X   1433.25
```

Figure 18: Mass participation and base shear

3.4 Conclusion:

Seismic analysis of existing Building: Hill point is completed. These points are observed:

- Number of reinforcement after designing are different from actual scenario.
- Lots of deflection is seen in members.
- No member failure is observed.
- In actual building the column cross section area is same at different floors.
- Reading can come different in actual seismic scenario as it was impossible to go and measure piers.
- No stairs are provided to go on the roof of the building so live load is taken as 0 on the roof.
- No parapet wall is present in actual building on roof due to under construction so no DL is taken for parapet wall.
- For irregular buildings which have total height more than 12mts we do dynamic analysis. Dynamic analysis can be done in 2 ways:
  - □ Time history method
  - □ Response pattern.

Chapter 4: Seismic Evaluation of Existing Building: Masonry Structure

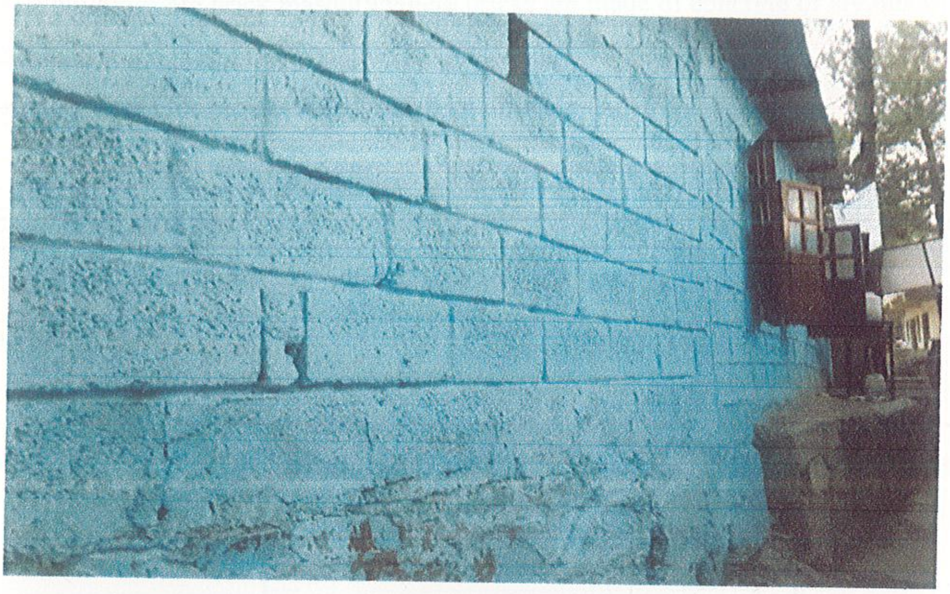

Figure 19: Various Restaurant and shops around College.

General Information:

- 10 Small masonry buildings around college.
- 1 Building consisting of several shops and restaurants (sunny's)
- Most buildings are brick masonry where bricks are made of concrete or are mix of brick and stone masonry (example: lalaji ka dhaba).
- Building opted for project work: Lalaji ka dhaba

Lala ji ka dhaba:

- 3 sides of building are made of brick masonry and the 4th side is made of stone masonry.

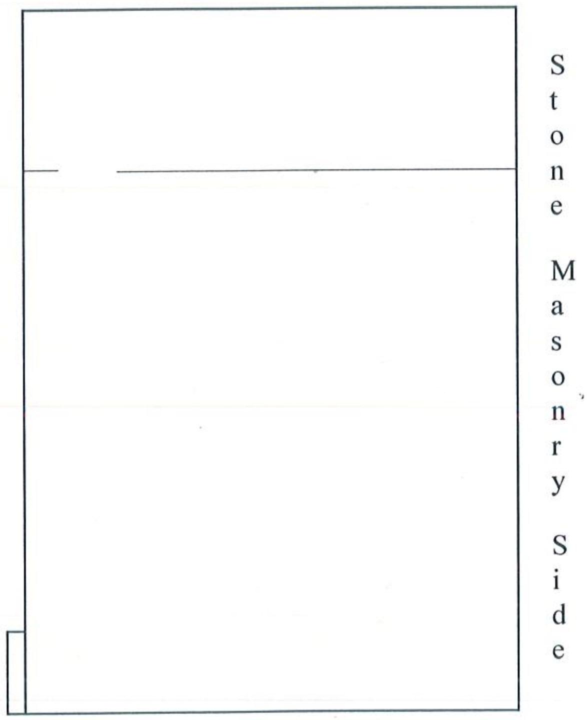

Figure 20: Showing stone masonry side of restaurant

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Rebound no.	68	70	65	70	70	66	68	70
Average								68.37

Table 5: Rebound hammer readings of stone masonry in kg/cm2

Rebound no.	30	28	30	34	34	32	30	34
Average								31.5

Table 6: Rebound hammer readings of brick masonry in kg/cm2

Results:

- One side of building is well protected by stone masonry having high capacity to bear compressive loading.
- As building is single storey no heavy load is present.
- Building have no visible cracks,,spalling, staining etc which are common is masonry structures.
- Perforated Concrete bricks are used mostly in construction around college.

Chapter 5: Retrofit of masonry Buildings

5.1 REPAIR TECHNIQUES

If the stress demand exceeds the capacity of the walls, retrofit is required. The retrofit includes repair of existing defects and increasing the lateral strength, stiffness and structural integrity.

Retrofit of Non-engineered Buildings, are also applicable for masonry buildings. The retrofit techniques can be broadly classified as local (those for improving the strength of a member) and global (those for improving the performance of the building). The repair and local retrofit techniques specific to masonry buildings are first described.

5.1.1 Repointing

For repointing, first the wall should be made wet and all loose debris cleared. The joints that are to be repointed should be raked to a depth of 2 times the joint height. Next, fresh mortar should be placed by trowels. The mortar should be non-shrinking type. The repointed portion should be cured properly.

5.1.2 Grout Injection

Grout can be injected to strengthen the walls. The Strengthening is useful for historical buildings. The grout mixture should be chosen based on the following requirements.

1. High water retention
2. Minimum or no shrinkage, preferable to have slight expansion.
3. Highly flowable without any segregation
4. High tensile strength
5. Good bond with the existing masonry.

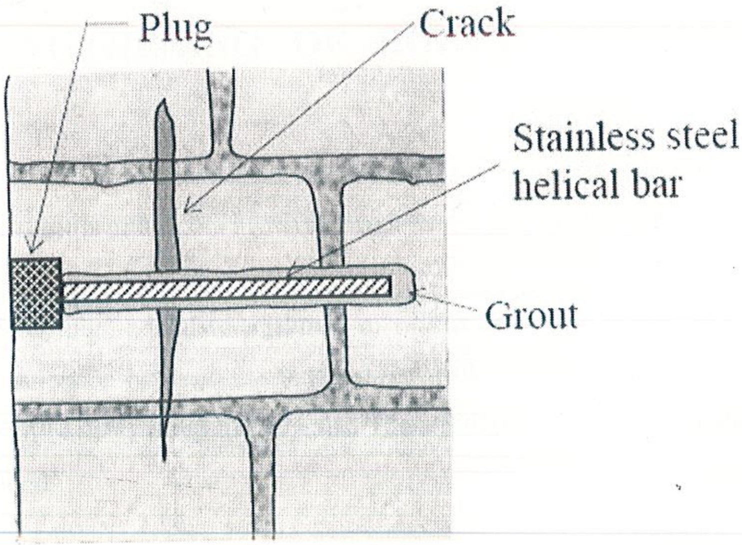
After grout injection, the improvement in properties may be assessed using non-destructive tests. Small cores can be made through the thickness of a wall and the flow of grout can be assessed.

5.1.3 Grout Filling

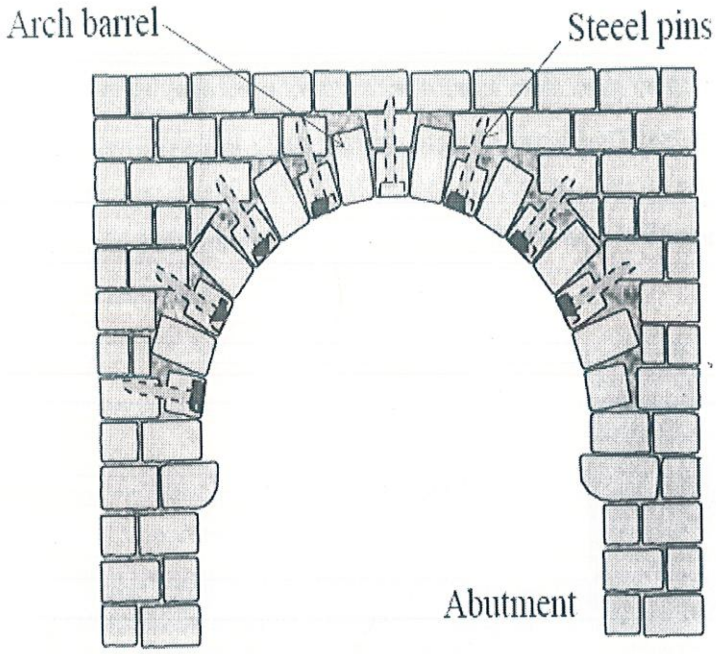
Selected cells in a hollow block masonry wall can be filled with grout. Filling the voids with
grout will increase the compressive strength and make the wall more impermeable to water
penetration. The inside of the cavity should be pre-wetted, then drained prior to grouting.

5.1.4 Crack Stitching

It is possible to introduce internal ties in a masonry wall by drilling a hole, placing a bar and
finally grouting the hole. A similar 'pinning technique' can be used for stitching cracks in the
walls and strengthening the arches (Figure 21).



a) Crack stitching



b) Strengthening a masonry arch

Figure 21 Pinning technique

5.2 STRENGTHENING OF ROOFS AND UPSTAIRS FLOORS

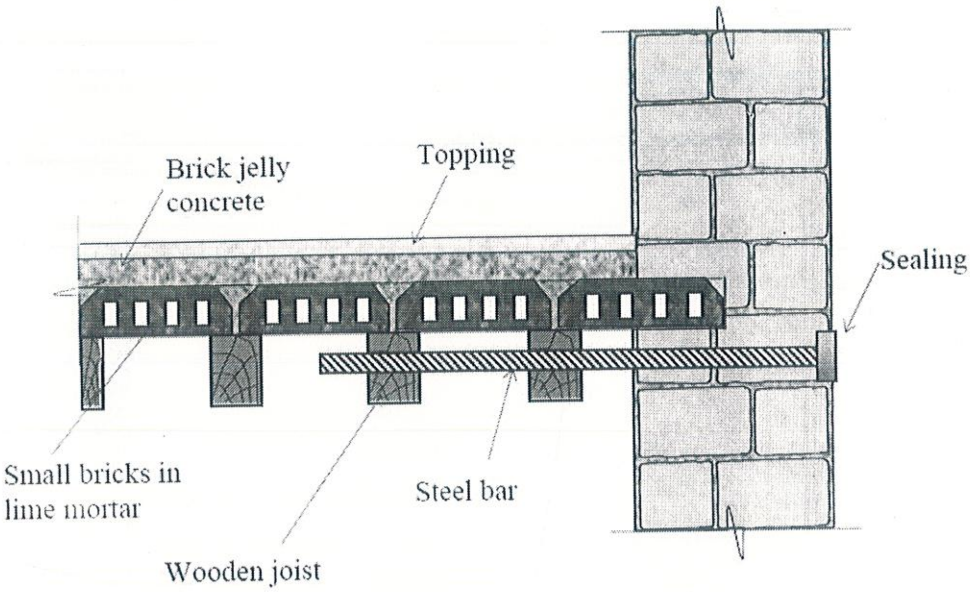
Strengthening of roofs and floors involves two issues. First, the integrity of the slab has to be

improved by providing adequate thickness or braces for the in-plane shear capacity. Second, the connection between the slab and the walls has to be improved so that the seismic load can be transferred to the walls. The strengthening of two typical types of roof is elaborated.

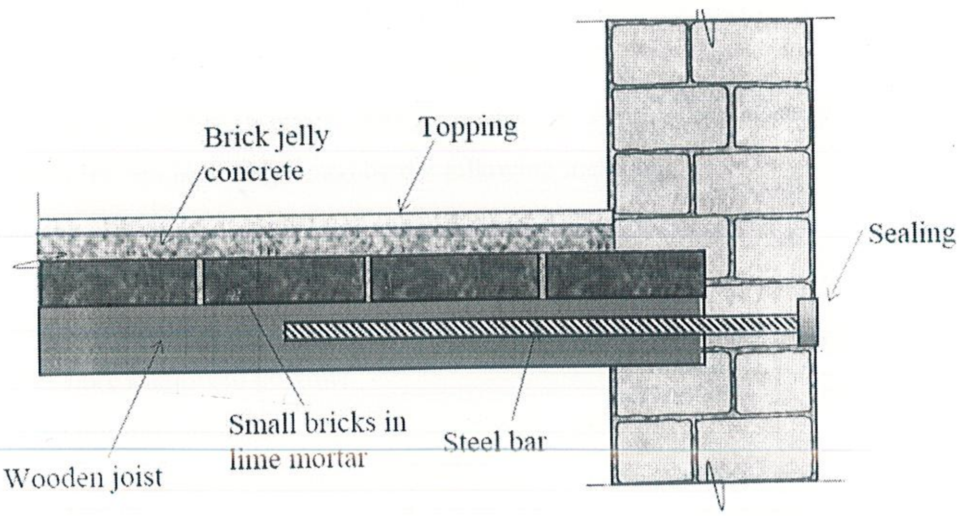
5.2.1 Madras Terrace Slab

Madras terrace slab exists in old masonry buildings as roof or upstairs floors. It is generally

constructed of wooden joists spanning between the walls. Small size bricks are laid across the
joists in a brick-on-edge fashion and are then topped with a layer of lime or cement mortar. Brick jelly concrete and topping (tiles or floor finish) are laid subsequently. In order to improve the diaphragm action, the pinning technique can be adopted as shown in Figure 22. The steel bars (pins) ensure integration of the walls with the roof (or floor) for the transfer of seismic load.



a) Joists parallel to wall



b) Joist perpendicular to wall

Figure 22 Pinning technique for Madras terrace slab

5.2.2 Jack Arch Roof

Jack arch roofs are common in old masonry buildings for spanning larger distance between walls. Tie rods can be provided between the springing of the arches (Figure 23). This will relieve the walls from the thrust of the arches and the load transferred to the walls will be vertical.

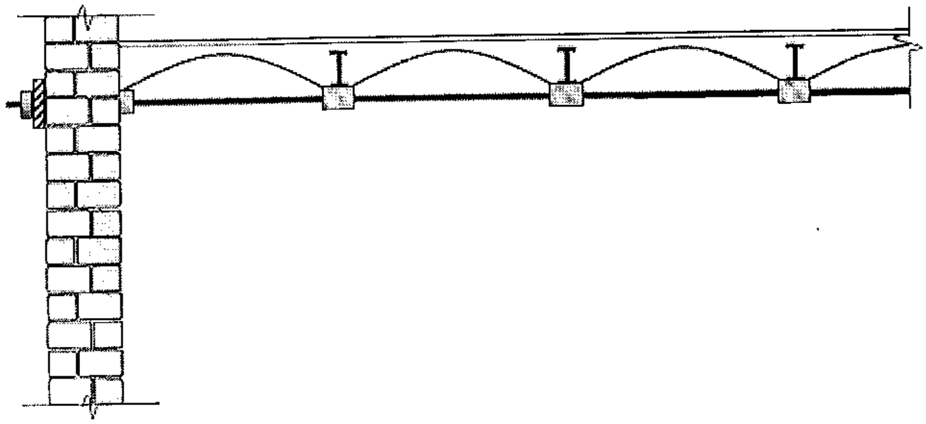


Figure 23 Strengthening of jack arch roof by ties

5.3 STRENGTHENING OF WALLS

The walls support the roof and upstairs floor, as well as provide resistance to lateral load. The walls can be strengthened by the following methods.

(a) Grouting

(b) External reinforcement

(c) Use of steel plates

(d) Use of fibre reinforced polymer

(e) Internal reinforcement.

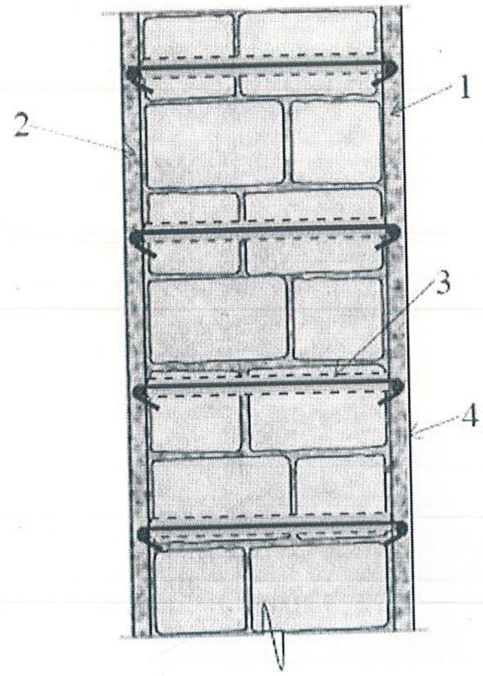
5.3.1 External Reinforcement

An external reinforcement overlay is an effective strengthening technique for existing masonry

walls. The overlay can be done by one of the following methods.

1. Ferro-cement with wire mesh
2. Reinforcement mat with shotcrete

In ferro-cement strengthening, first the plaster is removed and mesh reinforcement (welded wire fabric with a mesh size of 50 mm × 50 mm) is placed on one or both sides of the wall (Figure 24). The mesh reinforcement is tied in place by steel wires at 500 mm to 700 mm interval and the holes are grouted. Finally, a 25 to 40 mm thick layer of micro-concrete or plaster is applied on the reinforcement. The sandwiched wall is expected to behave better during an earthquake (IS 13935: 1993).



1 Wire mesh on front face
2 Wire mesh on back face
3 Clamps
4 Ferro-cement plaster

Figure 24 Strengthening of wall with ferro-cement

For substantial strengthening, a reinforcement mat can be attached to the wall with dowels. The vertical bars are anchored in the foundation. The reinforcement can be designed for adequate in-plane shear capacity and out-of-plane bending capacity of the wall. Shotcrete can be applied over the reinforcement mat.

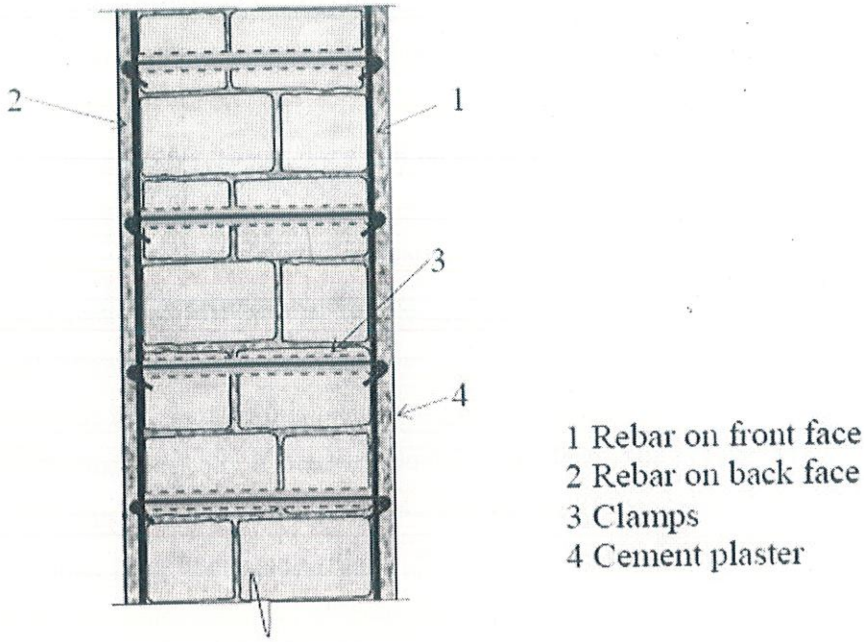


Figure 25 Strengthening of wall with reinforcement mat

5.3.2 Use of Steel Plates

Steel plates or angles can be used to strengthen masonry walls. A typical strengthening strategy is shown in Figure 26.

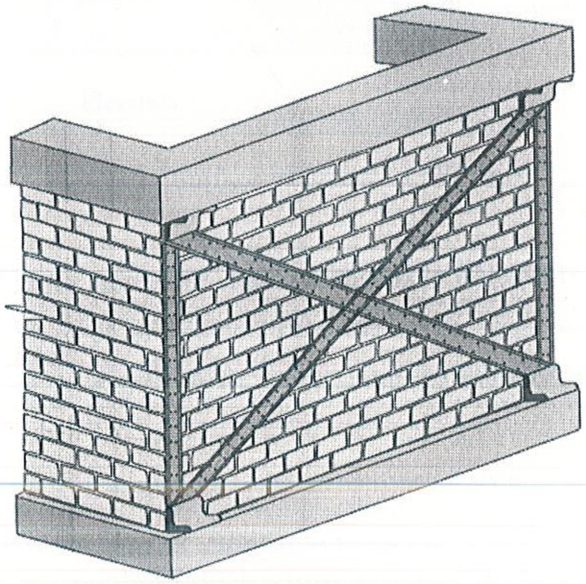


Figure 26 Strengthening of wall with steel plates

5.3.3 Use of Fibre Reinforced Polymer

Fibre reinforced polymer (FRP) composites are tailor-made, flexible, easy to apply and can be

made architecturally pleasing. Hence, they can be extensively used in retrofit. Three types of

Strengthening techniques namely, surface mounting of FRP bars, surface mounting of FRP strips and overlay of FRP wraps, can be applied to enhance the out-of-plane bending strength of a wall.

Surface mounting of FRP bars In this technique grooves are cut through mortar bed joints horizontally and vertically if needed, about 25 mm deep. The grooves are half filled with epoxy adhesive. Small diameter (about 6 mm) FRP bars are inserted and covered with another layer of adhesive (Figure 27).

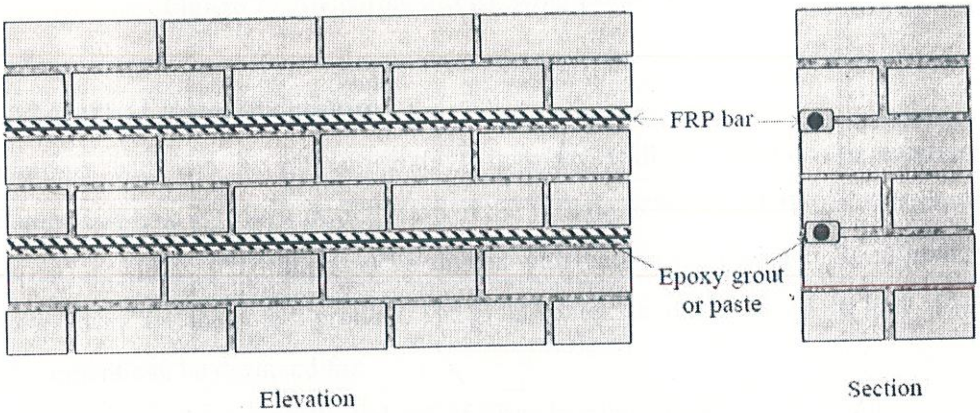


Figure 27 Surface mounting of FRP bars

Surface mounting of FRP strips FRP strips are applied to walls vertically or diagonally to improve their out-of-plane bending capacities. The diagonal strip application enhances the in-plane shear capacity by acting similar to a tension chord of a diagonal brace.

Overlay of FRP wraps This technique involves applying a layer of epoxy to the surface of the wall, impregnating the FRP wrap with epoxy, placing the overlay on the wall surface, and finally finishing with another layer of epoxy. The bond is a key factor that determines the success of an FRP overlay.

An undesirable mode of failure is peeling off due to insufficient anchorage. Figure 28 shows a typical anchorage for an FRP wrap by embedded FRP bars.

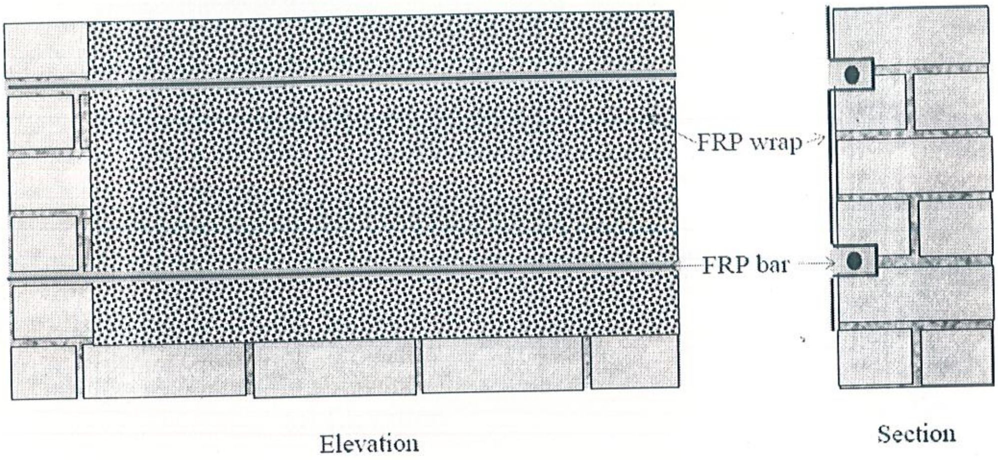


Figure 27 Anchoring of FRP wrap using FRP bars

5.3.4 Internal Reinforcement

Reinforcing bars can be placed inside a masonry wall to maintain it's exterior appearance. A hole is drilled from the top of the wall up to the foundation. For hollow block masonry units, the drilling can be aligned with the space in the units. Reinforcing bars are placed and the hole is grouted. The grout covers the voids around the hole. The reinforcement can be designed for

adequate in-plane shear capacity and out-of-plane bending capacity of the wall.

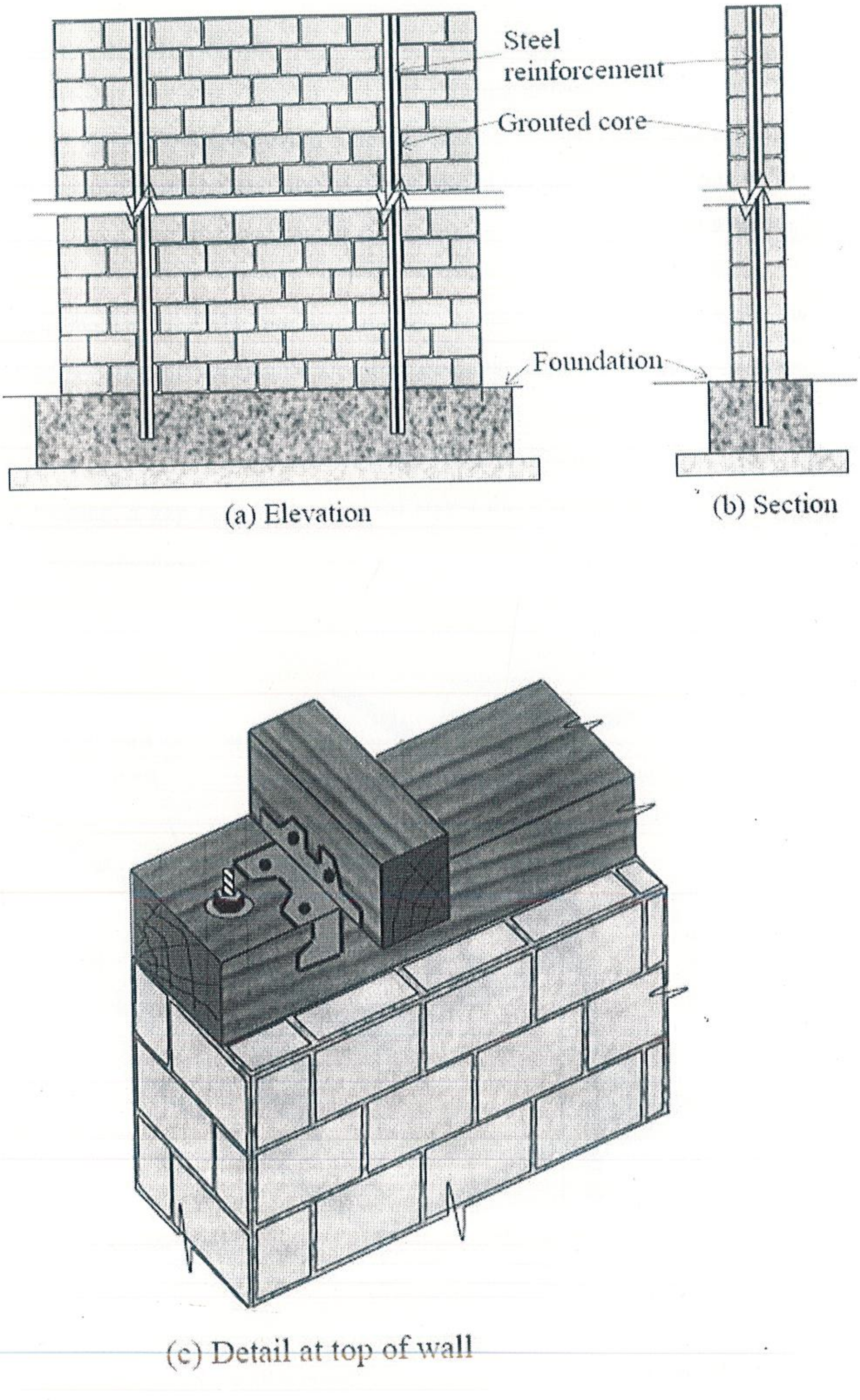


Figure 29 Strengthening of wall with internal reinforcement

5.3.5 Anchoring the Walls

Anchoring a wall to the roof, floors and other walls enhances the box action. The various types of wall connections in a multi-storeyed masonry building are shown in Figure 30. To ensure the lateral support of the wall at the top, the anchorage to the roof is essential. The schemes shown under strengthening of Madras terrace slab provides anchorage to the walls. A few other schemes of anchorage are shown here.

The anchors can be external or internal. Internal anchors can be used in situations where external anchors are not acceptable for either aesthetic or functional reasons. Figure 31 shows the use of external anchors such as steel angles. Parapet walls collapse during earthquake if they are not anchored properly. For a partition wall that is not designed for load bearing, a gap is to be maintained above the wall and slotted angles can be provided for anchorage.

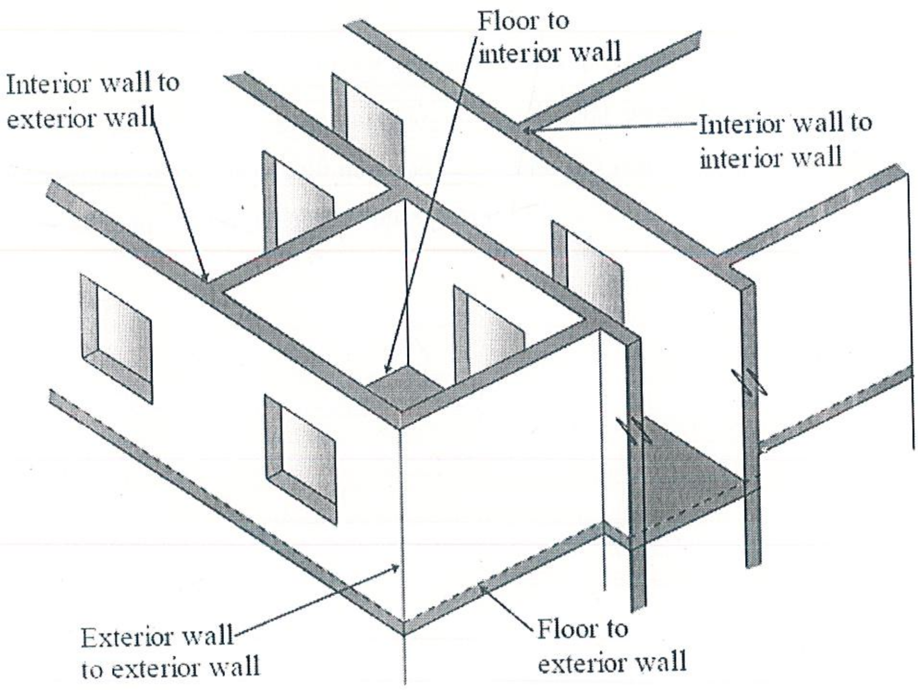


Figure 30 Various wall connections in a multi-storeyed masonry building

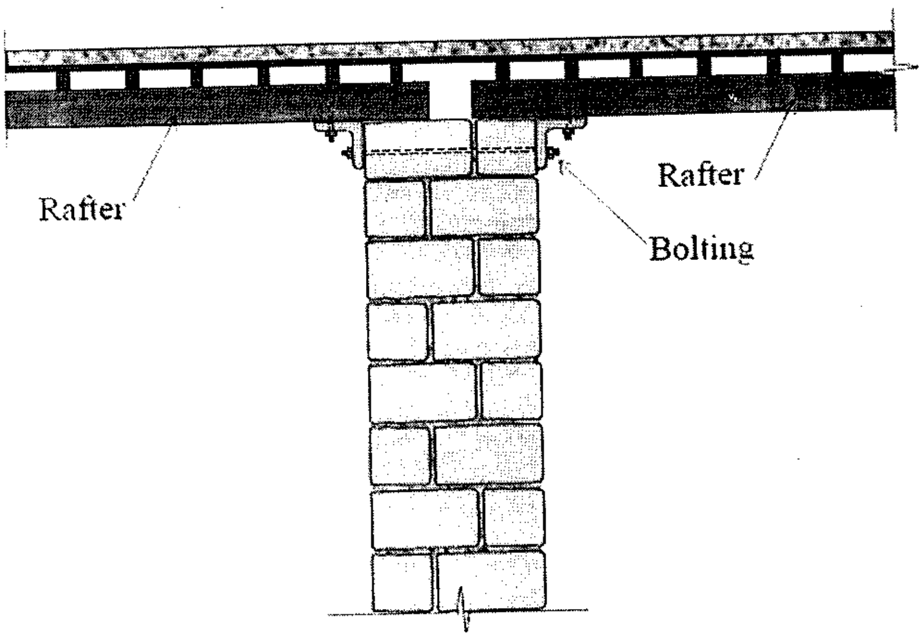


Figure 31 Anchoring of walls.

The internal anchoring can be done by dowel bars at the corners and junctions of the walls. An example of stitching two existing perpendicular walls. Else, dowels can be inserted at regular intervals of 500 mm and taken into the walls to sufficient length so as to develop the full bond strength (Figure 32).

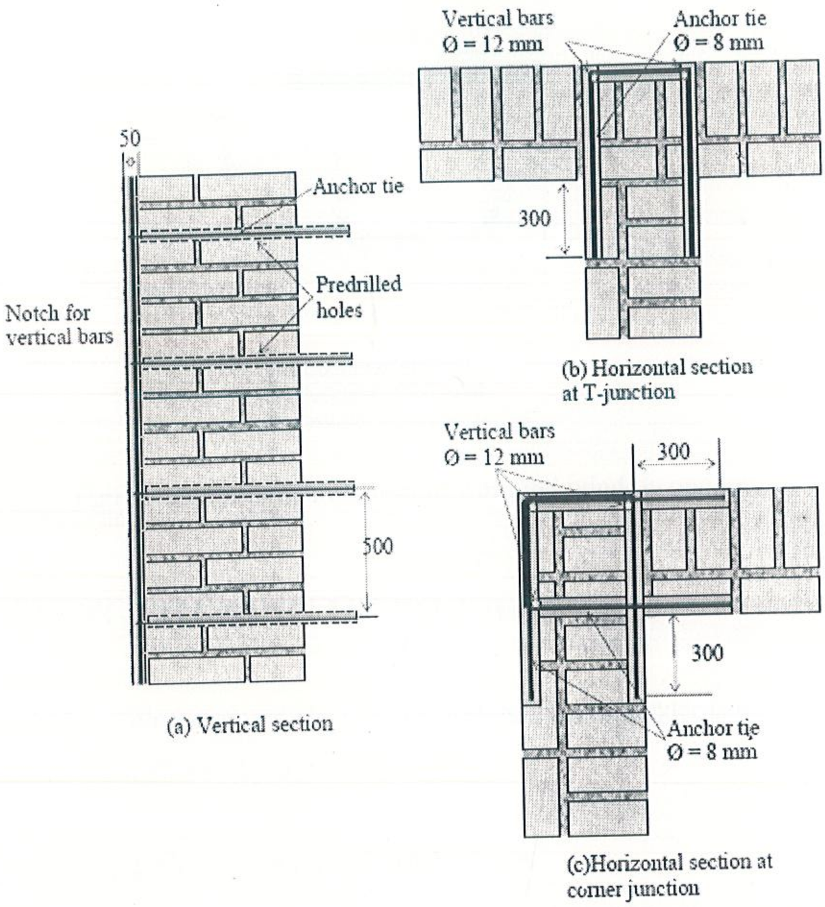


Figure 32 Insertion of dowel bars at corners and T-junctions (dimensions in mm)

5.3.6 Reinforcing the Openings

When the openings do not comply with the requirements of IS 4326: 1993, they can be either closed or reinforcement bars can be provided in the jambs (Figure 33).

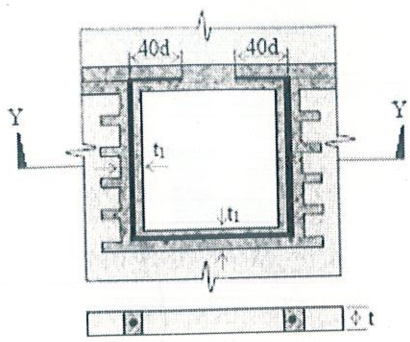


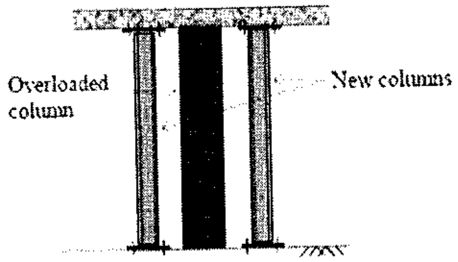
Figure 33 Strengthening masonry around window opening

5.4 STRENGTHENING OF PILLARS

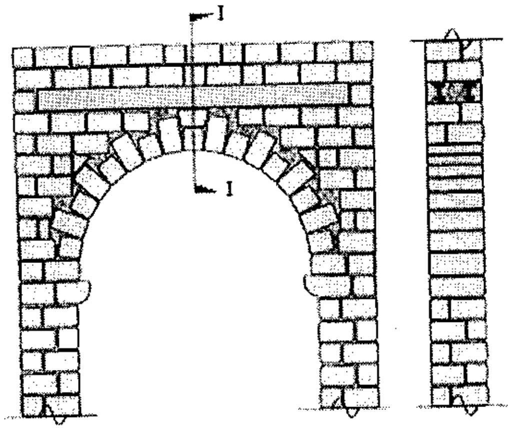
In absence of any reinforcement, the masonry pillars are weak under lateral forces. Such pillars can be strengthened by concrete jacketing.

5.5 STRESS RELIEVING TECHNIQUES

This technique involves insertion of a new structural member in order to relieve an either overloaded or damaged component. A brick pillar or pier which is overloaded or damaged can be relieved by constructing columns on either side of the damaged pier as shown in Figure 34a. A weak brick arch can be relieved by a lintel consisting of steel beams, inserted just above the arch (Figure 34b). The piers below the arch are relieved of the lateral thrust from the arch.



(a) Insertion of new columns



(b) Insertion of lintel

Section I-I

Figure 34 Stress relieving by insertion of new members

Chapter 6: Retrofit of reinforced concrete Building

6.1 Global Retrofit Strategies

When a building is found to be severely deficient for the design seismic forces, the first step in seismic retrofit is to strengthen and stiffen the structure by providing additional lateral load resisting elements. Additions of infill walls, shear walls or braces are grouped under global retrofit strategies. A reduction of an irregularity or of the mass of a building can also be considered to be global retrofit strategies. The analysis of a building with a trial retrofit strategy should incorporate the modelling of the additional stiffening members.

Addition of Infill Walls The lateral stiffness of a storey increases with infill walls. Addition of infill walls in the ground storey is a viable option to retrofit buildings with open ground storeys (Fig. 35). Due to the 'strut action' of the infilled walls, the flexural and shear forces and the ductility demand on the ground storey columns are substantially reduced. Of course, infill walls do not increase the ductility of the overall response of the building.

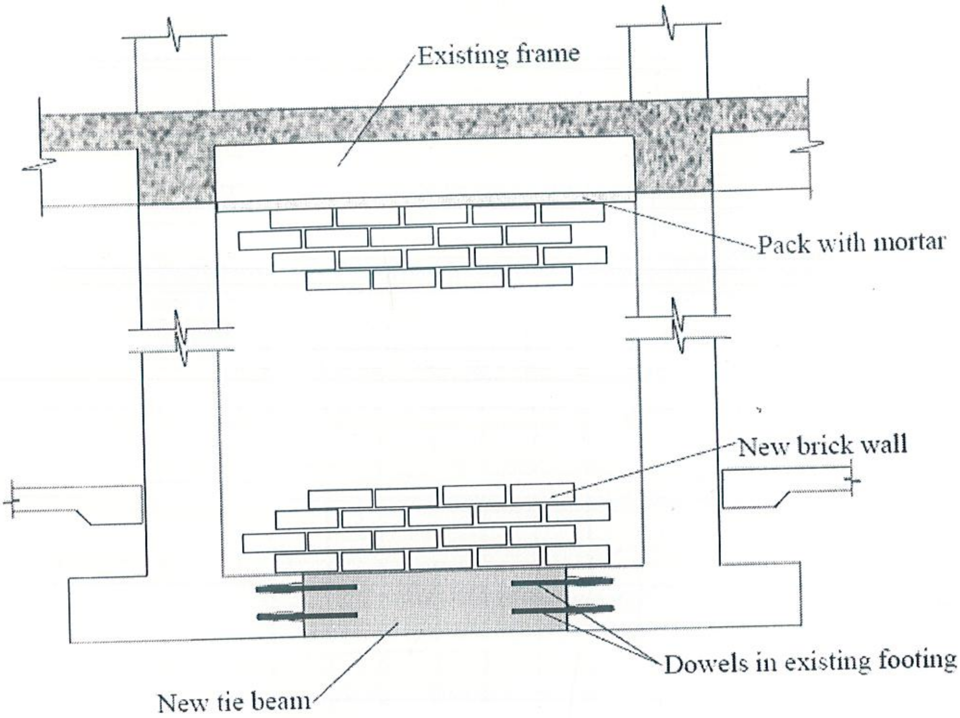


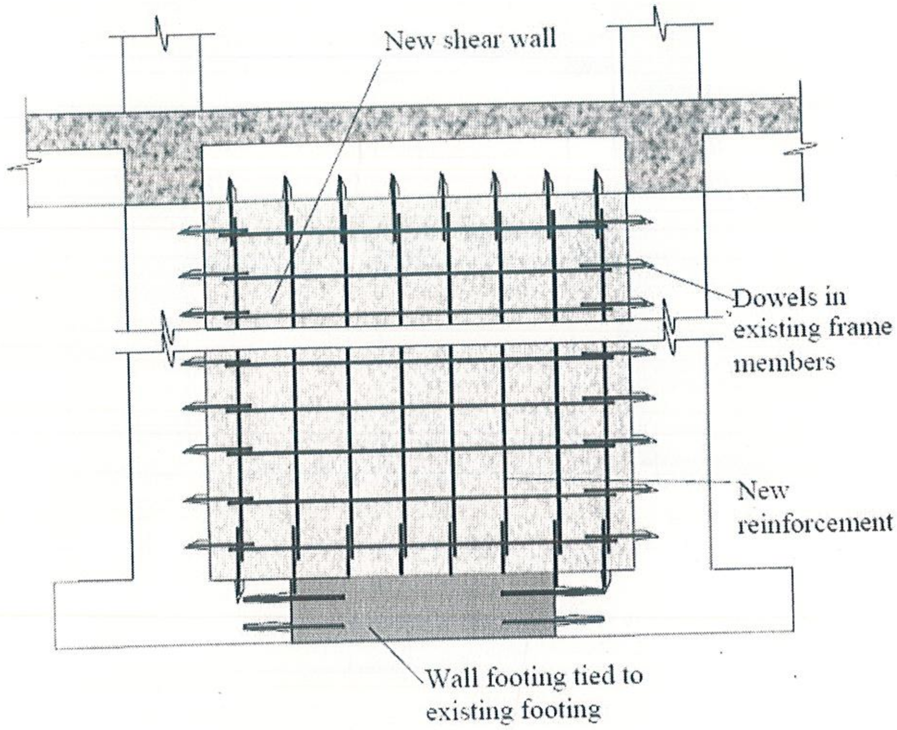
Figure 35 Addition of a masonry infill wall

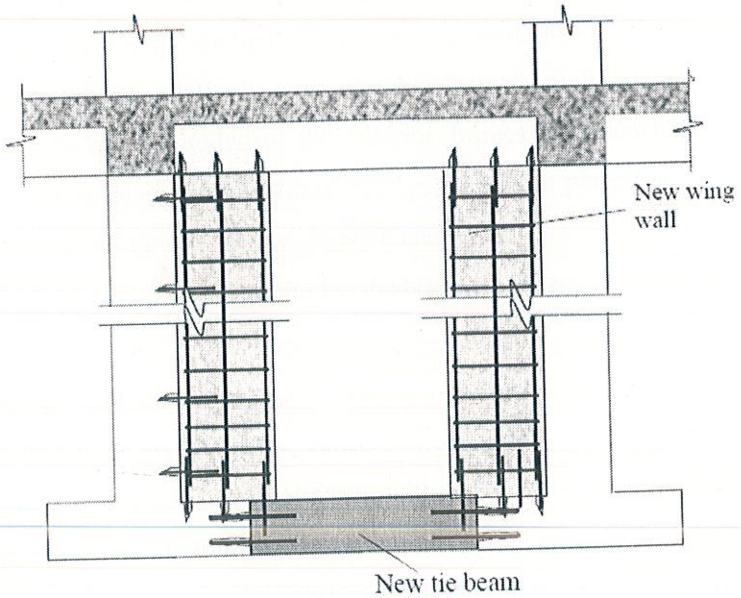
Addition of Shear Walls or Wing Walls or Buttress Walls Shear walls, wing walls or buttress are added to increase lateral strength and stiffness of a building. The shear walls are effective in buildings with flat labs or flat plates. Usually the shear walls are placed within bounding columns (Fig. 36a), whereas wing walls are placed adjacent to columns (Fig. 36b). The buttress walls are placed on the exterior sides of an existing frame (Fig. 36c). The critical design issues involved in the addition of such a wall are as follows.

a) To integrate the wall to the building for transferring of lateral forces.

b) To design the foundations for the new wall.

The disadvantage is that if only one or two walls are introduced, the increase in lateral resistance is concentrated near the new walls. Hence, it is preferred to have distributed and symmetrically placed walls. The shift of the centre of rigidity should not be detrimental. For a buttress wall, the new foundation should be adequate to resist the overturning moment due to the lateral seismic forces without rocking or uplift. The stabilising moment is only due to the self weight of the wall. This can be low as compared to the overturning moment.





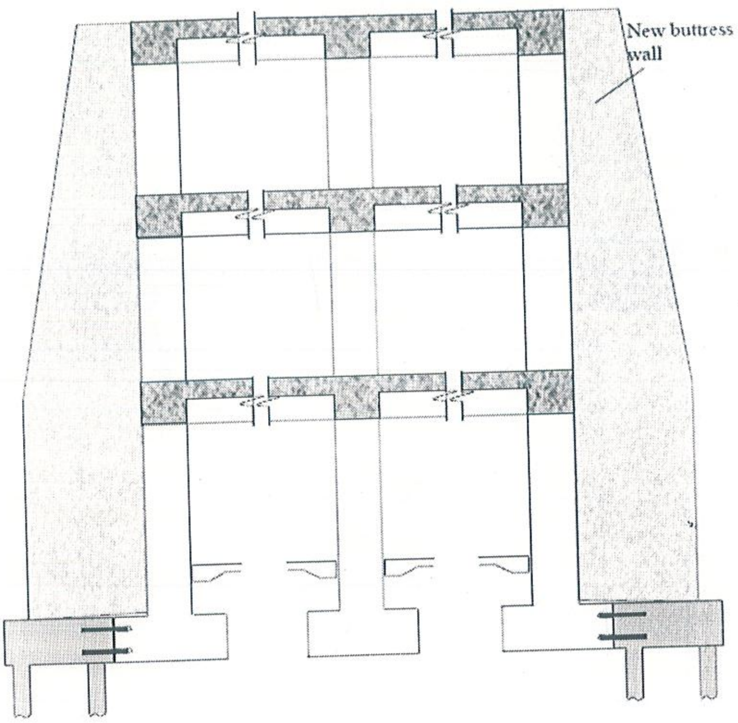


Figure 36 a) Addition of a shear wall (Courtesy: FEMA 172), b) Addition of wing walls, c) Addition of buttress walls

Addition of Steel Braces

A steel bracing system can be inserted in a frame to provide lateral stiffness, strength, ductility, hysteretic energy dissipation, or any combination of these (Fig. 37). The braces are effective for relatively more flexible frames, such as those without infill walls. The braces can be added at the exterior frames with least dişruption of the building use. For an open ground storey, the braces can be placed in appropriate bays while maintaining the functional use. Passive energy

dissipation devices may be incorporated in the braces to enhance the seismic absorption.

The

types of bracing, analysis and design of braces. The connection between the braces and the existing frames is an important consideration of this strategy. One technique of installing braces is to provide a steel frame within the designated RC frame. The steel frame is attached to the RC frame by installing headed anchors in the later (FIB Bulletin 24, 2003). Else, the braces can be connected directly to the RC frame. Here, since the braces are connected to the frames at the beam-column joints, the forces resisted by the braces are transferred to the joints in the form of axial forces, both in compression and tension. While the addition of compressive forces may be tolerated, the resulting tensile forces are of concern.

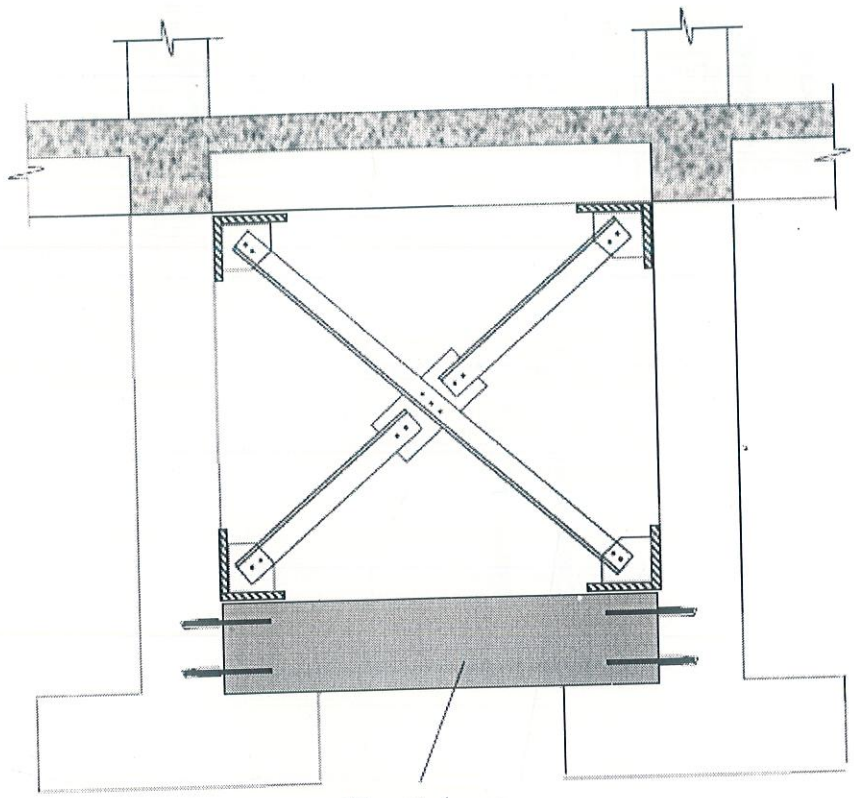


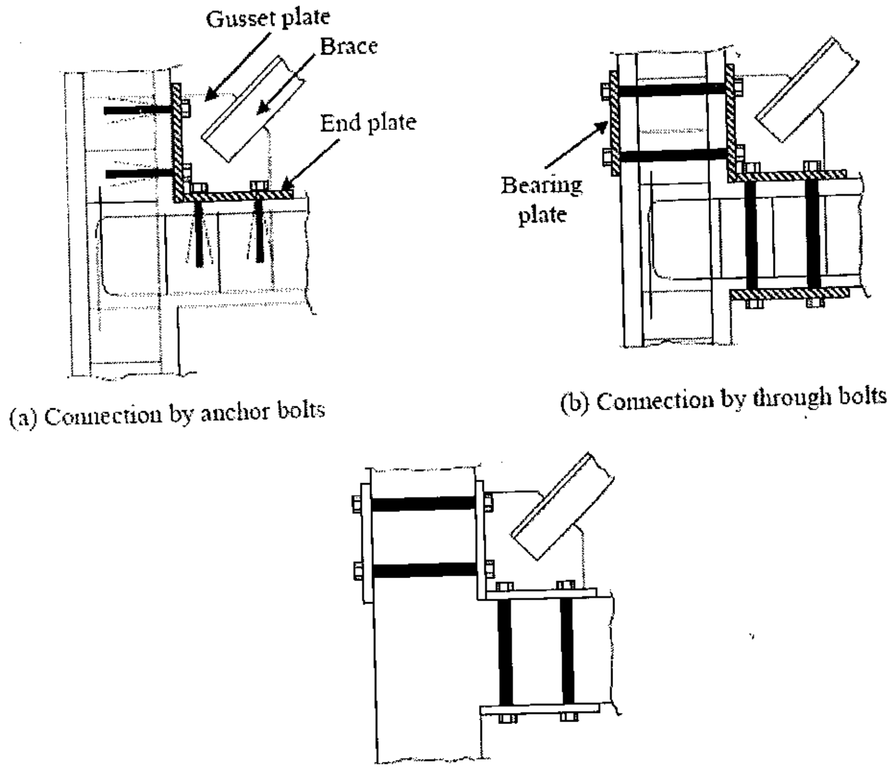
Figure 37 Addition of steel braces

A few types of connections are shown in Figure 38.

Type I (Figure 38a): The force in brace is transferred to the frame through the gusset plate, end plates and anchor inserts.

Type II (Figure 38b): This type of connection is similar to Type I, except for the method of anchoring the end plates at the joint. An end plate is connected using through bolts which are anchored at the opposite face to a bearing plate. In this type, the widths of end plate and bearing plate are equal to or less than the width of beam or column.

Type III (Figure 38c): This type of connection is similar to Type II, except for the location of bolts. In this type, the end plate and bearing plate project beyond the width of the beam and column. Since the bolts are outside the members, drilling of holes through the members is avoided.



(a) Connection by anchor bolts

(b) Connection by through bolts

(c) Connection by bolts placed outside the members

Figure 38 Types of connection of braces to an RC frame

Addition of Frames

A new frame can be introduced to increase the lateral strength and stiffness of a building. Similar to a new wall, integrating a new frame to the building and providing foundations are critical design issues.

Reduction of Irregularities

The plan and vertical irregularities are common causes of undesirable performance of a building under an earthquake. Reduction of the irregularities may be sufficient to reduce force and deformation demands in the members to acceptable levels. Addition of infill walls, shear walls or braces can alleviate the deficiency of soft and/or weak storeys. Discontinuous components of the lateral load resisting system such as floating columns can be extended up to the foundation. In this case, the supporting cantilever beams have to be checked for the sagging moment. The infill walls of partial height can be extended to reduce the vulnerability of short and stiff (*captive*) columns.

Torsional irregularities can be corrected by the addition of frames or shear walls to balance the distribution of stiffness and mass. An eccentric mass due to an overhead water tank can be relocated. Seismic joints can be introduced to transform a single irregular building into multiple regular structures. Although partial demolition can have impact on the appearance and utility of the building, it can be an effective measure to reduce irregularity.

Reduction of Mass

A reduction in mass of the building results in reduction of the lateral forces. Hence, this option can be considered instead of structural strengthening. The mass can be reduced through demolition of unaccounted additional storeys, replacement of heavy cladding or removal of heavy storage and equipment loads, or change in the use of the building.

Energy Dissipation Devices and Base Isolation

Most energy dissipation devices not only supplement damping, but also provide additional lateral stiffness to a building. Base isolation devices reduce the structural force entering a building by elongating the time period of the structure and thus decreasing the base shear force.

6.2 Local Retrofit Strategies

Local retrofit strategies pertain to retrofitting of columns, beams, joints, slabs, walls and foundations. The local retrofit strategies are categorised according to the retrofitted elements. The analysis of a building with a trial local retrofit strategy should incorporate the modelling of the retrofitted elements.

The local retrofit strategies fall under three different types: concrete jacketing, steel jacketing (or use of steel plates) and fibre-reinforced polymer (FRP) sheet wrapping. In this chapter the first two types are discussed. Out of the first two types, each one has its merits and demerits.

Column Retrofitting

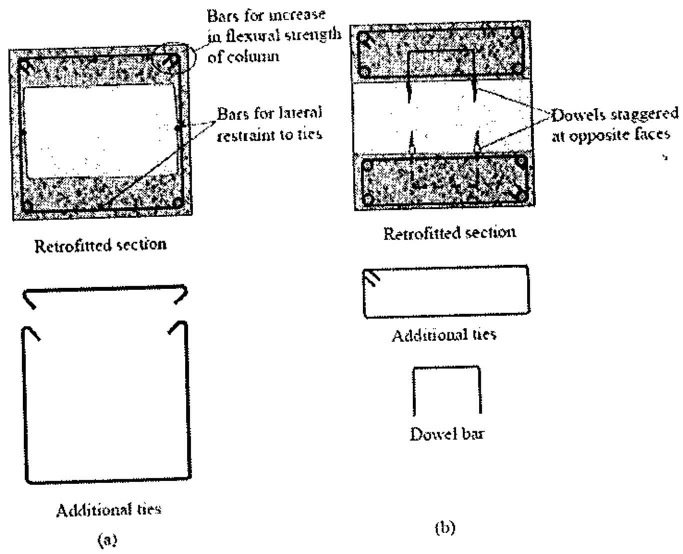
The retrofitting of deficient columns is essential to avoid collapse of a storey. Hence, it is more important than the retrofitting of beams. The columns are retrofitted to increase their flexural and shear strengths, to increase the deformation capacity near the beam-column joints and to strengthen the regions of faulty splicing of longitudinal bars. The columns in an open ground storey or next to openings should be prioritised for retrofitting. The retrofitting strategy is based on the "strong column weak beam" principle of seismic design. During retrofitting, it is preferred to relieve the columns of the existing gravity loads as much as possible, by propping the supported beams. The individual retrofit strategies are described next.

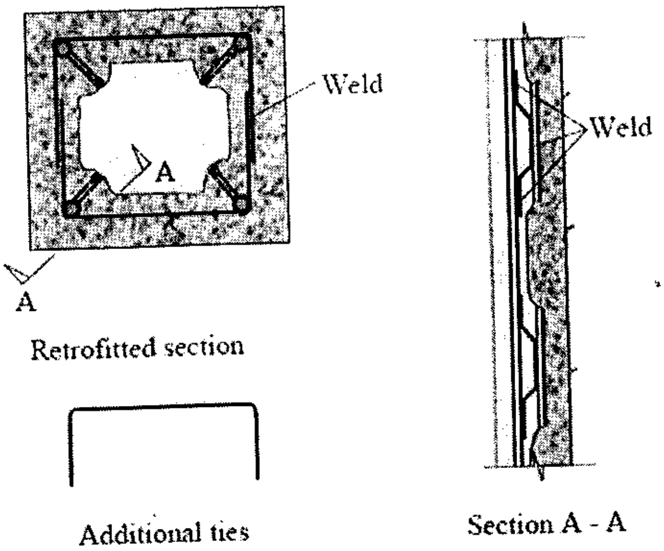
1. Concrete Jacketing

Concrete jacketing involves addition of a layer of concrete, longitudinal bars and closely spaced ties. The jacket increases both the flexural strength and shear strength of the column. Increase in ductility has been observed (Rodriguez and Park, 1994). If the thickness of the jacket is small there is no appreciable increase in stiffness. Circular jackets of ferro-cement have been found to be effective in enhancing the ductility. The disadvantage of concrete jacketing is the increase in the size of the column. The placement of ties at the beam-column joints is difficult, if not impossible (Stoppenhagen et al., 1995). Drilling holes in the existing beams damages the concrete, especially if the concrete is of poor quality. Although there are disadvantages, the use of concrete jacket is relatively cheap. It is important to note that with the increase in flexural capacity, the shear demand (based on flexural capacity) also increases. The additional ties are provided to meet the shear demand.

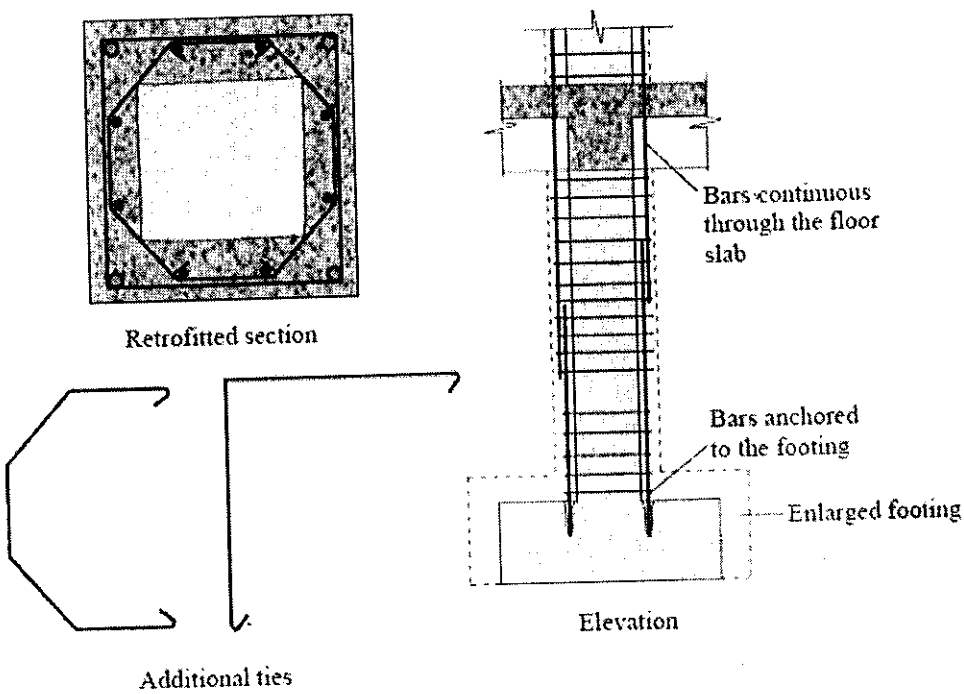
There are several techniques of providing a concrete jacket (Figure 39). A technique is selected based on the dimensions and required increase in the strength of the existing column, available space of placing the longitudinal bars. To increase the flexural strength, the additional longitudinal bars need to be anchored to the foundation and should be continuous through the

floor slab. Usually the required bars are placed at the corners so as to avoid intercepting the beams which are framing in to the column. In addition, longitudinal bars may be placed along the sides of the column which are not continuous through the floor (Figure 39a). These bars provide lateral restraint to the new ties. A tie cannot be made of a single bar due to the obstruction in placement. It can be constructed of two bars properly anchored to the new longitudinal bars. It is preferred to have 135° hooks with adequate extension at the ends of the bars. An alternative arrangement to the drilling of holes near the joint, by confining the joint with steel angles has been tried by researchers. For an interior joint if there are beams framing in all the four sides, then the confining action of the beams is dependable.





(c)



(d)

Figure 39 Techniques for concrete jacketing of columns

Since the thickness of the jacket is small, casting micro-concrete or the use of shotcrete are preferred to conventional concrete. To ensure the composite action of the existing and the new concrete, the options for preparing the surface of the existing concrete are hacking by chisel, roughening by wire buff or using bonding chemicals. Slant shear tests have shown that the preparation of the surface is adequate to develop the bond between the existing and new concrete.

Inserting dowels in the existing column at a spacing of 300 to 500 mm enhances the composite

action (Figure 39b). The dowels are attached by epoxy pumped in to the drilled holes. The length of insertion depends on the type of epoxy and the strength of the existing concrete.

Based on the information of the epoxy from the manufacturer's catalogue and the evaluated concrete strength, the length of insertion is determined. Of course drilling holes damages the existing column. Moreover, it has been observed that the presence of dowels increases the disintegration of the concrete jacket during the formation of a plastic hinge under dynamic loads. If the jacket is all around the existing column, then the dowels can be avoided. The shrinkage of the new concrete generates friction with the existing concrete. If the jacket is only partially around the existing column, the existing bars can be exposed at locations. The new bars can be welded to the existing bars using Z- or U- shaped bent bars (Figure 39c). Of course it has been observed that welding of two different grades of steel increases corrosion.

The minimum specifications for the concrete jacket are as follows (Draft Code).

a) The strengths of the new materials must be equal to or greater than those of the existing column. The compressive strength of concrete in the jacket should be at least 5 MPa greater than that of the existing concrete.

b) For columns where extra longitudinal bars are not required for additional flexural capacity, a minimum of 12 mm diameter bars in the four corners and ties of 8 mm diameter should be provided.

c) The minimum thickness of the jacket should be 100 mm.

d) The minimum diameter of the ties should be 8 mm and should not be less than ⅓ of the diameter of the longitudinal bars. The angle of bent of the end of the ties should be 135°. e) The centre-to-centre spacing of the ties should not exceed 200 mm. Preferably, the spacing should not exceed the thickness of the jacket. Close to the beam-column joints, for a height of ¼ the clear height of the column, the spacing should not exceed 100 mm.

A simplified analysis for the flexural strength of a retrofitted column can be done by the traditional method of interaction curves (SP 16: 1980, "Design Aids for Reinforced Concrete to IS 456: 1978, published by the Bureau of Indian Standards) assuming a composite section. The publication of the International Federation for Structural Concrete (FIB Bulletin 24, 2003)

recommends such an analysis. Even if the grade of concrete in the jacket is higher, it can be considered to be same as that of the existing section. Such an analysis assumes that there is perfect bond between the new and old concrete. The yield moment and the ultimate flexural capacity can be conservatively limited to 90% of the calculated values. The increase in shear capacity can be calculated based on the amount of additional ties. For the requirement of confinement, only the additional ties are to be considered.

2. Steel Jacketing

Steel jacketing refers to encasing the column with steel plates and filling the gap with non-shrink grout. The jacket is effective to remedy inadequate shear strength and provide passive confinement to the column. Lateral confining pressure is induced in the concrete as it expands

laterally. Since the plates cannot be anchored to the foundation and made continuous through the floor slab, steel jacketing is not used for enhancement of flexural strength. Also, the steel jacket is not designed to carry any axial load. If the shear capacity needs to be enhanced, the jacket is provided throughout the height of the column. A gap of about 25 to 50 mm is provided at the ends of the jacket so that the jacket does not carry any axial load. For enhancing the confinement of concrete and deformation capacity in the potential plastic hinge regions, the jacket is provided at the top and bottom of the column. Of course there is no significant increase in the stiffness of a jacketed column. Steel jacketing is also used to strengthen the region of faulty splicing of longitudinal bars. As a temporary measure after an earthquake, a steel jacket can be placed before an engineered scheme is implemented.

Circular jackets are more effective than rectangular jackets. A jacket is made up of two pieces of semi-circular steel plates which are welded at the site. A circular jacket can be considered equivalent to continuous hoop reinforcement. Of course circular jackets may not be suitable for columns in a building since the columns are mostly rectangular in cross-section. In a rectangular jacket, steel plates are welded to corner angles. Anchor bolts or through bolts may increase confinement but it involves drilling into the existing concrete. A simpler form of strengthening is to weld batten plates to the corner angles. This form is referred to as steel profile jacketing as opposed to the encasement provided by continuous plates. Figure 40 shows the different techniques of providing a steel jacket. The steel plates need protection against corrosion and fire.

The shear strength of the jacket (Vj) can be calculated by considering the jacket to act as a series of independent square ties of thickness and spacing tsj, where tsj is the thickness of the plates (Aboutaha et al., 1999). For rectangular columns,

$$V_j = A_{sj} \frac{f_{sj}\, d_{sj}}{s_{sj}}$$

Here, A_{sj} is the total area of the assumed square tie, $A_{sj} = 2tsj^2$, f_{sj} is the allowable stress of the jacket, d_{sj} is the depth of the jacket (can be equated to the transverse depth of the column) and s_{sj} is the spacing between the square ties, $s_{sj} = t_{sj}$. The allowable stress of the jacket can be assumed to be half of its 'yield' stress. The required thickness t_{sj} can be calculated from the required value of V_j.

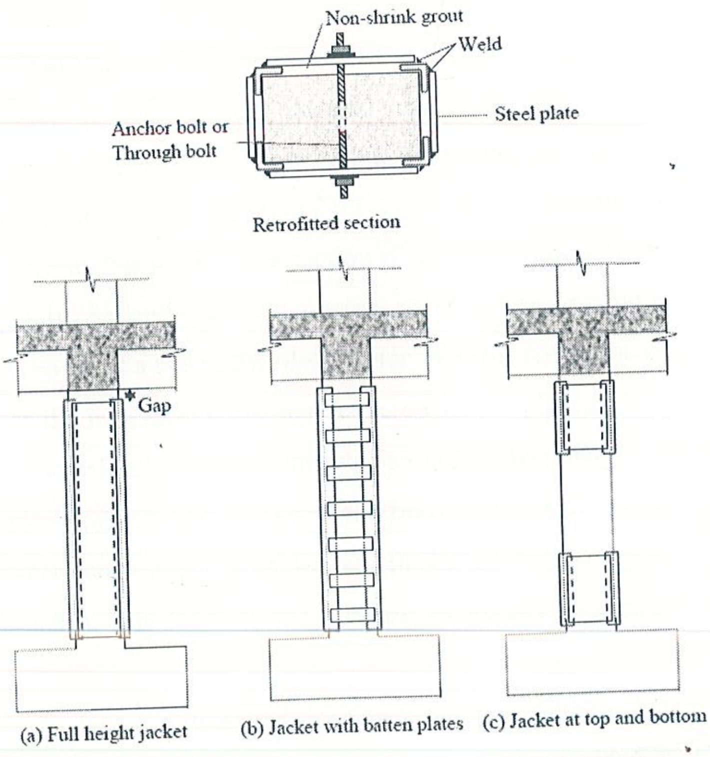


Figure 40 Techniques for steel jacketing of columns

3. Fibre Reinforced Polymer Sheet Wrapping

Fibre-reinforced polymer (FRP) has desirable physical properties like high tensile strength to weight ratio and corrosion resistance. FRP sheets are thin, light and flexible enough to be inserted behind pipes and other service ducts, thus facilitating installation. In retrofitting a column with FRP sheets, there is increase in ductility due to confinement without noticeable increase in the size. The main drawbacks of FRP are the high cost, brittle behaviour and inadequate fire resistance.

Beam Retrofitting

The beams are retrofitted to increase their positive flexural strength, shear strength and the deformation capacity near the beam-column joints. The lack of adequate bottom bars and their anchorage at the joints needs to be addressed. Usually the negative flexural capacity is not enhanced since the retrofitting should not make the beams stronger than the supporting columns.

Of course the strengthening of beams may involve the retrofitting of the supporting columns. The individual retrofit strategies are described next.

1. Concrete Jacketing

Concrete is added to increase the flexural and shear strengths of a beam. The strengthening involves the placement of longitudinal bars and closely spaced stirrups. There are disadvantages in this traditional retrofit strategy. First, the drilling of holes in the existing concrete can weaken the section if the width is small and the concrete is not of good quality. Second, the new concrete requires proper bonding to the existing concrete. In the soffit of a beam, the bleed water from the new concrete creates a weak cement paste at the interface. If the new concrete is not placed all around, restrained shrinkage at the interface induces tensile stress in the new concrete. Third, addition of concrete increases the size and weight of the beam. Instead of conventional concrete, fibre reinforced concrete can be used for retrofit. In

addition to strength, this leads to the increase of energy absorption capacity. It is important to

note that with the increase in flexural capacity, the shear demand (based on flexural capacity) also increases. Additional stirrups need to be provided to meet the shear demand. There are a few options for concrete jacketing (Figure 41). The difficulty lies in anchoring the new bars. A technique is selected based on the deficiency and the available space for placing the bars. The techniques given in IS 13935: 1993 involves drilling holes in the existing beam. But drilling holes for the stirrups at closing spacing damages the beam, especially if the concrete is of poor quality. The additional longitudinal bars should be continuous through the beam-column joints. The bars are placed at the corners so as to avoid intercepting the transverse beams. Additional longitudinal bars may be placed at the sides for checking temperature and shrinkage cracks. These bars need not be continuous through the joints.

If the beam supports a masonry wall, then closed stirrups may not be possible. In such a situation the ends of U-stirrups may be threaded and anchored by nuts at the top surface of the

slab (Figure 41a). If there is no wall above the beam or the beam supports a removable partition wall, a pair of U-stirrups can be welded to form a closed stirrup (Figure 41b). In the technique shown in Figure 41c, the cover concrete is removed and the new stirrups are welded to the existing stirrups. The technique shown in Figure 41d may be adequate for strengthening for gravity loads. But unless the slab is thick, the stirrups will not be properly anchored to sustain the dynamic seismic forces.

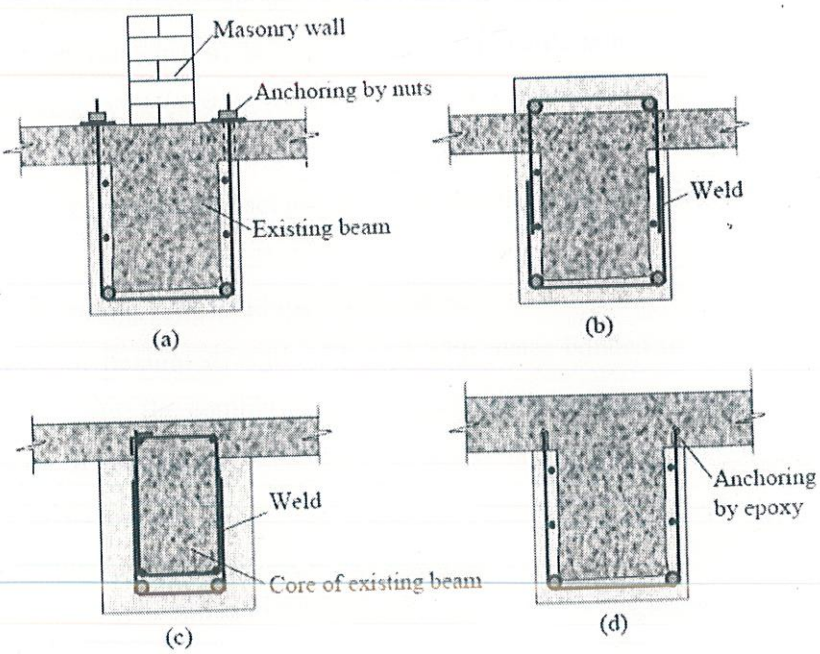


Figure 41 Techniques for concrete jacketing of beams

Similar to concrete jacketing of columns, the use of micro-concrete or shotcrete is preferred to conventional concrete. The surface of the existing concrete is to be prepared to ensure the composite action of the existing and the new concrete.

A simplified analysis for the flexural strength of a retrofitted section can be performed by the traditional method of beam analysis. Even if the grade of concrete in the jacket is higher, it can be considered to be same as that of the existing section. Such an analysis assumes a perfect bond between the new and existing concrete. For a rigorous analysis considering different grades of concrete, a layered approach is required.

2. Bonding Steel Plates

The technique of bonding mild steel plates to beams is used to improve their flexural and shear strengths. The addition of steel plate is rapid to apply, does not reduce the storey clear height significantly and can be applied while the building is in use. The plates are attached to the tension face of a beam to increase the flexural strength, whereas they are attached to the side face of a beam to increase the shear strength.

The plates can be attached by adhesives or bolts. The plates attached by adhesives are prone to premature debonding and hence, the beam tends to have a brittle failure. A beam with plates attached by bolts tends to have a ductile failure. But the use of bolts involves drilling in the existing concrete, which may weaken the section if the width is less or if the concrete is not of good quality. Any exposed steel plate is prone to corrosion and fire. Hence, adequate protection is required for beams retrofitted with steel plates.

The analysis for flexural strength of beams with plates bonded to the tension face is based on satisfying the equilibrium and compatibility equations and the constitutive relationships. It models the adhesive failure due to the stress concentration at the location of plate cut-off. The essential features of the model are as follows.

1. The steel plate is assumed to act integrally with the concrete beam and conventional beam theory is used to determine the flexural capacity.

2. The normal and shear stresses at the interface of concrete and the plate at the location of plate cut-off are calculated to check the failure of the adhesive.

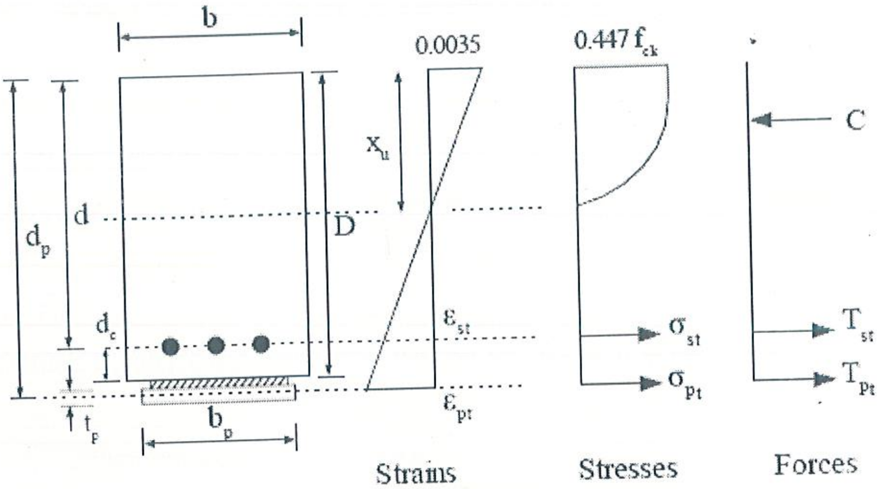


Figure 42 Strain and stress diagrams and internal forces of a tension-face plated beam

Since retrofitting is required mostly near the beam-column joints, the equations for a rectangular section are applicable. Of course a similar set of equations can be derived for a flanged section when the span region of a beam requires strengthening. The width of the plate

(*bp*) is limited to the width of the beam (b). The thickness of the plate (*tp*) is limited such that the section does not become over-reinforced. The adhesive failure is checked by the following

equation.

$$\tau_0 + \sigma_0 \tan 28^\circ \leq c_{all}$$

Here, τ0 and σ0 are the shear and normal stresses, respectively, at the interface of concrete and the plate at the location of plate cut-off. The allowable coefficient of cohesion for the adhesive is denoted as *call*. The expressions of *τ0* and *σ0* are based on the shear force at the location of plate cut-off, elastic modulus of the plate and the elastic and shear moduli of the adhesive (Ziraba et al., 1994).

The beams strengthened by plates bonded to the side face are subjected to the following modes of failure: fracture of bolts, buckling of plates and splitting of concrete. Barnes et al. (2001) derived expressions for the enhancement of shear capacity of such beams.

3. FRP Wrapping

Like steel plates, FRP laminates are attached to beams to increase their flexural and shear

strengths.

Beam-Column Joint Retrofitting

The retrofitting of a beam-column joint aims to increase its shear capacity and effective confinement. Since access to a joint is not readily available, retrofitting a joint is difficult. The

strengthening is carried out along with that for the adjacent columns and beams. The retrofitting

should aim at the following improvements.

a) To prevent the pullout of any discontinuous bottom bars in the beams.

b) To reduce the deterioration of the joint under cyclic loading.

τ 0 +σ 0 tan 28 ≤ *call* □

The methods of retrofit that have been investigated are as follows.

1. Concrete Jacketing

A joint can be strengthened by placing ties through drilled holes in the adjacent beams (Stoppenhagen et al., 1995). To avoid drilling holes in the beams, a steel cage can be fabricated

around the additional vertical bars in the column to provide confinement (Alcocer and Jirsa, 1993). A simpler option is a concrete fillet at the joint to shift the potential hinge region of the

beam away from the column face.

2. Steel Jacketing

If space is available, steel jacketing can be used to enhance the performance of joints (Ghobarah et al., 1997). A simpler option is to attach plates in the form of brackets at the soffits of the beams.

3. FRP Wrapping

In the use of FRP sheets to strengthen the joints, the considerations are number of layers, orientation and anchorage of the FRP sheets and the preparation of surface of the existing concrete.

Wall Retrofitting

A concrete shear wall can be retrofitted by adding new concrete with adequate boundary members (Seth, 2002). The new concrete can be added by shotcrete. For the composite action,

dowels need to be provided between the existing and new concrete (Figure 43). The foundation of the wall is to be sufficiently strengthened to resist the overturning moment without rocking or uplift.

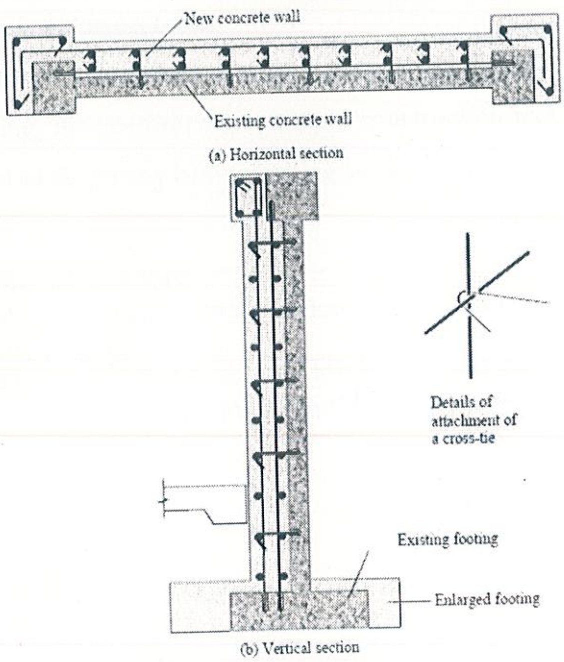


Figure 43 Strengthening a wall using concrete

A cross-tie connecting the layers of reinforcement on the two faces of the new wall should be hooked as shown in Figure 39. It should pass through diagonally opposite quadrants formed by the vertical and horizontal bars for the masonry infill walls, whose failure can cause injury, additional concrete with wire mesh or FRP sheets can be used to strengthen for out-of-plane bending. Steel braces fitted to the RC frame have been used to check the out-of-plane bending of walls. Steel strips bolted to the walls have been investigated.

Conclusion:

- "Seismic evaluation on existing buildings" tells us about that building will sustain a real earthquake scenario or not.
- It's economic to retrofit the building rather than any other alternate.
- As this region of himachal pradesh lies in high risk zone so it's better to do seismic study.
- General observation:
    - Building's in solan- Shimla region are not designed or prepared for earthquake loads.
    - Most of the buildings in Shimla are constructed on higher inclined angle which is not acceptable.
    - Construction in nearby area of college is mostly masonry. Single storey building, no reinforcement, simple construction techniques. But as the do not undergo any heavy loading so they sustain easily.
- Hill Point
    - It is framed structure.
    - Building designed contain different reinforcement then the building actually present.
    - After applying seismic load building sustained the earthquake.
    - Column width in hillpoint is same from top to bottom.

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