DESIGN OF EARTHQUAKE RESISTANT BUILDING USING STAAD-PRO

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The woods are lovely, dark and deep.
But I have promises to keep,
And miles to go before I sleep,
And miles to go before I sleep.

Robert Frost

CERTIFICATE

This is to certify that the work entitled, **"DESIGN OF EARTHQUAKE RESISTANT BUILDING USING STAAD-PRO"** submitted by Sahil Sharma(061619),Sahil Chaudhry(061618) and Rohan Dutt(061617) in partial fulfillment for the award of degree of Bachelor of Technology in Civil Engineering of Jaypee University of Information Technology has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

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ACKNOWLEDGMENT

Sir Isaac Newton once said" **If I have seen farther than others, it is because I have stood on the shoulders of Giants."** In the same way this project work has been influenced by books, and the able guidance of our project guide.

This project comes near to the culmination of all the concepts assimilated while studying various structural engineering subjects. It has presented us with an opportunity to use the technical know-how imparted to us to a real life project.

Designing an earthquake resistant building involves all the concepts of Structural Engineering, Foundation Engineering, Geotechnical Engineering and Mechanics. Our esteemed mentor Mrs. Poonam Dhiman Department of Civil Engineering, Jaypee University of Information Technology, not only cleared all our ambiguities but also generated a high level of interest and gusto in the subject. We are truly grateful to her.

The prospect of working in a group with a high level of accountability fostered a spirit of teamwork and created a feeling of oneness which thus, expanded our range of vision, motivated us to perform to the best of our ability and create a report of the highest quality.

To do only the best quality work, with utmost sincerity and precision has been our constant endeavour.

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ABSTRACT

This project consists of designing, an Earthquake Resistant Building using STAAD-PRO. The project was divided into two parts, in the first semester a two storey industrial building was designed using moment distribution method and in the second semester we checked the results of the building with STAAD-PRO and then designed a eight storey multi-storey building using STAAD-PRO. Calculations of loads have been done as per guidelines of IS 875:1987(Part1 and Part 2) and IS 1893:2002. The method used for the analysis is Moment Distribution Method and the method for design is Limit State Method. Analysis and Design of Building has been carried out first manually and then it was done using STAAD -PRO, which is an analysis and design software package for structural engineering. Design of various components of buildings such as slab, beams, foundation and columns have been designed as per SP-16, IS 456:2000 and IS 13920.The analysis and design of multi-storey building was done using STAAD-PRO.

1
INTRODUCTION

1.1 The Earth, its Interior and Earthquakes

1.1.1 Components:

The differentiated Earth consists of following components:

1. Inner Core (radius ~1290*km*) - solid and consists of heavy metals (*e.g.*, nickel and iron)
2. Outer Core (thickness ~2200*km*) - liquid in form
3. Mantle- (thickness ~2900*km*) - the ability to flow
4. Crust (thickness ~5 to 40*km*) - consists of light materials (*e.g.*, basalts and granites).

1.1.2 The Circulations:

High temperature and pressure gradients in the mantle are generated between the Crust and the Core, thus developing The Convection Currents. These convection currents result in a circulation of the earth's mass and hot molten lava comes out and the cold rock mass goes into the Earth.

1.1.3 Plate Tectonics :

When the Crust and some portion of the Mantle slides on the hot molten outer core due to convective flows, the 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 he surface of the Earth consists of seven major tectonic plates :

1) Eurasian Plate
2) African Plate
3) South American
4) Pacific Plate
5) Indo-Australian Plate
6) North American Plate

These plates move in different directions and at different speeds from those of the neighbouring ones. There are three types of inter-plate interactions convergent, divergent and transform boundaries.

1.1.4 The Earthquake

When the rocks along a weak region in the Earth's Crust reach their strength, a sudden movement takes place in the 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 during the deformations that occur due to the gigantic tectonic plate actions that occur in the Earth. After the earthquake is over, the process of strain build-up at this modified interface between the rocks starts all over again. This process is termed as Elastic Rebound Theory.

1.1.4 Types of Earthquakes and fault

Most earthquakes in the world occur along the boundaries of the tectonic plates and are called Inter-plate Earthquakes .A numbers of earthquakes also occur within the plate itself away from the plate boundaries. The slip generated at the fault during earthquakes is along both vertical and horizontal directions called Dip Slip and lateral directions called Strike Slip.

1.1.5 Seismic Wave

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:–

1) Body waves
2) Surface waves

Body waves consist of:-

1. Primary Waves (P-waves): Fastest particles that undergo extensional and compression strains along direction of energy transmission

2. Secondary Waves (S-waves) : Particles oscillate at right angles to it.

3. Love waves: Cause surface motions similar to that by S-waves, but with no vertical component. Also cause maximum damage to structures by their racking motion on the surface in both vertical and horizontal directions.

4. Rayleigh waves: Make a material particle oscillate in an elliptic path in the vertical plan.

1.2 Measuring Instruments

1. Seismograph - instrument that measures earthquake shaking(as shown in figure 1). It has three components –

a). The sensor- pendulum Magnet and string mass
b). The recorder- pen and chart paper
c). The timer- the motor

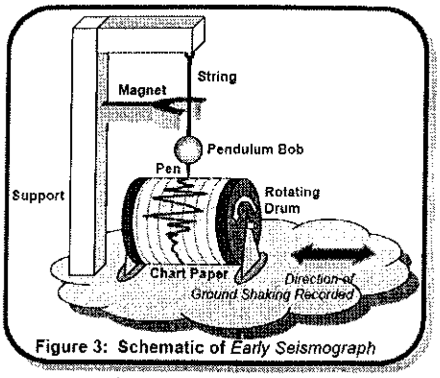


Figure 1: Early Seismograph

The principle on which it works is simple – 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.

1.3 Characteristics of Strong Ground Motions

The variation of ground acceleration with time recorded at a point on ground during an earthquake is called an accelerogram. They carry distinct information regarding ground shaking; peak amplitude, duration of strong shaking, frequency content and energy content (*i.e.,* energy carried by ground shaking at each frequency) are often used to distinguish them.

1.4 Magnitude & Intensity

1.4.1. Terminology :

1. Focus or Hypocenter- *t*he point on the fault where slip starts
2. Epicentre - the point vertically above this on the surface of the Earth
3. Focal Depth- the depth of focus from the epicentre
4. Epicentral distance- *d*istance from epicentre to any point of interest
5. Foreshocks- Smaller earthquakes occurring before a Big Earthquake
6. Aftershocks- Smaller earthquakes occurring after a Big Earthquake

1.4.2. Magnitude :

Magnitude is a quantitative measure of the actual size of the earthquake. There are many types of Magnitude Scales:

1. Richter Scale or Local Magnitude Scale
2. Body Wave Magnitude
3. Surface Wave Magnitude
4. Wave Energy Magnitude

Group	Magnitude	Annual Average Number
Great	8 and higher	1
Major	7 – 7.9	18
Strong	6 – 6.9	120
Moderate	5 – 5.9	800
Light	4 – 4.9	6,200 (estimated)
Minor	3 – 3.9	49,000 (estimated)
Very Minor	< 3.0	M2-3: ~1,000/day; M1-2: ~8,000/day

Table 1: Global occurrence of earthquakes

Earthquakes are often classified into different groups based on their size. Annual average number of earthquakes across the Earth in each of these groups is also shown in the table; it indicates that on an average one Great Earthquake occurs each year.

1.4.3. Intensity :

Intensity is a qualitative measure of the actual shaking at a location during an earthquake. There are many intensity scales. Two commonly used ones are the "Modified Mercalli Intensity (MMI) Scale" and the "MSK Scale". Both scales are quite similar and range from I (least perceptive) to XII (most severe). The intensity scales are based on three features of shaking :

1. Perception by people and animals
2. Performance of buildings
3. Changes to natural surroundings.

The destruction of the buildings take place when the Intensity is at intensity XIII or higher.

1.4.4. Difference b/w Magnitude & Intensity:

Magnitude of an earthquake is a measure of its size. The magnitude of the earthquake is a *single* value for a given earthquake. On the other hand, intensity is an indicator of the severity of shaking generated at a given location. Clearly, the severity of shaking is much higher near the epicentre than farther away. Thus, during the same earthquake of a certain magnitude, different locations experience different levels of intensity.

MMI	V	VI	VII	VIII	IX	X
PGA (*g*)	0.03-0.04	0.06-0.07	0.10-0.15	0.25-0.30	0.50-0.55	>0.60

Table 2: PGA's During shaking at different Intensities

1.5 Basic Geography and Tectonic Features

Subduction and plates

India lies at the north-western end of the Indo-Australian Plate, which encompasses India, Australia, a major portion of the Indian Ocean and other smaller countries. This plate is colliding against the huge Eurasian Plate and going under the Eurasian Plate; this process of one tectonic plate getting under another is called subduction (as shown in figure 2).

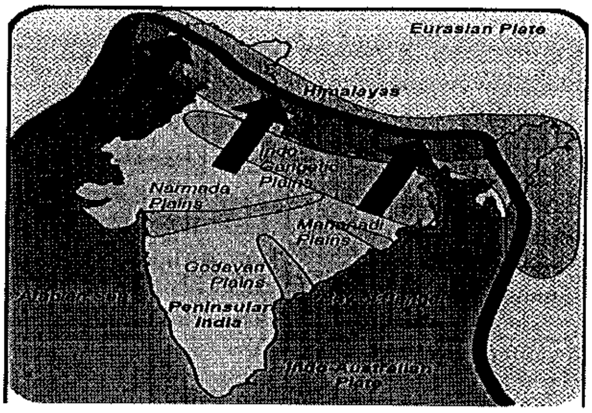


Figure 2: Techtonic Plates in India

Three chief tectonic sub-regions of India are the mighty Himalayas along the north, the plains of the Ganges, other rivers, and the peninsula. The Himalayas consist primarily of sediments accumulated over long geological time in the Tethys. The Indo-Gangetic basin with deep alluvium is a great depression caused by the load of the Himalayas on the continent.
The peninsular part of the country consists of ancient rocks deformed in the past Himalayan-like collisions. Erosion has exposed the roots of the old mountains and removed most of the topography. The rocks are very hard, but are softened by weathering near the surface.

1.6 Prominent Past Earthquakes in India

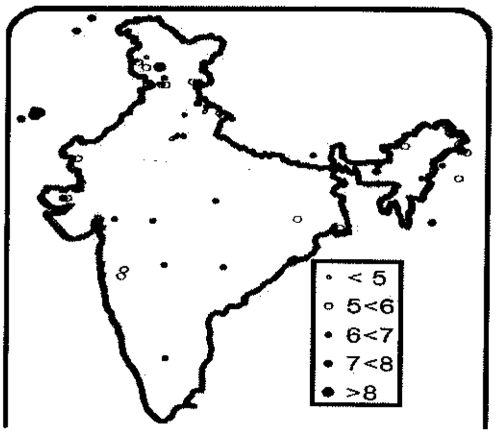


Figure 3 :Some major Earthquakes in India

The January 2001 Bhuj earthquake (M7.7)

The 1897 Assam Earthquake which caused severe damage up to *500km* radial distances

1934 Bihar-Nepal earthquake in which many structures went afloat was over *300km* (called the Slump Belt)

Date	Event	Time	Magnitude	Max. Intensity	Deaths
16 June 1819	Cutch	11:00	8.3	VIII	1,500
12 June 1897	Assam	17:11	8.7	XII	1,500
8 Feb. 1900	Coimbatore	03:11	6.0	X	Nil
4 Apr. 1905	Kangra	06:20	8.6	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.4	X	11,000
31 May 1935	Quetta	03:03	7.6	X	30,000
15 Aug. 1950	Assam	19:31	8.5	X	1,530
21 Jul. 1956	Anjar	21:02	7.0	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch	20:56	5.4	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi	02:53	6.6	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.4	IX	7,928
22 May 1997	Jabalpur	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli	12:35	6.6	VIII	63
26 Jan. 2001	Bhuj	08:46	7.7	X	13,805

Table 3: Major Earthquakes in India

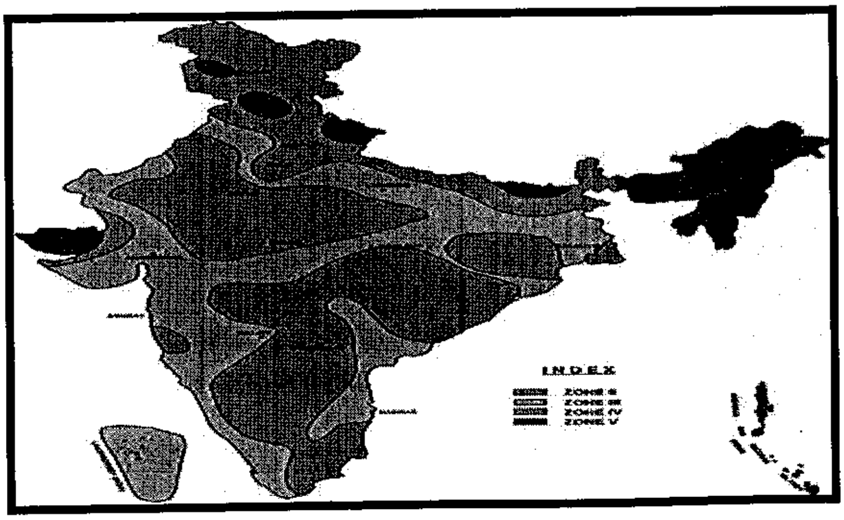


Figure 4: Indian Seismic Zone Map as per IS:1893 (Part 1)-2002

1.7 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 Law 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.
In the building, since the walls or columns are flexible, the motion of the roof is different from that of the ground.

1.7.1 Stiffness Forces

The inertia force experienced by the roof is transferred to the ground via the columns, causing forces in columns. During earthquake shaking, the columns undergo relative movement between their ends. But, given a free option, columns would like to come back to the straight vertical position, i.e., columns resist deformations.

In the straight vertical position, the columns carry no horizontal earthquake force through them. But, when forced to bend, they develop internal forces. The larger is the relative horizontal displacement between the top and bottom of the column, the larger this internal force in columns.

Also, the stiffer the columns are (i.e., bigger is the column size), larger is this force.

For this reason, these internal forces in the columns are called stiffness forces. In fact, the stiffness force in a column is the column stiffness times the relative displacement between its ends.

1.8 Importance of Architectural Features

The behaviour of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Hence, at the planning stage itself, architects and structural engineers must work together to ensure that the unfavourable features are avoided and a good building configuration is chosen.

1.8.1 Size of Buildings

In tall buildings with large height-to-base size ratio , the horizontal movement of the floors during ground shaking is large. In short but very long buildings, the damaging effects during earthquake shaking are many. And, in buildings with large plan area like warehouses, the horizontal seismic forces can be excessive to be carried by columns and walls(as shown in figure 5).

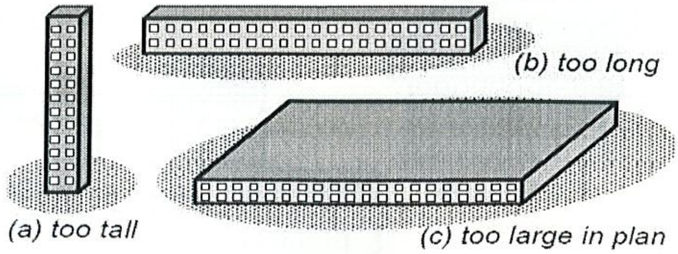


Figure 5: Effect of Size Of the Building on Earthquake Damage

1.8.2 Horizontal Layout of Buildings

In general, buildings with simple geometry in plan have performed well during strong earthquakes. Buildings with re-entrant corners, like those U, V, H and + shaped in plan, have sustained significant damage. Many times, the bad effects of these interior corners in the plan of buildings are avoided by making the buildings in two parts. (as shown in figure 6).

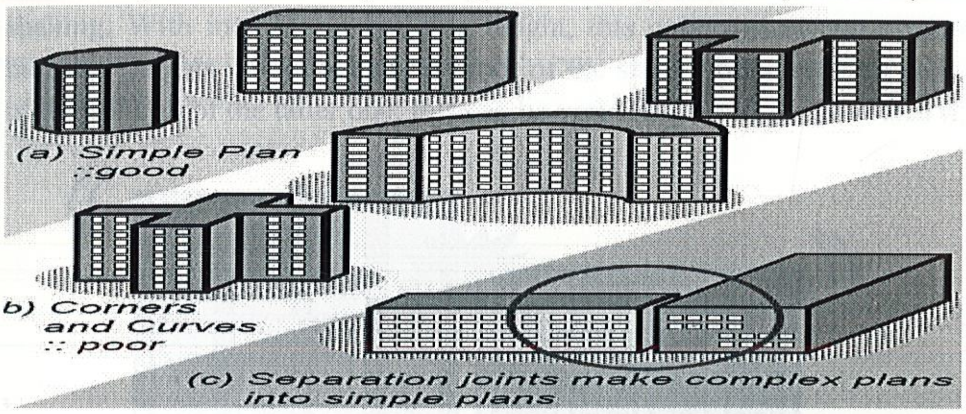
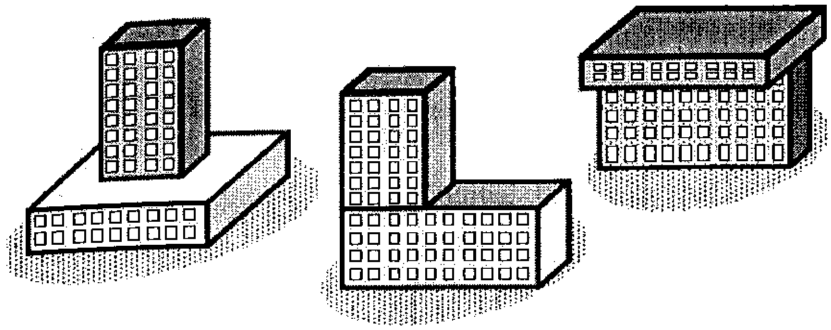


Figure 6: Effect of Horizontal Layout of the Building on Earthquake Damage

1.8.3 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 as shown in figure 7 (like the hotel buildings with a few storeys wider than the rest) cause a sudden jump in earthquake forces at the level of discontinuity. (as shown in figure 7).



(a) Setbacks

Figure 7: Effect of Vertical Layout of the Building on Earthquake Damage

1.8.4 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. When building heights do not match, the roof of the shorter building may pound at the mid-height of the column of the taller one; this can be very dangerous. (as shown in figure 8).

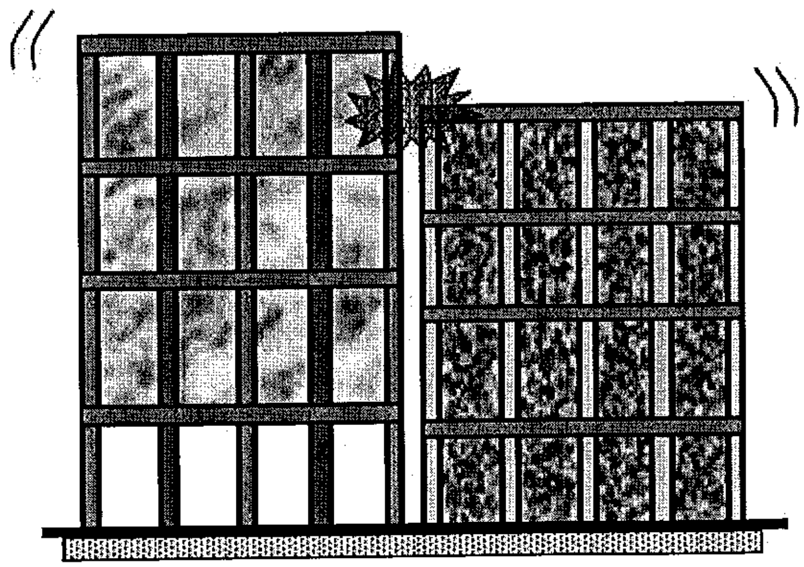


Figure 8: Collision of Buildings

1.8.5 Twisting of Building Members

In buildings with unequal vertical members (i.e., columns and/or walls) also the floors twist about a vertical axis and displace horizontally. Also buildings, which have walls only on two sides (or one side) and thin columns along the other, twist when shaken at the ground level.

Twist in buildings, called torsion by engineers, makes different portions at the same floor level to move horizontally by different amounts. This induces more damage in the columns and walls on the side that moves more. It is best to minimize this twist by ensuring that buildings have symmetry in plan. If this twist cannot be avoided, special calculations need to be done to account for this additional shear forces in the design of buildings; the Indian seismic code (IS 1893, 2002) has provisions for such calculations. But, for sure, buildings with twist will perform poorly during strong earthquake shaking.

1.9 The Earthquake Problem

Severity of ground shaking at a given location during an earthquake can be minor, moderate and strong. Minor shaking occurs frequently, moderate shaking occasionally and strong shaking rarely.

Earthquake-Resistant Buildings

The engineering intention is to make buildings earthquake resistant; such buildings resist the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake. Thus, safety of people and contents is assured in earthquake-resistant buildings, and thereby a disaster is avoided. This is a major objective of seismic design codes throughout the world.

Earthquake Design Philosophy

The earthquake design philosophy may be summarized as follows (Figure 1):
(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 severe (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, engineers designing earthquake-resistant buildings recognize that some damage is unavoidable. Different types of damage (mainly visualized though cracks; especially so in concrete and masonry buildings) occur in buildings during earthquakes. Some of these cracks *are* acceptable (in terms of both their size and location), while others are not. For instance, in a reinforced concrete frame building with masonry filler walls between columns, the cracks between vertical columns and masonry filler walls are acceptable, but diagonal cracks running through the columns are not (Figure

2). In general, qualified technical professionals are knowledgeable of the causes and severity of damage in earthquake-resistant buildings.

1.10 Importance of Ductility of buildings for Good Seismic Performance

1.10.1 Construction martial

In India, most non-urban buildings are made in masonry. Masonry can carry loads that cause *compression* (*i.e.,* pressing together), but can hardly take load that causes *tension* (*i.e.,* pulling apart).Masonry is generally made of
Burnt clay bricks, cement mortar, stone masonry with mud mortar. Concrete is another material that has been popularly used in building construction .Concrete is much stronger in compression but poor in tension. In general, both masonry and concrete are brittle, and fail suddenly. Steel is used in masonry and concrete buildings as reinforcement bars. These reinforcement bars can sustain both tension and compression. Moreover, steel is a *ductile material.* This important property of ductility enables steel bars to undergo large elongation before breaking. The amount and location of steel in a member should be such that the failure of the member is by steel reaching its strength in tension before concrete reaches its strength in compression.

1.10.2 Earthquake resistant design of building

Consider a multi-storey building consisting of beams and columns. The seismic inertia forces generated at its floor levels are transferred through the various beams and columns to the ground. 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.

1.10.3 Quality control in construction

Special care is needed in construction to ensure that the elements meant to be ductile are indeed provided with features that give adequate ductility. Regular testing of construction materials at qualified laboratories (at site or away), periodic training of workmen at professional training houses, and on-site evaluation of the technical work are elements of good quality control.

1.11 Effect of flexibility of buildings on their earthquake response

1.11.1 Oscillations of Flexible Buildings

Most buildings are flexible, and different parts move back-and-forth by different amounts when the ground shakes. The building will oscillate back-and-forth horizontally and after some time come back to the original position .These oscillations are periodic. The time taken (in seconds) for each complete cycle of oscillation (*i.e.*, one complete back-and-forth Motion) is the same and is called Fundamental Natural Period T of the building. Value of T depends on the Building flexibility and mass; more the flexibility, the longer is the T, and more the mass, the longer is the T. Fundamental natural periods T of normal single storey to *20* storey buildings are usually in the range 0.05-2.00 sec.

1.11.2 Importance of Flexibility

In general, earthquake shaking of the ground has waves whose periods vary in the range *0.03*-33sec. Intensity of earthquake waves at a particular building location depends on a number of factors, including the magnitude of the earthquake, the epicentral distance, and the type of ground that the earthquake waves travelled through before reaching the location of interest. One way of categorizing the buildings is by their fundamental natural period T. 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 shaken more than the others. The response of building also depend upon the thickness of soil under the building .

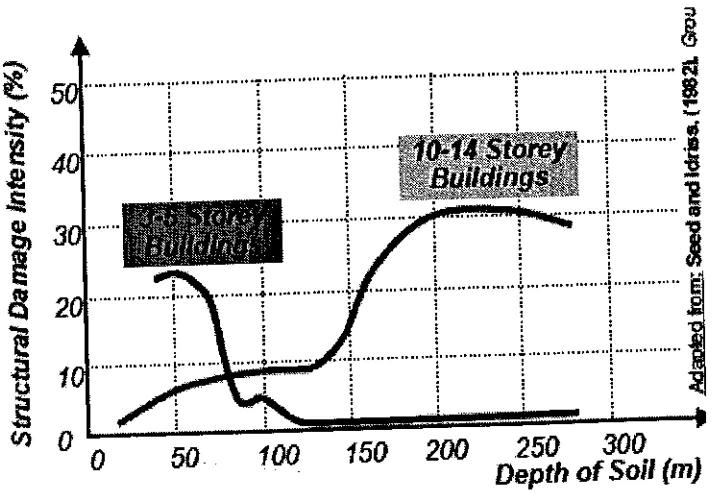


Figure 9: Relation b/w Structural Damage and Soil Depth

Flexible buildings undergo larger relative horizontal displacements, which may result in damage to various nonstructural building components and the contents. These damages may not affect safety of buildings, but may cause economic losses, injuries and panic among its residents.

1.12 Indian Seismic Codes

1.12.1 Importance of Seismic Design

Seismic codes help to improve the behavior of structures so that they may withstand the earthquake effects without significant loss of life and property. An earthquake-resistant building has four virtues in it, namely:

(a) Good Structural Configuration: Its size, shape and structural system carrying loads are such that they ensure a direct and smooth flow of inertia forces to the ground.

(b) Lateral Strength: The maximum lateral (horizontal) force that it can resist is such that the damage induced in it does not result in collapse.

(c) Adequate Stiffness: Its lateral load resisting system is such that the earthquake-induced deformations in it do not damage its contents under low-to moderate shaking.

(d) Good Ductility: Its capacity to undergo large deformations under severe earthquake shaking even after yielding, is improved by favorable design and detailing strategies.

Seismic codes cover all these aspects.

1.12.2 Indian Seismic Codes

IS 1893

IS 1893 is the main code that provides the seismic zone map and specifies seismic design force. This force depends on the mass and seismic coefficient of the structure; the latter in turn depends on properties like seismic zone in which structure lies, importance of the structure, its stiffness, the soil on which it rests, and its ductility. The revised 2002 edition, Part 1 of IS1893, contains provisions that are general in nature and those applicable for buildings. In contrast, the 1984 edition of IS1893 had provisions for all the above structures in a single document.

Seismic design of bridges in India is covered in three codes, namely *IS 1893 (1984)* from the BIS, *IRC 6 (2000)* from the Indian Roads Congress, and Bridge Rules *(1964)* from the Ministry of Railways.

IS 4326, 1993

This code covers general principles for earthquake resistant buildings.

IS 13827, 1993 and IS 13828, 1993

Guidelines in IS 13827 deal with empirical design and construction aspects for improving earthquake resistance of earthen houses, and those in IS 13828 with general principles of design and special construction features for improving earthquake resistance of buildings of low-strength masonry.

IS 13920, 1993

In India, reinforced concrete structures are designed and detailed as per the Indian Code IS 456 (2002). However, structures located in high seismic regions require ductile design and detailing. Provisions for the ductile detailing of monolithic reinforced concrete frame and shear wall structures are specified in IS 13920 (1993).

1.13 Behaviour of Brick Masonry Houses During Earthquakes :

1.13.1 Behaviour of brick masonry walls

Ground vibrations during earthquakes cause inertia forces at locations of mass in the building. These forces travel through the roof and walls to the foundation. Of the three components of a
Masonry building (roof, wall and foundation), the walls are most vulnerable to damage caused
By horizontal forces due to earthquake. A wall topples down easily if pushed horizontally at the top in a direction perpendicular to its plane (termed weak direction), but offers much greater resistance if pushed along its length (termed strong direction). The ground shakes simultaneously in the vertical and two horizontal directions during earthquakes. However, the horizontal vibrations are the most damaging to normal masonry buildings. Horizontal inertia force developed at the roof transfers to the walls acting either in the weak or in the strong direction. If all the walls are not tied together like a box, the walls loaded in their weak direction tend to topple. Further, walls also need to be tied to the roof and foundation to preserve their overall integrity.

1.13.2 Improving behaviour of masonry wall

Masonry walls are slender because of their small thickness compared to their height and length. A simple way of making these walls behave well during earthquake shaking is by making them act together as a box along with the roof at the top and with the foundation at the bottom. Firstly,
connections between the walls should be good. This can be achieved by (a) ensuring good interlocking of the masonry courses at the junctions, and (b)employing horizontal bands at various levels, particularly at the lintel level. Secondly, the sizes of door and window openings need to be kept small. Thirdly, the tendency of a wall to topple when pushed in the weak direction can be reduced by limiting its length-to-thickness and height to- thickness ratios. Design codes specify limits to this ratio.

1.13.3 Choice and quality of building materials

Bricks with low porosity are to be used as masonry units and they must be soaked in water before use to minimize the amount of water drawn away from mortar. Excessive porosity is detrimental to good masonry behaviour because the bricks suck away water from the adjoining mortar, which results in poor bond between brick and mortar, and in difficulty in positioning masonry units. Various mortars are used, *e.g.*, mud, cement-sand, or cement-sand-lime. Of these, mud mortar is the weakest; it crushes easily when dry, flows outward and has very low earthquake resistance. Cement-sand mortar with lime is the most suitable. This mortar mix provides excellent workability for laying bricks, stretches without crumbling at low earthquake shaking, and bonds well with bricks. Also10mm thick mortar layer is generally satisfactory from practical and aesthetic considerations. Indian Standards prescribe the preferred types and grades of bricks and mortars to be used in buildings in each seismic zone

1.14 Importance of Simple Structural Configuration in Masonry Buildings

The structural configuration of masonry buildings includes aspects like (a) overall shape and size of the building, and (b) distribution of mass and (horizontal) lateral load resisting elements across the building. Large, tall, long and unsymmetrical buildings perform poorly during earthquakes. Consider a four-wall system of a single storey masonry building. During earthquake shaking, inertia forces act in the strong direction of some walls and in the weak direction of others. Walls shaken in the weak direction seek support from the other walls, Thus, walls transfer loads to each other at their junctions (and through the lintel bands and roof). Hence, the masonry courses from the walls meeting at corners must have good interlocking. Also openings too close to wall corners hamper the flow of forces from one wall to another. Further, large openings weaken walls from carrying the inertia forces in their own plane. Thus, it is best to keep all openings as small as possible and as far away from the corners as possible.

Earthquake- resistant features

Indian Standards suggest a number of earthquake resistant measures to develop good *box-type* action in masonry buildings and improve their seismic performance. For instance, it is suggested that a building having horizontal projections when seen from the top.During earthquakes, separated blocks can oscillate independently and even hammer each other if they are too close. Thus, adequate gap is necessary between these different blocks of the building. The Indian Standards suggest minimum seismic separations between blocks of building. Inclined staircase slabs in masonry buildings offer another concern. An integrally connected staircase slab acts like a cross-brace between floors and transfers large horizontal forces at the roof and lower levels. To overcome this, sometimes, staircases are completely separated and built on a separate reinforced concrete structure. Adequate gap is provided between the staircase tower and the masonry building to ensure that they do not pound each other during strong earthquake shaking.

1.15 Importance of providing horizontal Bands in Masonry Buildings

1.15.1 Role of horizontal bands

Horizontal bands are the most important earthquake-resistant feature in masonry buildings. The

bands are provided to hold a masonry building as a single unit by tying all the walls together There are four types of bands in a typical masonry building, namely gable band, roof band, lintel band and plinth band (Figure 1), named after their location in the building. The lintel band is the most important of all, and needs to be provided in almost all buildings. The gable band is employed only in buildings with pitched or sloped roofs. In buildings with flat reinforced concrete or reinforced brick roofs, the roof band is not required, because the roof slab also plays the role of a band. In buildings with pitched or sloped roof, the roof band is very important. Plinth bands are primarily used when there is concern about uneven settlement of foundation soil. The lintel band ties the walls together and creates a support for walls loaded along weak direction from walls loaded in strong direction. This band also reduces the unsupported height of the walls and thereby improves their stability in the weak direction.

1.15.2 Design of lintel bands

The straight lengths of the band must be properly connected at the wall corners. This will allow the band to support walls loaded in their weak direction by walls loaded in their strong direction. Small lengths of wood spacers (in wooden bands) or steel links (in RC bands) are used to make the straight lengths of wood runners or steel bars act together. In wooden bands, proper nailing of straight lengths with spacers is important. Likewise, in RC bands, adequate anchoring of steel links with steel bars is necessary

1.15.3 Indian standards

The Indian Standards IS:4326-1993 and IS:13828 (1993) provide sizes and details of the bands. When wooden bands are used, the cross-section of runners is to be at least 75mm×38mm and of spacers at least 50mm×30mm. When RC bands are used, the minimum thickness is 75mm, and at least two bars of 8mm diameter are required, tied across with steel links of at least 6mm diameter at a spacing of 150 mm centres.

1.16 Importance of Vertical Reinforcement in Masonry Buildings

1.16.1Role of masonry walls

When the ground shakes, the inertia force causes the small-sized masonry *wall piers* to disconnect from the masonry above and below. These masonry sub-units rock back and forth, developing contact only at the opposite diagonals. The rocking of a masonry pier can crush the masonry at the corners. Rocking is possible when masonry piers are slender, and when weight of the structure above is small. Otherwise, the piers are more likely to develop diagonal (X-type) shear cracking; this is the most common failure type in masonry buildings. In un-reinforced masonry buildings, the cross-section area of the masonry wall reduces at the opening. During strong earthquake shaking, the building may *slide* just under the roof, below the lintel band or at the sill level. Sometimes, the building may also slide at the plinth level depending upon numerous factors.

1.16.2 Mechanism of vertical reinforcement

Embedding vertical reinforcement bars in the edges of the wall piers and anchoring them in the

Foundation at the bottom and in the roof band at the top , forces the slender masonry piers to Undergo bending instead of rocking. In wider wall piers, the vertical bars enhance their capability to resist horizontal earthquake forces and delay the X-cracking. Adequate cross-sectional area of these vertical bars prevents the bar from yielding in tension. Further, the vertical bars also help protect the wall from sliding as well as from collapsing in the weak direction.

1.16.3 Protection of openings in walls

The most common damage, observed after an earthquake, is diagonal X-cracking of wall piers, and also inclined cracks at the corners of door and window openings. During earthquake shaking, walls with openings deform. Under this type of deformation, the corners that come closer develop cracks. The cracks are bigger when the opening sizes are larger. Steel bars provided in the wall masonry all around the openings restrict these cracks at the corners. In summary, lintel and sill bands above and below openings, and vertical reinforcement adjacent to vertical edges, provide protection against this type of damage

1.17 Making Stone Masonry Buildings Earthquake Resistant

1.17.1 Behaviour during past earthquakes

In a typical rural stone house, there are thick stone masonry walls (thickness ranges from 600 to 1200 mm) built using rounded stones from riverbeds bound with mud mortar These uncoursed walls have two exterior vertical layers (called wythes) of large stones, filled in between with loose stone rubble and mud mortar. These buildings are one of the most deficient building systems from earthquake-resistance point of view. The main deficiencies include excessive wall thickness, absence of any connection between the two wythes of the wall, and use of *round* stones (instead of *shaped* Ones). Such dwellings have shown very poor performance during past earthquakes in India and other countries. The main patterns of earthquake damage include:

(a) Bulging/separation of walls in the horizontal direction into two distinct wythes
(b) Separation of walls at corners and T-junctions
(c) Separation of poorly constructed roof from walls, and eventual collapse of roof
(d) Disintegration of walls and eventual collapse of the whole dwelling.

1.17.2 Earthquake resistant features

The Indian Standard IS: 13828-1993 states that inclusion of special earthquake-resistant Design and construction features may raise the earthquake resistance of these buildings and reduce the loss of life. However, in spite of the seismic features these buildings may not become totally free from heavy damage and even collapse in case of a major earthquake. These features include:

(a)Ensure proper wall construction the wall thickness should not exceed 450mm. Round stone boulders should not be used in the construction! Instead, the stones should be shaped using chisels and hammers. Use of mud mortar should be avoided in higher seismic zones. Instead, cement-sand mortar should be 1:6 (or richer) and lime-sand mortar 1:3 (*or richer*) should be used.

(b) Ensure proper bond in masonry courses: The masonry walls should be built in construction lifts not exceeding 600mm. Through-stones (each extending over full thickness of wall) or a pair of overlapping bond-stones (each extending over at least ¾th

thickness of wall) must be used at every 600mm along the height and at a maximum spacing of 1.2m along the length.

(c) Provide horizontal reinforcing elements: The stone masonry dwellings must have horizontal bands. These bands can be constructed out of wood or reinforced concrete, and chosen based on economy. It is important to provide at least one band (either lintel band or roof band) in stone masonry construction.

(d) Control on overall dimensions and heights: The unsupported length of walls between cross-walls should be limited to 5m; for longer walls, cross supports raised from the ground level called buttresses should be provided at spacing not more than 4m. The height of each storey should not exceed 3.0m. In general, stone masonry buildings should not be taller than 2 storeys when built in cement mortar, and 1 storey when built in lime or mud mortar. The wall should have a thickness of at least one-sixth its height.

1.18 The Effect of Earthquake on Reinforced Concrete Building

The Reinforced Concrete frame resists the inertial forces developed due to the earthquakes which are directly proportional to the mass of the building .This mass is mostly present at the roof level of any building and from here it is transferred to the beams and columns and then to the foundation ultimately into the ground. As these forces get accumulated to the lower stories the lower stories should be made stronger.

1.18.1 Comparison of Gravity and Earthquake Forces

In case of gravity forces, the tension will be developed at the centre of the beam and top ends. In case of earthquake forces, the tension on beam ends will be on either of top and bottom faces. To ensure that the building should remain safe the columns should be made stronger than beams and the foundation stronger than columns (as the load is transferred from beams to columns and then to foundation). If we make columns stronger than the beams the beams will be damaged first and though the whole building may get deformed but it will not collapse (to ensure this the beams should have ductility and proper detailing). However if the columns are made weaker than the beams then the columns will undergo local failures at their top and bottom ends and the building may collapse.

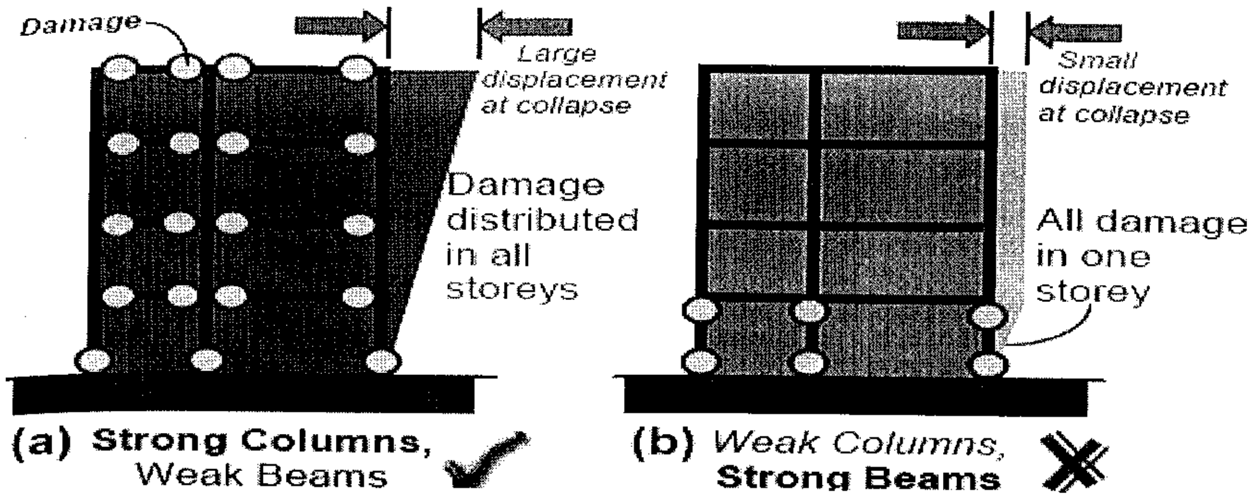


Figure 10: Design strategy for earthquake resistant structures

1.19 Resistance of RC Beams against Earthquakes

1.19.1 Failure in Beams

The failure in beams can be of two types:-

(1) **Flexural failure (failure in bending)**

(a) **Brittle failure (over reinforced)**: - In this type of failure the steel provided is more and thus concrete fails first and this failure is brittle. This situation is undesirable.

(b) **Ductile failure (under-reinforced)**: - In this situation the steel provided is less and the steel fails first but before failing it elongates and cracks develop, until eventually concrete fails in compression.

(2) **Shear failure**: - A beam may also fail in shear. In such a case a crack develops from mid depth near the supports.

1.20 Ductile detailing requirements of RC beams

The longitudinal bars help to prevent flexural failure. The Indian Ductile Detailing Code (IS13920 -1993) specifies:-

(a) At least two bars should go through the full length of the beam at top and bottom.

(b) At the ends the steel provided at the bottom should be at least half of that provided on the top.

The stirrups in RC beams have the following functions:-

(a) They prevent shear failure in beams

(b) They hold the concrete in its position and prevent in from bulging out due to flexure.

(c) They prevent the buckling of the compressed longitudinal bars, due to flexure.

The Indian Standard IS13920 -1993 specifies following requirements related to stirrups in reinforced concrete beams:-

(a) The diameter of the stirrup bars should not be less than 6mm in beams less than 5m long and not less than 8mm in beams longer than 5m.

(b) Both the ends of stirrup should be bent at an angle of 135° and they should be extended to a sufficient length to prevent them from opening during earthquake.

(c) Maximum spacing of stirrups should be less than half the depth of the beam.

For beams of longer lengths following specifications are made for overlapping of bars:-

(a) Such overlapping should be made away from the face of the column.

(b) Overlapping should not be made in the locations where the bars will yield by large amount.

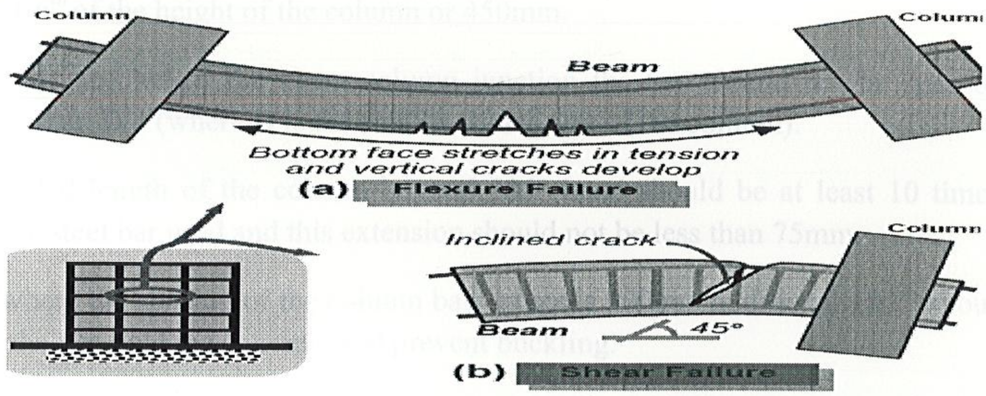


Figure 11: Failure in beams under the effect of earthquake

1.21 Resistance of Columns against Earthquakes

1.21.1 Failure of Columns

The failure of RC columns can be of two types:-

(1) Axial-Flexural failure

(2) Shear failure

1.21.2 Design Strategy

The design procedure includes selection of a suitable material, choosing the size and the shape of the cross-section and the amount and distribution of steel reinforcement.

1.21.3Ductile detailing of Columns

The Indian Ductile Code IS13920-1993 specifies that the columns should be at least 300 mm wide. The column width up 200 mm is allowed if the unsupported length is less than 4m and the length of the beam is less than 5m.

The horizontally placed ties have following functions:-

(a) They prevent shear failure.

(b) They prevent excessive bending of bars (buckling)

(3) They help to hold the concrete in columns

The Indian Ductile Code IS13920-1993 has following specifications for earthquake resistant columns:-

(a) At the ends the ties should be closely spaced over the length least of, larger dimension of the column, $1/6^{th}$ of the height of the column or 450mm.

(b) At the ends and below the beam column junction the ties should not be spaced at a distance more than D/4 (where D is the smaller dimension of the column).

(c) The extended length of the column beyond 135° bend should be at least 10 times the diameter of the steel bar used and this extension should not be less than 75mm.

In columns where the spacing of the column bars exceeds 300mm additional 180 ° should be used to help the ties hold the concrete and prevent buckling.

In case of overlapping of bars following points should be considered:-

(a) For ordinary situations the overlapping should be 50 times that of the bar used.

(b) The lap length should be provided at the middle of the column and not near the top and bottom ends.

(c) Only half the bars in a storey should be lapped.

(d) In case of lapping the ties should not be spaced more than 150 mm.

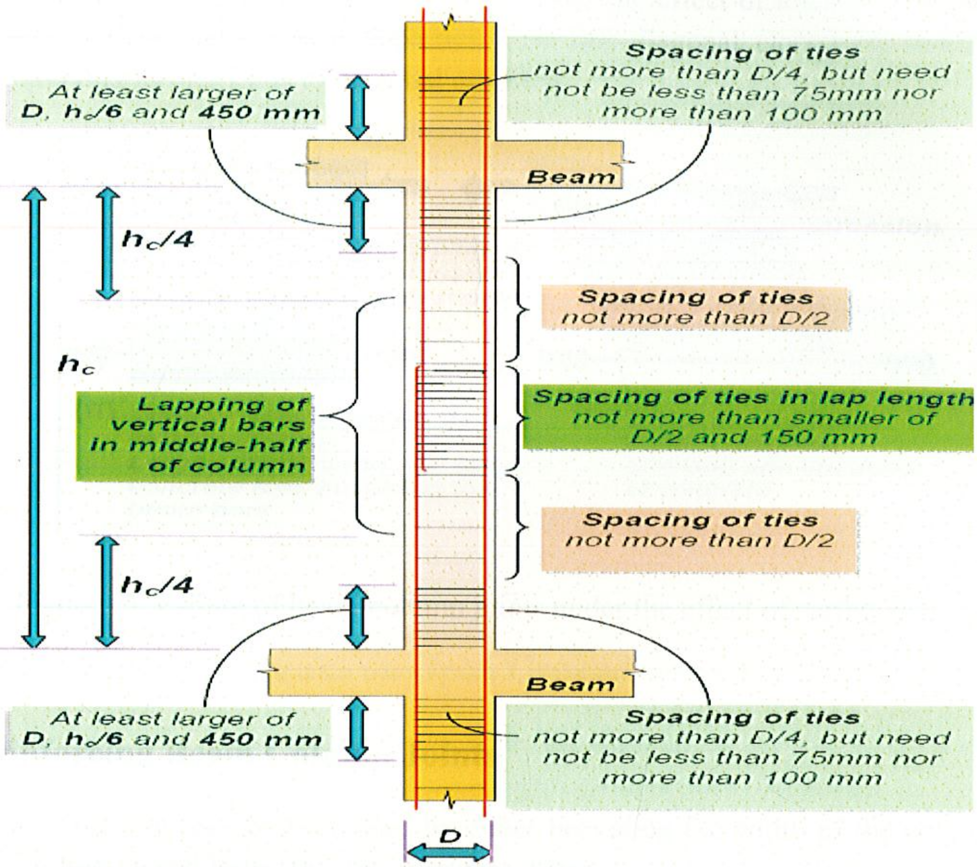


Figure 12: Ductile detailing of column as per IS: 13920 – 1993

1.22 The Resistance of Beam-Column Joints against Earthquake

The beam-column joints have limited force carrying capacity, so under the effect of earthquake forces they may get severely damaged and this damage may be irreparable. Hence it should be ensured that these joints are made earthquake resistant.

1.22.1 Behaviour of Joints under the Effect of Earthquake

During an earthquake the beams adjoining a joint are subjected to the moments in the same direction (clockwise or anticlockwise) as that of earthquake. Under the effect of these moments the top bars in the joint are pulled in one direction and the bottom bars are pulled in another direction. These forces are balanced by the bond strength developed between the concrete and steel in the joint region. It should be ensured that at the joint region the concrete has high strength, proper grip between steel and concrete and the column is of sufficient width to avoid the slipping of bars in the beam. Under the effect of this pull and push force the joint may undergo geometrical distortion with one diagonal elongating and the other shortening and this further leads to diagonal cracking.

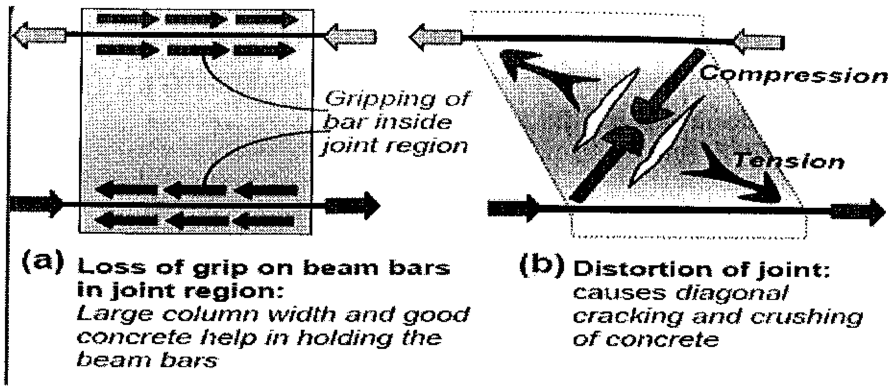


Figure 13: Failure of beam-column joints under the effect of earthquake

1.22.2Reinforcing Beam Column Joints

This diagonal cracking may be prevented by either providing the width of the column to be more or providing closed loop steel ties at closer distance around the columns near the joint region. These ties hold the concrete and resist shear force thus preventing cracking and crushing of concrete.

1.22.3Anchoring of Beam Bars

The anchoring of the beam bars may be improved by using columns of larger cross-section. The American Concrete Institute specifies that the width of the column should be at least 20 times the diameter of the largest longitudinal bar used in the adjoining beam. In the exterior joint where beam terminate into the columns the beam bars need to be anchored into the column to ensure proper gripping of the bar in the joint. The length of anchorage for a Fe415 is 50 times its diameter. This length is measured from the face of the column to the end of the bar anchored. In the interior joints the beam bars should go through the joint region without any cut in this region and these bars should be placed within the column bars without any bend.

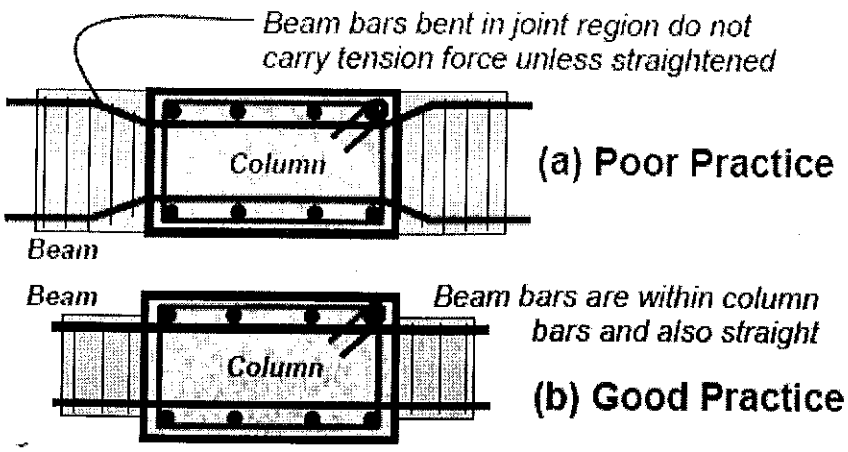


Figure 14: Ductile detailing of beam-column joints

1.23 The Effect of Earthquake on Open Ground Storey Building

If the ground storey of a building is kept open for the purpose of parking (it does not have any partition walls) then such a building is called open ground storey building.

An open ground storey building has following features:-

(1) It is relatively more flexible in the ground storey than the upper stories (the relative horizontal displacement in the ground storey is much larger). This relatively flexible ground storey is called soft storey.

(2) The open ground storey is relatively weaker (the total earthquake force it can carry in the ground storey is considerably smaller than the upper stories).Often such buildings are called soft storey building.

1.23.1 Behaviour during an earthquake

These open ground storey buildings are extremely vulnerable during an earthquake. The presence of walls on the upper stories makes them much stiffer than the open ground storey. The upper stories move together as a single block and most of the displacement occurs in the bottom soft storey. The columns in the open ground storey are subjected to large stresses. If the columns are weak and do not have sufficient strength to resist these stresses then the column may get severely damaged and the building may even collapse.

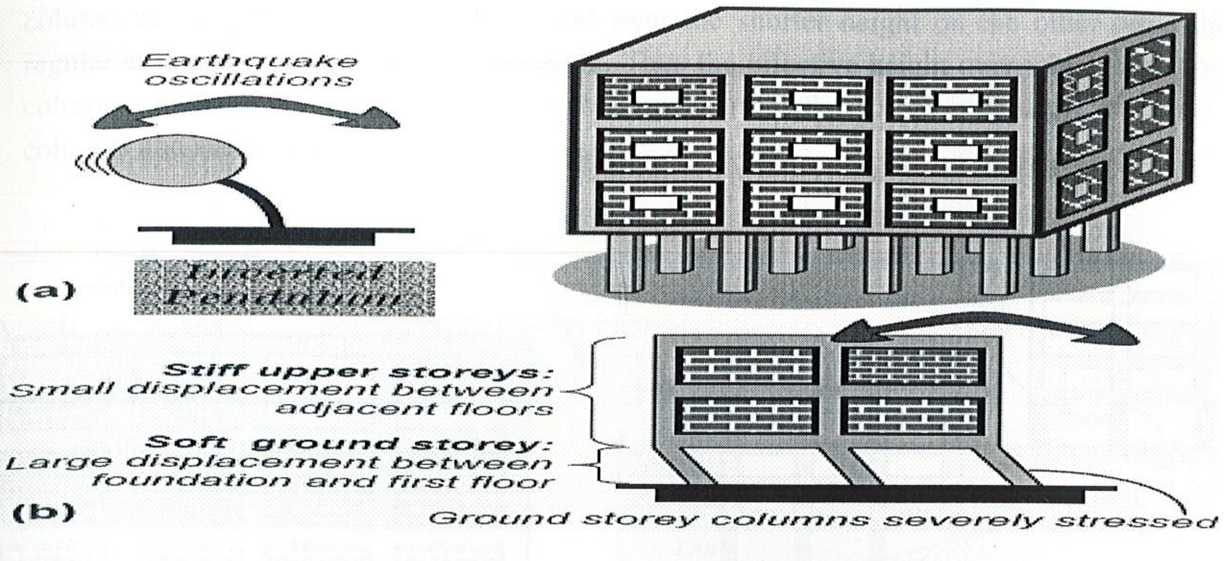


Figure 15: Behavior of open ground storey building during an earthquake

1.23.2 Design Method

The Indian Seismic Code IS: 1893 has included special design provisions related to soft storey buildings:-

(1) It specifies when a building should be considered a soft or weak storey building.

(2) It specifies higher design forces for the soft storey as compared to the rest of the building.

The code suggests that the forces in the beams, columns and the shear walls under the effect of seismic loads specified in the code may be obtained by considering bare frame analysis. But the beams and the columns in the open ground storey are required to be designed 2.5 times the forces obtained from bare frame analysis. For new RC building we should avoid open ground storey, so it is suitable to construct walls in the ground storey. The existing open storey buildings should be suitably strengthened to avoid their collapse during an earthquake.

1.24 The Effect of Earthquake on Short Storey Building

If the columns are of different height within the same storey then the short column effect will take place. The shorter columns will suffer more damage than the longer columns. The two examples of short columns are when the building is made on the sloping floor or building with mezzanine floor. There is another situation when the short column effect may occur when the masonry wall has been constructed only up to a partial height and in the remaining portion a glass window has to be made. In such cases when the slab moves horizontally during an earthquake the upper ends of the column undergo displacement by the same amount however the masonry walls resist the movement of the lower portion of the shorter column and it deforms by the full amount over the shorter height on the other hand the regular columns move over the entire height. Thus the effective height over which the short column can bend is small thus it attracts larger earthquake forces compared to regular columns and sustains more damage.

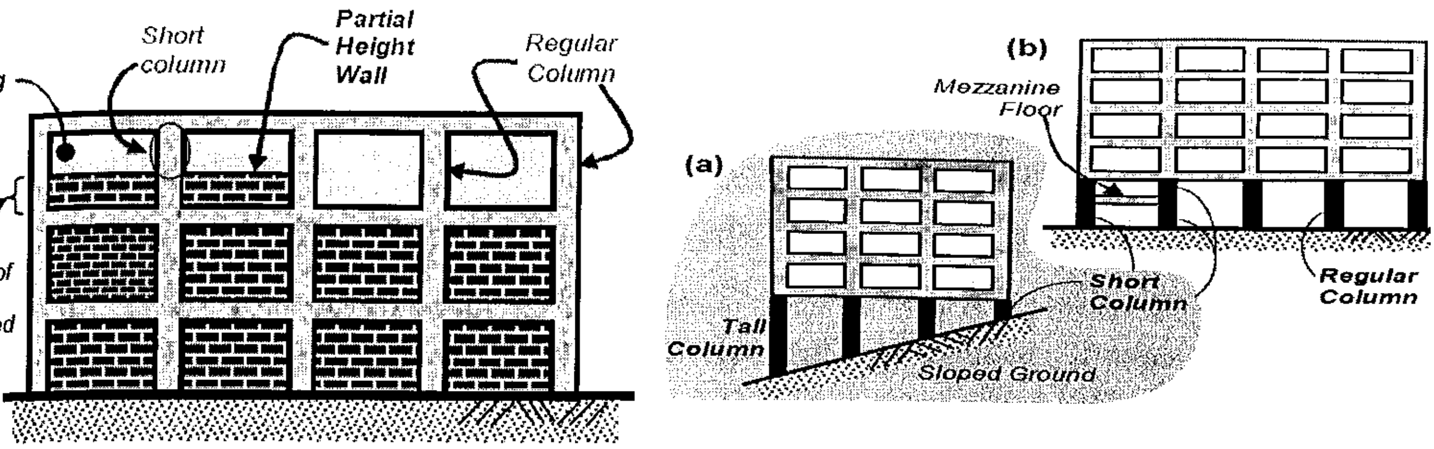


Figure 16: Examples showing short column effect

1.24.1 The Short Column Effect

The short storey buildings show poor performance because during an earthquake the short column and the longer column move horizontally by the same amount but the short column due to its larger stiffness attracts several times larger earthquake forces .If the short column is not designed for such large force then it might get deformed. This behaviour is called short column effect and it is in form of an X shaped crack on the column, which is due to shear failure.

1.24.2 Ductile Detailing to Overcome the Short Column Effect

In the new buildings the short column effect should be avoided during the architectural stage itself. If it is not possible to avoid short column effect it must be taken care of while designing. The Indian standard 13920:1993 (ductile detailing of RC columns) specifies that confining reinforcement over the entire height of the column that is likely to undergo short column effect. The special confining reinforcement must extend beyond the short columns into the columns vertically above and below by some distance.

1.25 Resistance of Shear Walls against Earthquakes

1.25.1Shear wall

The RC often have vertical plate like wall in addition to the columns , beams and slabs called shear walls, these generally extend from the foundation and generally extend over the entire length of the building. The thickness of these walls can be between 150-400mm depending on the vertical rise of the building. Shear walls are generally provided along both the length and width of the building. Properly designed and detailed shear walls have shown very good results during past earthquakes. The buildings which were having properly designed shear walls but were not detailed for seismic performance were saved from collapse.

1.25.2Architectural Aspects of Shear Walls

The shear walls provide large strength and stiffness to the building in the direction of their orientation, which reduces the lateral sway to the building and thus the damage to the building and its contents is reduced. As these walls carry large earthquake forces they may get overturned so their foundations have to be properly designed. Shear walls must be provided along both the length and width, however if they are provided along only one direction a proper grid of beams and columns must be provided along the other direction. Doors and windows may be provided in these walls but their size must be limited to ensure least interruption in the flow of force. Also they must be symmetrically located. Shear walls must be symmetrically located in the plan to reduce the ill effect of twisting of the building .Shear walls are more effective when they are located on the exterior perimeter of the building this increases resistance to twisting.

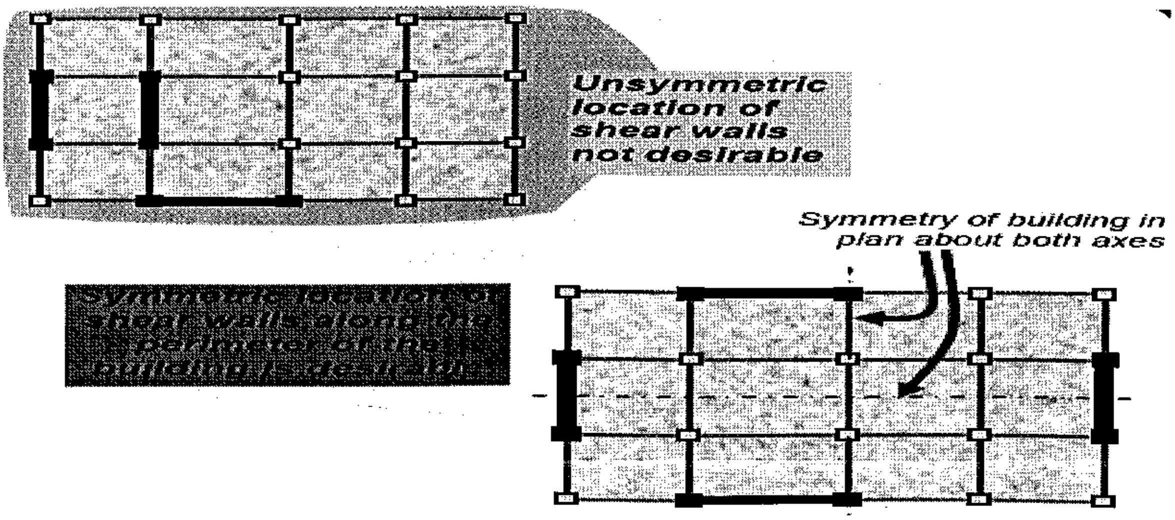


Figure 17: Shear walls placed symmetrically along the perimeter of the building

Geometry of Shear Walls

The shear walls are oblong (one dimension is larger than the other).Generally the shear walls are rectangular however they can even be L and U shaped. Thin walled hollow RC shafts around the elevator of the building also act as shear walls and must be taken advantage of to resist earthquake forces.

Ductile detailing of Shear Walls

Steel reinforcing bars are to be provided in regularly spaced vertical and horizontal grids. The vertical and horizontal reinforcement can be placed in one or two parallel layers called curtains. Horizontal reinforcement needs to be anchored to the ends of the walls. The vertical reinforcement should be uniformly distributed across the wall cross-section. Under the large overturning effects caused due to the earthquakes edges of the shear walls experience high tensile and compressive forces. To ensure that the concrete behave in a ductile way the concrete in the walls must be confined in a special way, these end regions with special confinement are called boundary elements.

1.26 Methods to Reduce the Effects of Earthquakes on Buildings

The conventional seismic design techniques protect the building from collapsing but they may become non functional after an earthquake. However there are certain public utility buildings such as hospitals which should remain functional in the aftermath of an earthquake. Special techniques are required for such buildings which remain undamaged during a severe earthquake.

Two basic techniques that are used to protect the buildings from damaging effects of earthquakes are Base Isolation Devices and Seismic Dampers.

1.26.1 Base Isolators

The idea behind base isolators is to detach (isolate) the building from the ground so that the earthquake forces are not transmitted up to the building or they are greatly reduced. In base isolation the building is placed on flexible pads that offer some resistance against the lateral movement, thus only a small portion of the earthquake forces is transferred to the building above. If the ground pads are properly chosen then the forces induced can be reduced to a few times lesser than the building directly built on the ground fixed base building. The flexible pads are called base isolators and the structures protected by means of these are called base-isolated buildings. Base isolation introduces flexibility in the structure. Base isolators sometimes also absorb energy and thus they also act as dampers. Base isolation is suitable for low to high rise buildings resting on hard soil, base isolation is not suitable for high rise buildings resting on soft soil.

1.26.2Seismic Dampers

Another method of improving seismic performance of the buildings is by installing seismic dampers. When the seismic energy is transferred through them they absorb part of the energy and thus damp the motion of the building. Dampers were used to protect the tall buildings from the winds since 1960's, but it was only in 1990's that they were used to protect buildings from earthquakes. Commonly used types of dampers are:-

(1) Viscous Dampers: Energy is absorbed by silicon based fluid passing between piston and cylinder.

(2) Friction Dampers:-Energy is absorbed by the rubbing of surfaces against each other having friction.

(3) Yielding Dampers: - Energy is absorbed by the metallic components that yield.

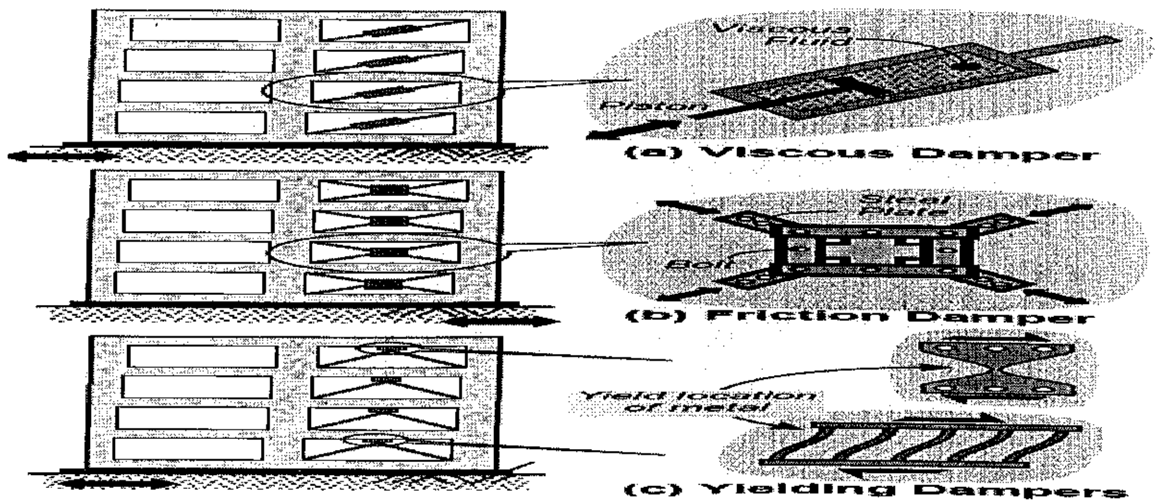


Figure 18: Types of Seismic Dampers

2

ANALYSIS OF THE BUILDING

2.1 Introduction to the Project

The project was divided into two parts, in the first semester a two storey industrial building was designed using moment distribution method and in the second semester we checked the results of the building with STAAD-PRO and then designed a eight storey multi-storey building using STAAD-PRO.

2.1.1 a Introduction to the problem

This project work consists of earthquake resistant analysis and design of a two storey industrial building which (with light machinery) is assumed to be located in the seismic Zone 4 as per IS 1893:2002. The height of the storeys are 4m and 3.5m and bay width is 4m in both horizontal directions.(as shown in figure 19) The size of both, floor and roof slabs is 4m x 5m with thickness equal to 150mm. The bearing capacity of the soil is assumed to be 120kN/m^2.

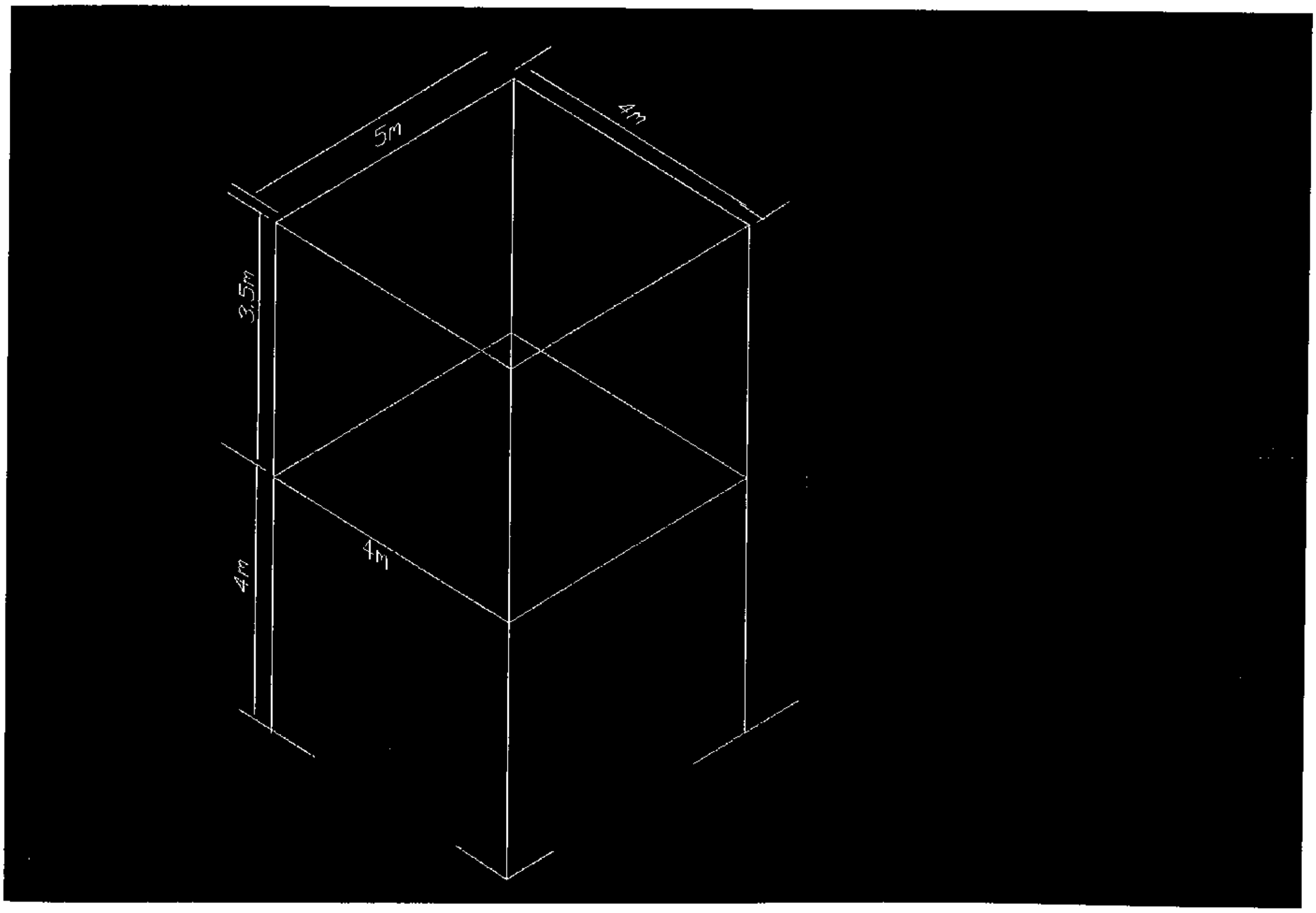


Figure19: 3D view of the building frame

2.1.1 b LOAD COMBINATIONS

A judicious combination of the load, keep in view the probability of:

a) They should act together, and
b) Their disposition in relation to other load and severity of stress or deformation caused by combination of various load is necessary to ensure the requirement safety and economy in the design of a structure.

In the absence of such recommendations the following loading combination whichever combination produce the most unfavorable effect in the building, foundation and the structural member concern may be adopted. It should also recognize in load combination that the simultaneous occurrence of maximum value of wind, earthquake, imposed and

a) DL.

b) DL+IL.

c) DL+WL.

d) DL+EL

g) DL+IL+EL

(DL=dead load, IL=imposed load, WL=wind load, EL=earthquake load

LOAD COMB 5 1.2(D.L.+L.L.+E.L.-X)

LOAD COMB 6 1.2(D.L.+L.L.-E.L.-X)

LOAD COMB 7 1.2(D.L.+L.L.+E.L.-Z)

LOAD COMB 8 1.2(D.L.+L.L.-E.L.Z)

LOAD COMB 9 1.5(D.L.+E.L.X)

LOAD COMB 10 1.5(D.L.+E.L.Z)

LOAD COMB 11 1.5(D.L.-E.L.X)

LOAD COMB 12 1.5(D.L.-E.L.Z)

LOAD COMB 13 0.9D.L. + 1.5E.L.X

LOAD COMB 14 0.9D.L. - 1.5E.L.X

LOAD COMB 15 0.9D.L. + 1.5E.L.Z

LOAD COMB 16 0.9D.L. - 1.5E.L.Z

2.1.2 Calculations of loads

For the seismic load calculations, following sizes of beams and columns were assumed:

Beam =180 mm width, 330 mm depth

Column=250 mm x 250 mm

Depth of Slab = 150 mm

a) DL and LL as per IS 875 (I and II)

DL of the Slab = 0.18 x 25 = 4.5 kN/m^2

Floor Finish = 0.23 kN/m^2 (Terrazzo Finish)

LL (light machinery) = 5kN/m^2

Total Load = 9.73 kN/m^2

b) Calculation of Earthquake Forces as per IS 1893:2002

Total Load (from slab to beam) in KN/m = (2.5 x 4 x 9.73)/2 = 48.75 kN/m^2

$$Ah = \frac{Z \times I \times S_a}{2 \times R \times g}$$

$Z = 0.24$ (Zone 4, IS-1893-2002)

$R = 5$ (IS-1893-2002)

$T = 0.075$ h=0.339

$H = 3.5+4 = 7.5$m

Find the value of S_a/g (Using IS-1893-2002)

$S_a/g = 2.5$

$$Ah = \frac{0.24 \times 1 \times 2.5}{2 \times 5} = 0.06$$

W_1 = Seismic Weight of the first floor = Beam + half slab + column + live load

DL of Beam: = 0.33 x 0.18 x4 x 25

DL of column = 0.1 x 0.3 (2 +3.5/2) x 25=9.375kn

DL of Slab = 4 x 2.5 x 0.18 x25 = 45

LL of Slab = 0.5 x 5 x 2.5 x 4 = 25

$$Q_i = \frac{V_B (W_i h_i^2)}{\sum_{j=1}^{n} W_j h_j^2}$$

Where

Q_i = Design Lateral Force at Floor i,

W_i = Seismic Weight of Floor i,

h_i = Height of the Floor i measured from base,

n = Number of Storeys in the Building is the number of levels at which the masses are located.

$W_1 = 80.24$

$W_2 = 78.74$

$W_1 h_1^2 = 80.24 \times 4^2 = 1283.84$

$W_2 h_2^2 = 78.74 \times 7.5^2 = 4429.13$

$$\sum_{j=1}^{n} W_j h_j^2 = 5713$$

$V_b = 0.06 \times 155.01 = 9.54\text{kN}$

$$Q_1 = \frac{1283.84}{5713} \times 9.54 = 2.7\ kN$$

$$Q_2 = \frac{4449.13}{5713} \times 9.54 = 7.4\ kN$$

Storey Shear at roof, $SF_1 = 7.4 + 2.7 = 10.1$ kN

Storey Shear at floor, $SF_2 = 7.4$ kN

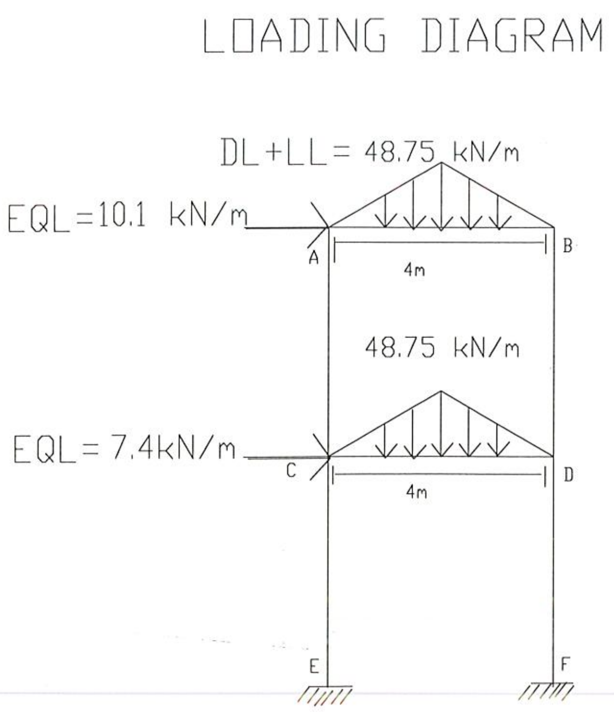


Figure 20: Loading Diagram for Earthquake, Live Load and Dead Loads

2.2 Analysis of frame by moment Distribution Method

Following tables show the analysis of the frame for load combination (DL+LL+EQL), using moment distribution method under.

1	joint	A		B		C			D			E	F
2	member	AB	AC	BA	BD	CA	CD	CE	DB	DC	DF	-	-
3	k	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{4}$	-	-
4	D.F	.466	.534	.466	.534	.364	.318	.318	.364	.318	.318	-	-
5	FEM	-40.63	0	40.63	0	0	-40.63	0	0	40.63	0	-	-
6	BAL	18.93	21.7	-18.93	-21.7	14.79	12.92	12.92	-14.79	-12.92	-12.92	-	-
7	CO	-9.47	7.40	-9.47	7.40	10.55	-6.46	0	-10.55	6.46	0	6.46	-6.46
8	BAL	.96	1.10	.96	- 1.10	-1.60	-1.40	-1.40	1.60	1.60	1.40	0	0
9	CO	-0.48	-0.8	0.48	0.8	0.55	0.70	0	- 0.55	- 0.70	0	- 0.70	- 0.70
10	BAL	0.60	0.68	-0.60	- 0.68	-0.46	-0.40	-0.40	0.46	0.40	0.40	-	-
11	CO	-0.30	-0.23	0.30	0.23	0.34	0.23	0	-0.34	-0.23	0	-0.20	-0.20
12	BAL	0.25	0.28	-0.25	- 0.28	-0.21	-0.18	-0.18	0.21	0.18	0.18	-	-
13	M_L	-30.14	30.14	30.14	-30.14	24.26	-35.12	10.97	-24.26	35.12	-10.97	-5.56	-5.56

Table 4: Bending Moment in each Member (Non Sway)

1	joint	A		B		C			D			E	F
2	member	AB	AC	BA	BD	CA	CD	CE	DB	DC	DF	-	-
3	k	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{4}$	-	-
4	D.F	.466	.534	.466	.534	.364	.318	.318	.364	.318	.318	-	-
5	FEM	-	50	0	50	50	0	-38.11	-50	-	-38.11	-38.11	-38.11
6	BAL	-23.3	- 26.7	23.3	- 26.7	-4.33	-3.78	-3.78	-4.33	-3.78	-3.78	-	-
7	CO	-11.65	-2.17	-11.65	-2.17	-13.35	-1.89	-	-13.35	-1.89	-	-1.89	-1.89
8	BAL	6.44	7.38	6.44	7.38	5.55	4.85	4.85	5.55	4.85	4.85	-	-
9	CO	3.22	2.78	3.22	2.78	3.69	2.28	-	3.69	2.28	-	2.43	2.43
10	BAL	-2.80	-3.2	2.80	-3.2	-2.17	-1.9	-1.9	-2.17	-1.90	-1.90	-	-
11	CO	-1.4	-1.09	-1.4	-1.09	-1.6	-.95	-	-1.6	-.95	-	0.95	0.95
12	BAL	1.16	1.33	1.16	1.33	0.93	0.81	0.81	0.93	0.81	0.81	-	-
13	CO	0.58	0.47	0.58	0.47	0.67	0.41	-	0.67	0.41	-	0.41	0.41
14	BAL	-0.49	-0.56	-0.49	-0.56	-0.39	-0.34	-0.34	-0.39	-0.34	-0.34	-	-
15	M_2	-28.24	28.24	28.24	28.24	-39	-0.51	-38.47	-39	-0.51	-38.47	-	-
16	M_2C_2 C_2=0.384	-10.84	10.84	-10.84	10.84	14.98	-0.20	-14.77	14.98	-0.20	-14.77	-14.63	-14.63

Table 5: Analysis by Moment distribution method(Due to the Sway in the Lower Storey)

		A		B		C			D			E	F
1	joint	A		B		C			D			E	F
2	member	AB	AC	BA	BD	CA	CD	CE	DB	DC	DF	EC	FD
3	k	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{4}$	$\frac{I}{3.5}$	$\frac{I}{4}$	$\frac{I}{4}$	-	-
4	D.F	.466	.534	.466	.534	.364	.318	.318	.364	.318	.318	-	-
5	FEM	-	-50	0	-50	-50	0	0	-50	-	-	-	-
6	BAL	23.3	26.7	23.3	26.7	18.2	15.9	15.9	18.2	15.9	15.9	-	-
7	CO	11.65	9.10	11.65	9.10	13.35	7.95	0	13.35	7.95	0	7.95	7.95
8	BAL	-9.67	-11.08	-9.67	-11.08	-7.75	-6.77	-6.77	-7.75	-6.77	-6.77	-	-
9	CO	-4.84	-3.88	-4.84	-3.88	-5.54	-3.34	0	-5.54	-3.34	0	-3.34	-3.34
10	BAL	4.06	4.66	4.06	4.66	3.23	2.82	2.82	3.23	2.82	2.82	-	-
11	CO	2.03	1.62	2.03	1.62	2.33	1.41	0	2.33	1.41	0	1.41	1.41
12	BAL	-1.70	-1.95	-1.70	-1.95	-1.36	-1.19	-1.19	-1.36	-1.19	-1.19	-	-
13	CO	-0.85	-0.68	-0.85	-0.68	-.98	-.60	0	-.98	-.60	0	-.60	-.60
14	BAL	0.71	0.82	0.71	0.82	0 .58	0.50	0.50	0.58	0.50	0.50	-	-
15	M_1	24.69	-24.69	24.69	-24.69	-27.94	16.68	11.26	-27.94	16.68	11.26	5.42	5.42
16	M_1C_1 C_1=0.236	5.83	-5.83	5.83	-5.83	-6.60	3.94	2.66	-6.60	3.94	2.66	1.28	1.28

Table 6: Analysis by Moment distribution method (Due to the Sway in the upper Storey)

nt	A		B		C			D			E	F
mber	AB	AC	BA	BD	CA	CD	CE	DB	DC	DF	EC	FD
(total ment)=$M_L+M_1C_1+M_2C_2$	-35.16	35.16	25.12	- 25.12	32.64	-31.38	-1.15	-15.88	38.96	-23.09	-18.92	-18.92

Table7: Bending Moment in Each Member

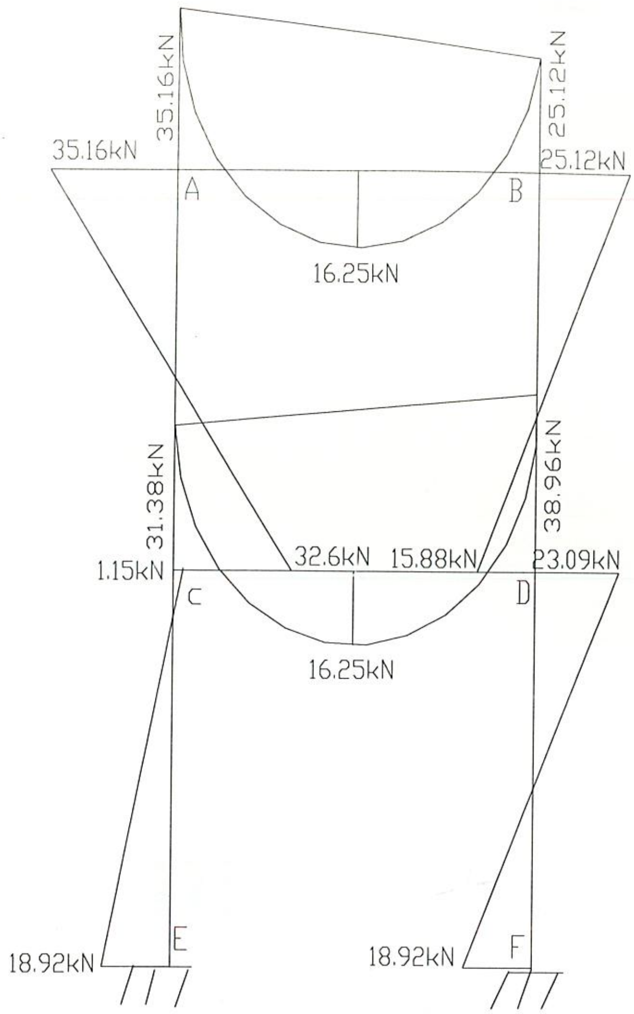


Figure21: Bending Moment Diagram for all members

3
DESIGN OF THE BUILDING

Design Procedure

The members of the building have been designed using IS:456 :2000.

3.1 Design of columns using SP-16

The columns of the building AC,BD, ,GI,HJ (as shown in Fig. 21) are 3.5m and columns CE,IK, DF and JL are 4m (figure18). All the columns have been designed for the maximum bending moment and loading which are on column AC . All columns are designed for forces of column AC.

For concrete, M25, f_{ck}=25N/mm^2

Fe415, fy=415 N/mm^2

Factored load= 50*1.5=75KN

Factored bending moment=38*1.5=57KNm

Now using SP-16

$$\frac{Pu}{fck*b*d} = \frac{75*10^3}{25*250*250} = 0.48$$

$$\frac{\mathrm{Mu}}{\mathrm{fck*b*d^2}} = \frac{57*10^6}{25*150*150^2} = .146$$

Assume 20mm bars with 30mm cover

d = 30 + 10 = 40mm = 4cm

d/D = 4/25 = .16

Refer chart 45 of SP-16

d/D=.15, f_y = 415

p/f_{ck} =.12 , p = .12*25 = 3

As = .03*25*25 = 18.75cm^2

Provide 4 bars with 20mm diameter and 4 bars with 16mm diameter.

As_1+As_2 = 1256.6mm^2+804.25mm^2 = 2060.84mm^2

Lateral Ties :

Minimum diameter of bars for ties

$$\Phi_t = \frac{\textit{Diameter of longitudinal bar}}{4} = 20/4 = 5\text{mm}$$

Or 5mm whichever is greater

Use 8 mm Φ bars at the spacing of least of the following :

1. The least lateral dimension i.e. 250mm
2. 16Φ(of longitudinal bars) i.e. 320mm
3. 300mm

Provide 8mm Φ mild steel ties@ 250 mm c/c.

Similarly for 16mm bars

$$\Phi_t = \frac{\textit{Diameter of longitudinal bar}}{4} = 16/4 = 4\text{mm}$$

or 5mm whichever is more

Use 8mmΦ bars at the spacing of least of the following :

1. The least of lateral dimension i.e. 250mm
2. 16Φ(of longitudinal bars) i.e. 256mm
3. 300mm

Provide 8mm Φ mild steel ties@ 250 mm c/c.

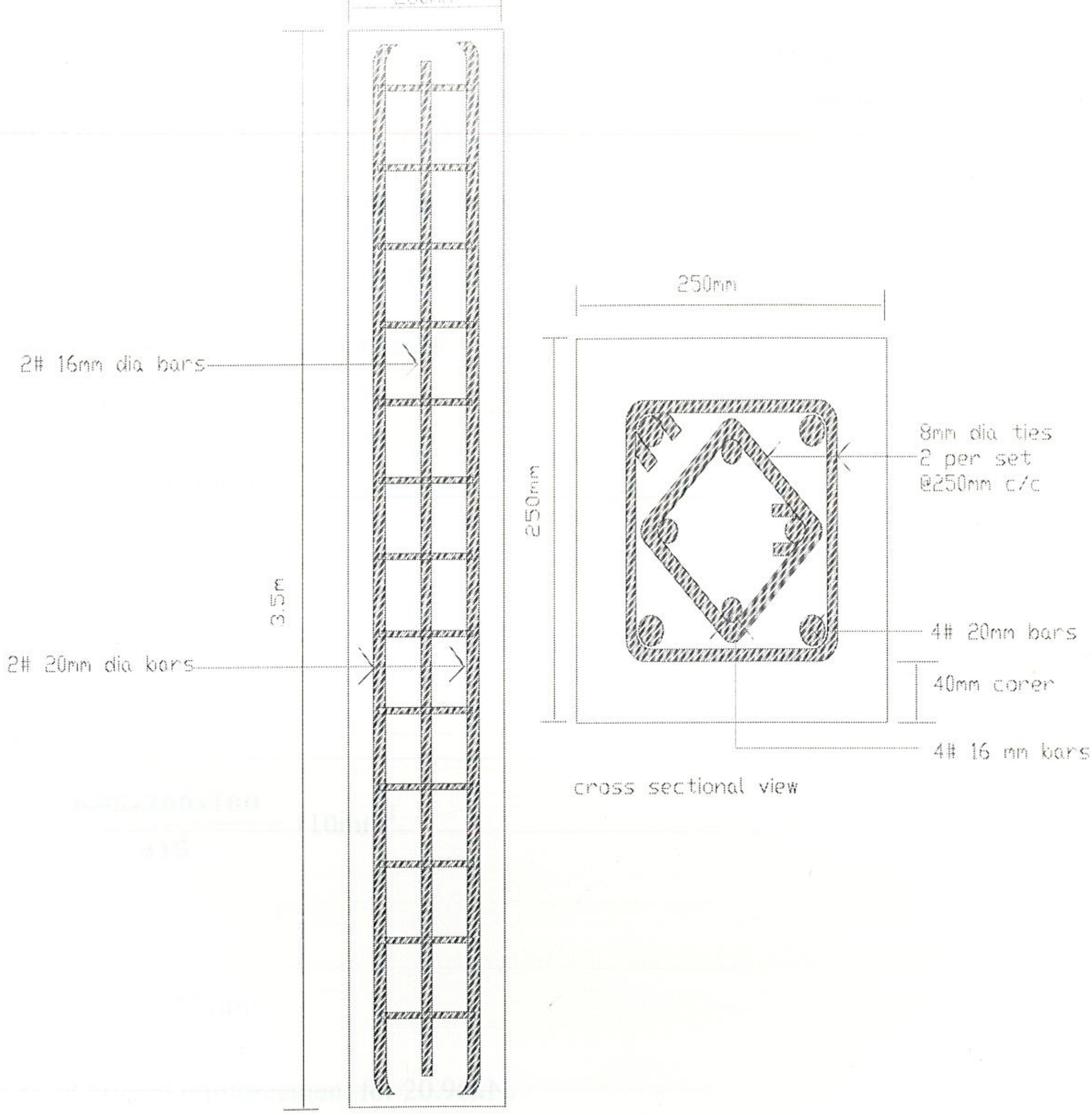


Figure 22: Detailing of Column

3.2 Design of Beam

The beams of the building AB, CD, GH and IJ are 4m and beams BH, DJ, , AG and CI are 5m. All the beams have been designed for the maximum bending moment which is on beam CD or IJ(figure 18). All beams are designed for forces of beam CD.

Factored Bending Moment $38.96 * 1.5 = 58.44kN$

Take d= 300mm

If Fe 415 is used and concrete of M25 grade are used

$0.1388\ f_{ck}ld^2 = 37.45kN$

$M_{additional} = 58.44 - 37.48 = 20.96kN$

Overall depth

D = 300 + 10 + 20 = 330mm

Effective Depth d = 300mm

For M25 & Fe415

$$A_{st\ min} = \frac{0.85*b*d}{fy} = \frac{0.85*300*180}{415} = 110mm^2$$

$Pt_{lim} = 1.201$

$$A_{st1} = \frac{1.201*180*300}{100} = 648.45mm_2$$

We have to provide additional reinforcement for 20.96kN.

$A_{st2} = (0.87 * f_y) = A_{sc}(f_{sc} - f_{cc})$

$$\frac{d}{d} = \frac{30}{300} = 0.1$$

$f_{cc} = 0.477 * 85 = 11.175kN$

fsc = 351.93MPa (for Fe 415 & $\frac{d}{d} = 0.1$)

$A_{st2} = 215mm^2 \approx 220mm^2$

$A_{st2} = \frac{Mad}{0.87fy(d-d')}$

$A_{st2} = \frac{20.96}{0.87*415*(300-30')}$

A_{st2} * $0.87f_y = A_{sc}$ ($f_{sc} - f_{cc}$)

215 * 0.87 * 415 = A_{sc} (351.93 – 11.175)

A_{sc} = 227.81mm^2

For Mid- Span:-

Max Moment at mid-span

16.5 * 1.5 = 24.75 kNm

$$R_u = \frac{4.6*24.75*10^6}{25*180*300^2}$$

$$A_{st} = \frac{25*180*300}{2*415}\left[1-\sqrt{1-.287}\ \right] = 252.04mm^2$$

Thus for end span, the total tension steel to be provided at end span

$A_{st} = A_{st1} + A_{st2}$

= 648.54 + 215 = 864mm^2

Provide 2#20mmΦ and 2#12mmΦ ≈ 854mm^2

Total Compression Steel to be provided

A_{sc} = 230mm^2

Provide 2#12mmΦ =226mm^2

For mid span

A_{st} 252.04mm^2≈ 250mm^2

A_{st} = 227mm^2

End Span :

Normal Shear Stress :

$\frac{48.75}{2}(2-0.3)$

= 41.44kN

$p_t = \frac{864*100}{150*300} = 1.7$

For M_{25} grade concrete & $p_t = 1.7$

$T_{uc} = .775$

$T_{u\,max} = 3.1$ for M_{25}

$T_u = \frac{Vu}{bd} = \frac{41.44*10^3}{150*300} = .921MPa$

$T_{uc} \leq T_v \leq T_{u\,max}$

$V_{us} = V_u - T_{uc}*bd$

$V_{us} = 41.44 - .775 * 300 * 150 = 6.57$

Required spacing of Stirrups

$S_v = 923.23$mm

$S_v = \frac{.87*415*56*300}{6.57*10^3}$

The spacing will be the least of the following

a) $0.75 * d = 0.75 * 300 = 225$mm
b) 450mm
c) $\frac{Asv*fy}{0.4b} = \frac{56*415}{0.4*300} = 194mm$
d) $923.23mm$

Thus provide 2 legged 6mm Φ 2 vertical stirrups @ 200mm spacing

For Mid –Span

$P_t = \frac{227*100}{150*300} = 0.504$

For M_{25} grade concrete and $p_t = .5$

$T_{uc} = .489$

$T_{uc\,max} = 3.1$ (for M_{25})

$T_{uc} \leq T_u \leq T_{uc\,max}$

$$T_u = \frac{41.44*10^3}{150*300} = .921$$

The section is acceptable

$V_{us} = V_u - T_{uc}$ bd

V_{us} = 41.44 - .489*300*150

= 19.64kN

$$S_v = \frac{.87*415*56*300}{19.64*10^3} = 312.09mm$$

The spacing will be the least of the following

a) 0.75 * d = 0.75 * 300 = 225mm
b) 450mm
c) $\frac{Asv*fy}{0.4b} = \frac{56*415}{0.4*300} = 194mm$
d) $312mm$

Thus provide 2 legged 6mm Φ 2 vertical stirrups @ 250mm spacing

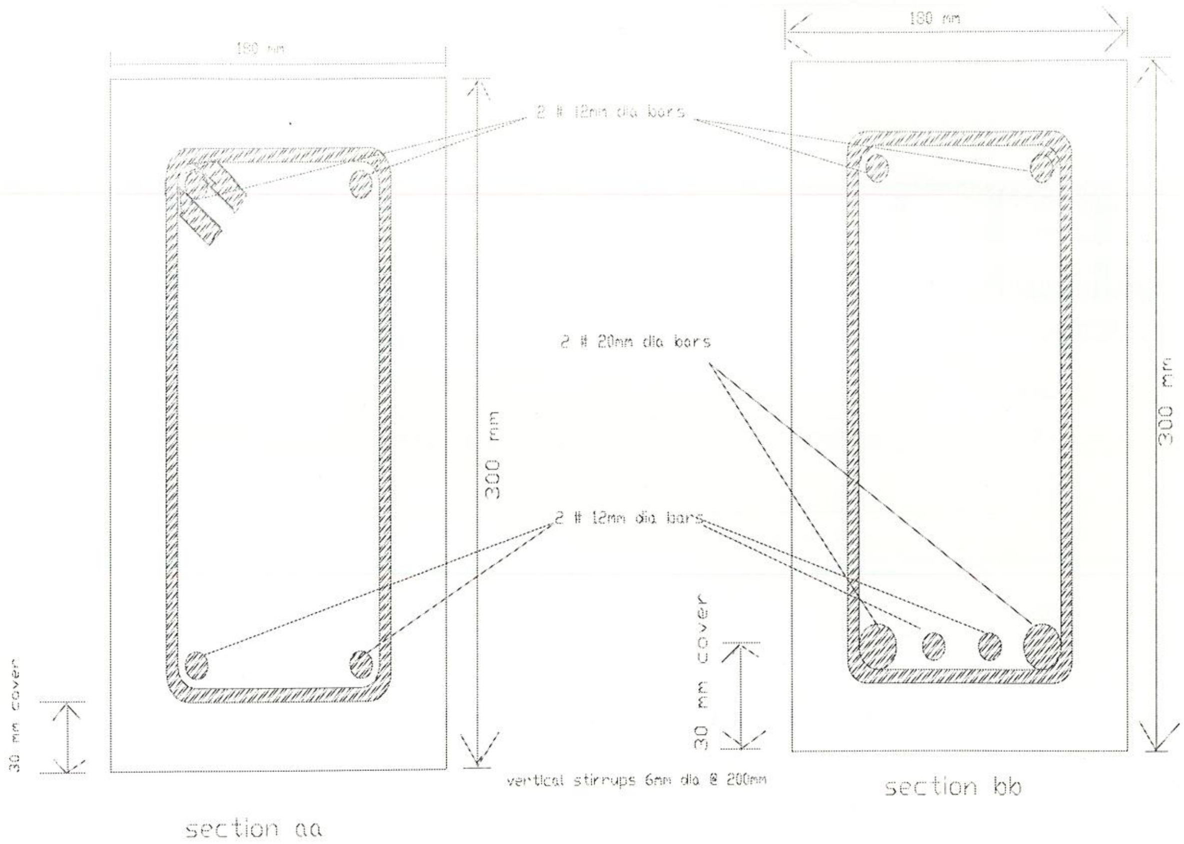


Figure 23 : Sectional view of Detailing of Beam

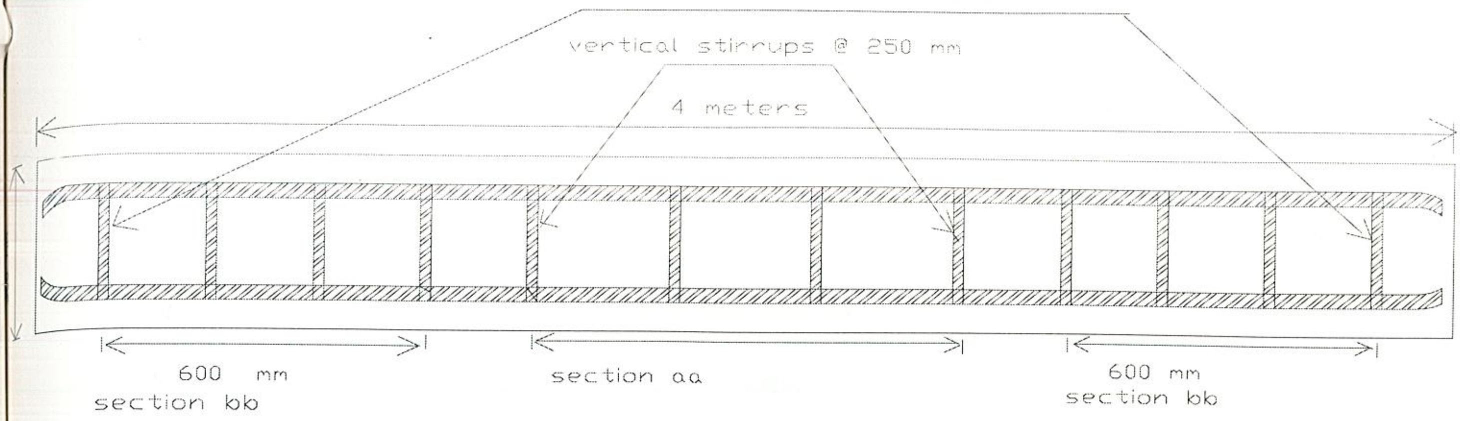


Figure 24 : Longitudinal View of Detailing of a Beam

3.3 Design of slab

The slab is 5m x 4m and the design for the floor and roof slab is same .The roof slab may be represented by the area ABHG and the floor slab by ABHG(figure 18).

Overall depth

= 122.7 + 15 + 5 = 142.70mm

Thus, 150mm thick slab with d=130mm

The efficient span of the slab in each direction is given by :

Clear Span + d (or width of support whichever is less)

Thus Effective span will be lesser of the following :

1) 4000 + 130 = 4130mm
2) 5000 + 130 = 5130mm

   Thus l_x = 4.13

   Analysis for Moment and Shear Force

   D.L of slab $w_g = 0.15 * 25 * 1 = 3.75$ kN/m

   Floor finish $w_f = 0.23$ kN/m^2

   Live Load = 5 kN/m^2

   Total Service Load = 8.98 kN/m^2

   Factored Load $W_u = 13.47$kN/m^2

Ratio $= \frac{ly}{lx} = \frac{5.13}{4.13} = 1.242$

Using Table 26 of IS:456 we find the values of α_x and α_y

α_x=0.0755 α_y=0.056

$M_{ux} = \alpha_x w_u(l_x)^2 = 17.35$ kNm/m

$M_{uy} = \alpha_y w_u(l_x)^2 = 12.87$ kNm/m

Thickness of slab from flexible consideration for a balanced design is obtained as :

$0.1388 * f_{ck} * bd^2 = 17.35 * 10^6$

d = 70.71 + 15 + 5 = 90.91mm

However, from serviceability limit state criterion of deflection, the depth adopted is 150mm

$R_{ux} = \frac{4.6Mux}{fck*bdx2}$

$$= \frac{4.6*17.35*10^6}{25*1000*130^2} = 0.189$$

$$R_{uy} = \frac{4.6Muy}{fck*bdy2}$$

$$= \frac{4.6*12.87*10^{-6}}{130^2*1000*25} = 0.140$$

Reinforcement:-

$$A_{st} = \frac{fck\ b\ d}{2\ fy}\left[1-\sqrt{1-Ru}\right]$$

$$= \frac{25*1000*130}{2*415}\left[1-\sqrt{1-0.189}\right]$$

$A_{st\ x} = 389.39mm^2$

$$A_{st\ y} = \frac{25bd}{415*2}\left[1-\sqrt{1-.140}\right]$$

$A_{sty} = 284.42mm2$

Minimum Distribution Steel

$$Ast = \frac{.15*1000*150}{100} = 225mm^2$$

Along short span provide 10mmΦ bars at 150mm c/c

(Ast $329.69mm^2 > 389.39mm^2$)

Along long span provide 10mmΦ loss at spacing 230mm

(Ast $314.16mm^2 > 284.42mm^2$)

Check for Deflection

The check is the criteria along the short span based on span to depth ratio = 20

$$Pt = \frac{100*Ast}{bd} = \frac{100*389.39}{1000*130}$$

Pt = 0.3

The modification Factor is 2.00 for Pt = 0.30

$$d = \frac{4000+130}{20*2} = 103.25 < 130mm$$

Hence, it is safe

Cracking

1. Maximum spacing permitted for short span steel is smaller of the following :

 3d = (3*130)

 =390mm or 450 mm

 i.e. 390mm

 Spacing provided

 150mm c/c < 390mm

2. Maximum spacing permissible for long span steel is smaller of the following :

3d = (3*130) or 450mm

i.e. 390mm

Spacing Provided

= 260mm c/c < 390mm

Check for Shear :

Shear is vertical along supports parallel to long span at a distance of the effective depth from forces of support.

$V_u = 13.47(\frac{4.0}{2} - 0.13)$

$V_u = 25.19kN$

Nominal Shear

$$T_u = \frac{25.19*10^3}{1000*130} = 0.194MPa$$

For a solid slab having pt =.26 and M_{25} grade concrete T_c = 0.37Mpa

The permissible shear stress

K x Tc = 1.3*.371 = 0.4823 MPa

0.4823MPa> 0.194

Hence no shear force is required

Check for development length

Development Length Ld

$$\frac{0.87*fy*\Phi}{4Tbd} = \frac{0.87*415*\Phi}{4*2.24}$$

Design Bend Stress

Tbd=2.24(for M25 and Fe415 IS:456)

Ld $\leq 1.3\left(\frac{Mu1}{Vu}\right) + Lo$

Vu= 13.47 + 2.525=27.82kN

Mu1 = $\frac{17.35}{2} = 8.68kNm$

Assume Lo = 10Φ

$$40.3\Phi \leq \frac{1.3*8.68*10^6}{27.82*10^3} + 10\Phi$$

$\Phi \leq 13.39$

Hence 10mm Φ bars are satisfactory

Along short edges

Vu = 27.82kN

Mu_l= 6.45kNm

$\Phi \leq 9.95$

The bar size adopted is satisfactory as it is very close to 10mm

Thus the land is more critical along short edge

Minimum length of embankment

Le=Ld/3 = 40.3 Φ/3 = 134.33mm

The length of embankment = Width of support – Clear Cover of 15mm

$180 - 15 = 165\text{mm} > \frac{40}{3}(134.33)$

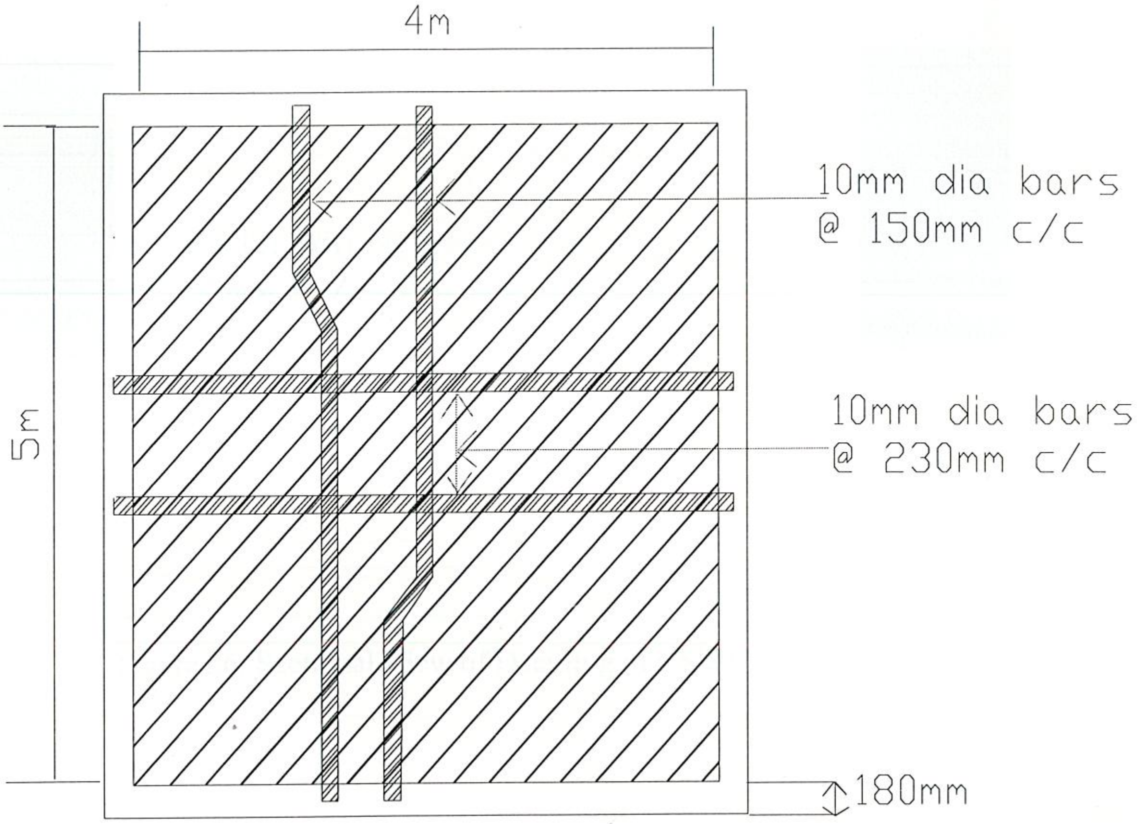


Figure 25: Top View of Detailing of Slab

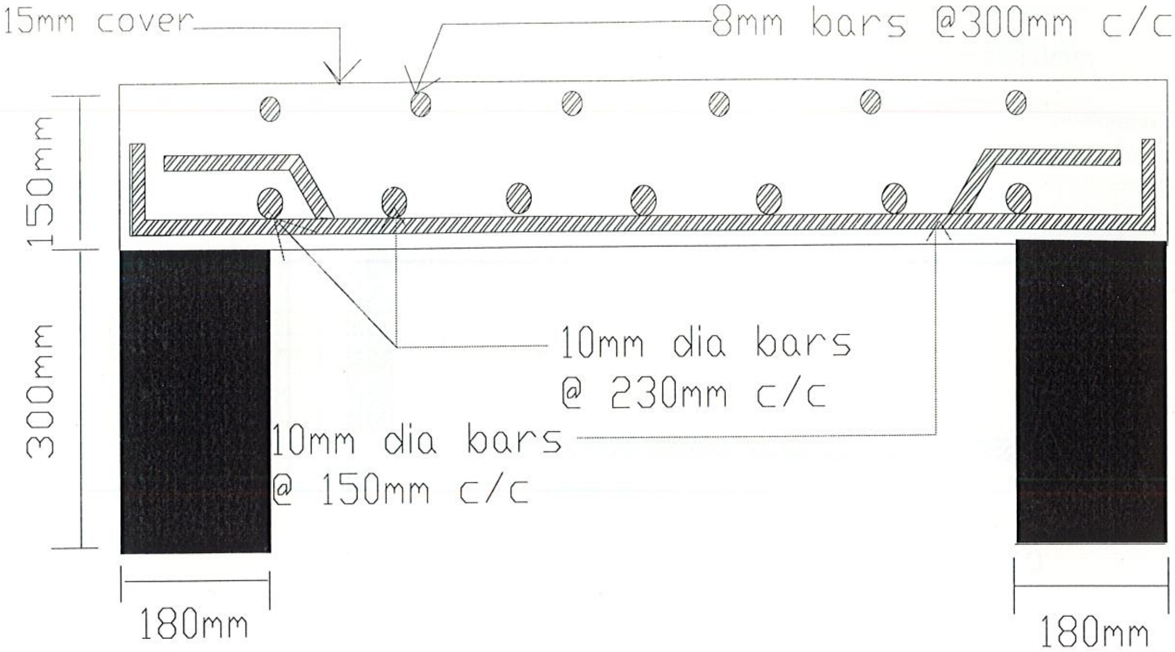


Figure 26: Sectional View of Detailing of a Slab

3.4 Detailing of Beam column joint

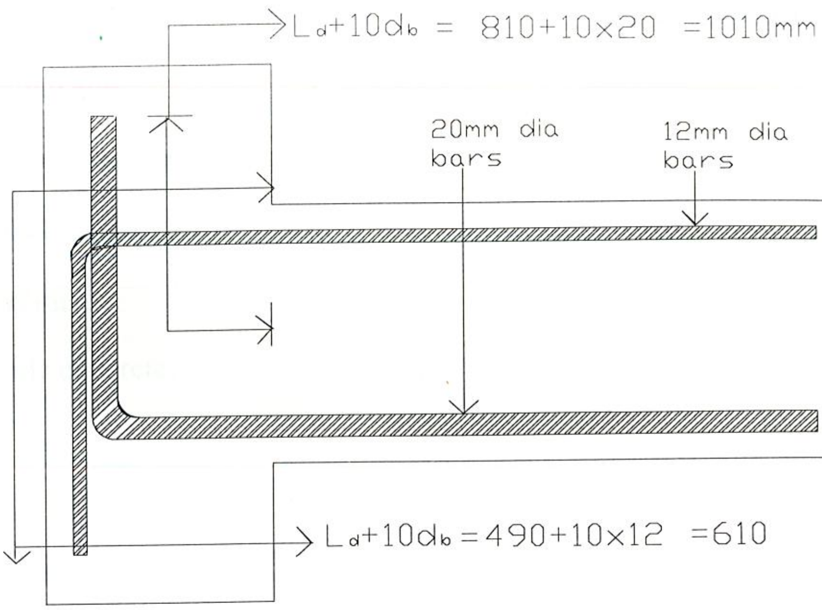


Figure 27: Beam column joint

3.5 Design of Footing

There are four footings which are under the columns CE, DF, JL and IK. They have been designed for maximum Bending moment which is 57kNm and load 100kN (factored).

Size of column = 250 x 250 mm

Bearing Capacity of Soil = 80 kN/m^2

Factored Load = 1.5 x 100 = 150kN

Factored Moment = 57kNm

For Fe415 and M25 Grade concrete:

$X_{u\,max}/d = 0.479$

$R_u = 3.452$

Calculation of the Size of footing

W=150kN

W_1= 10% of W = 10% of 150 = 15kN

$165 / B^2 + (57 \times 6)/B^3 = 80$

165 B +342 =80 B^3

Solving by trial and error we get B =2.04m

Take B =2.1m

Take square footing of size 2.1m x 2.1m

The maximum and minimum soil pressures are given by:

$$p_{o1} = \frac{W}{B^2} + \frac{6M}{B^3} = \frac{165}{2.1^2} + \frac{6 \times 57}{2.1^3} = 74.34 \text{ kN/m}^2$$

$$p_{o2} = \frac{W}{B^2} - \frac{6M}{B^3} = \frac{165}{2.1^2} - \frac{6 \times 57}{2.1^3} = .486 \text{ kN/m}^2$$

Pressure intensity under the column axis is:

p_o =0.5(74.34 + 0.486) =37.413 kN/m^2

Design of the section for bending compression

Arrange the footing centrally under the column

Intensity of the soil pressure below the column face is

$p_{o\,3} = 37.41 + ((74.34 - 37.41) \times .125))/1.05 = 41.81$ kN/m^2

Cantilever Length =0.5 x (B –b) =0.5 x 92.1-0.25) = 0.925m

Total force under cantilever = (2.1 x 0.925) x $\frac{41.81 + 74.34}{2}$ =112.81 kN

Distance of the centroid from AB:

$$\frac{41.81+2 \times 74.34}{41.81+74.34} \times \frac{1}{3} = 0.547\text{m}$$

B M = 112.81 x 0.545 =61.48 kN/m^2

M =1.5 x 6.148 x 10 ^{7}=9.15 x 10 ^{7} Nmm

$$d = \sqrt{(M_u/(R_u \times b_1))} = \sqrt{\frac{9.15 \times 10\ 7}{3.452 \times 250}}$$

d = 325.6`mm Take d= 340mm

Take d = 340mm

D = 340 +60 =400mm

Providing an Effective Cover of 60mm.

Effective Depth available for the second layer = 340 – 12 = 328mm.

Provide 12mm dia bars.

Provide D at the ends = 170mm

So d at the ends = 170-60 = 110mm

Design for shear

The depth found above should be safe for shear .

For two way shear the critical plane lies in d/2 = (340/2) = 170mm from the column face for which width $b_0 = b + (d/2) = 250 + 170 + 420$mm

The punching shear stress = $T_v = \frac{Fu}{4b_o \times d}$

F_u =Punching Shear =1.5 x (W – $p_o b_o^2$) = 1.5 x (150 – 37.413 x 0.42^2) = 215.10 kN

$d_0 = d_1 + 2\,(d - d_1)\;\; x\;(B - b - d)/2$

$d_0 = 110 + \left(\frac{340-110}{2100-250}\right) \times (2100 - 250 - 340)$ =297.73 mm

$$T_v = \frac{215.1 \times 1000}{4 \times 297.73 \times 0.42} = 0.430 \text{ N/mm}^2$$

Permissible Shear stress = k_s x T_c = 1 x 0.25 x$\sqrt{25}$ = 1.25 N/mm^2.

Hence the thickness found from the point of view of bending compression is safe.

For one way shear the critical section CD will be at a distance d = 340mm.

From the column face the cantilever length to the right of section CD

= 1.05 -0.125 – 0.34 = 0.585m

Intensity of pressure p_2 at CD is given by:

p_2 =0.486 + ((74.34 -0.486)/2.1) x (2.1 - 0.6) = 53.24 kN/m^2

The section at CD will be trapezoidal and the width at the tpo is given by

$b = 250 + \frac{2100-250}{1000}$ x 340 = 879mm

Effective Depth d' = 110 + $\frac{(340-110)}{1000}$ x 585 =244.55 mm

For balanced section

$x_{u\,max}/d$ =0.479 , let x_u/d =0.4 for under reinforced section

x_u =0.4 d' = 0.4 x 247.55 = 97.82mm

width of the section at neutral axis is given by $b_n = \left(\frac{2100-879}{144.5}\right)$

Shear force V_u = 1.5 x 2.1 x 0.585 x 0.5 x (74.34 + 53.24) = 117.55 kN

$T = \frac{V_u}{b_n \times d'}$ =(117.55/(1705.28 x 244.55) = 0.282 N/mm^2

Permissible shear stress at p = 0.3 % .For under reinforced section = 0.384 N/mm^2 with k=1

Hence the thickness provided from point of view of bending compression is adequate.

Design for Bending tension

For under reinforced section

$$A_{st} = (0.5 \times f_{ck)} \frac{1}{f_y} \times \frac{1 - \sqrt{1 - 4.6\, M_u} \quad (b_1\, d)}{f_{ck} b_1 d^2}$$

$$A_{st} = (0.5 \times 25) \frac{1}{415} \times \frac{1 - \sqrt{1 - 4.6 \times 9.15 \times 10^7} \quad (250 \times 240)}{25 \times 250 \times 340^2} = 1654.16\, mm^2$$

Provide 12mm bars @ 140mm c/c.

Check For Developmental Length

L_d =47 x 12 = 564 mm

Available length provides a side cover of 60mm

925 -60 =865mm > 564mm .

Hence it is safe.

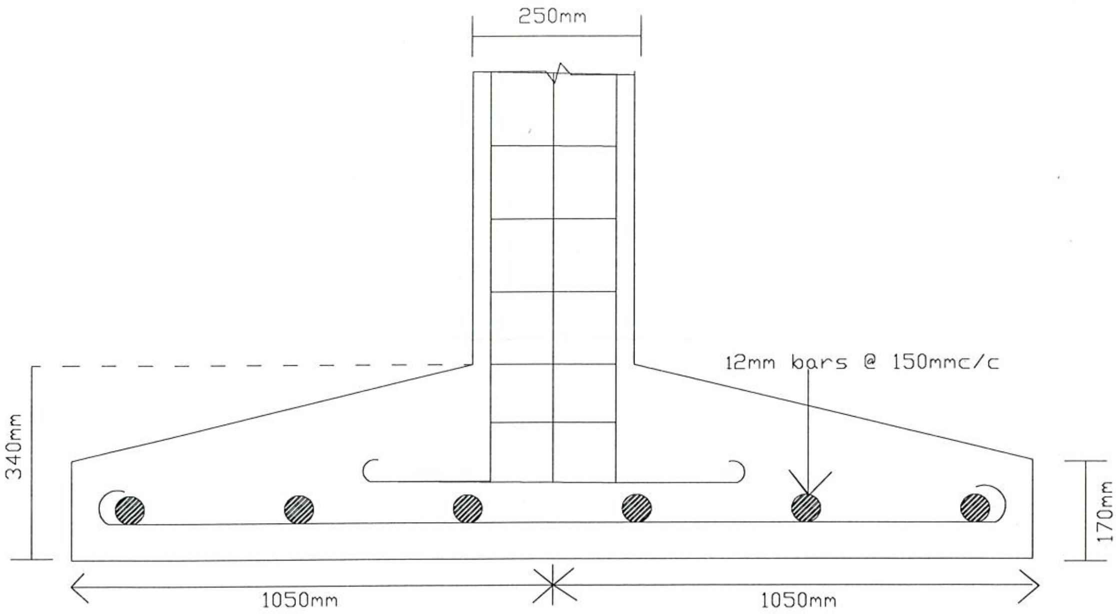


Figure 28: Detailing of Footing

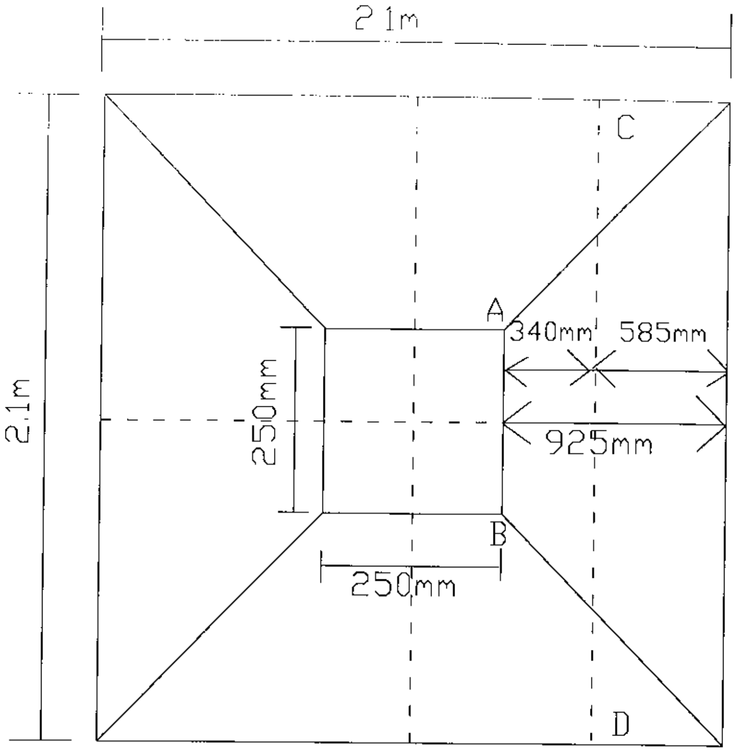


Figure 29: Top View of the Footing

4

ANALYSIS AND DESIGN OF THE BUILDING USING STAAD-PRO

4.1 Introduction

The two storey building analysed and designed using STAAD-PRO.

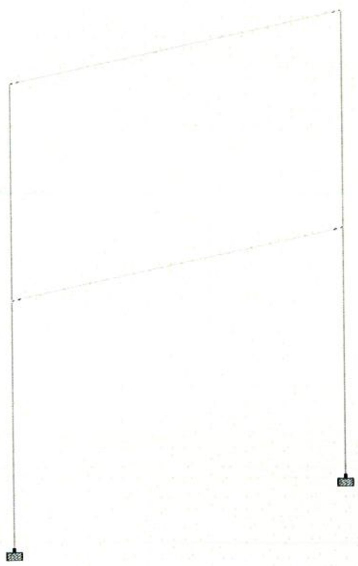


Figure 30 : 2-D and 3-D view of the frame

4.2 Loading Diagram

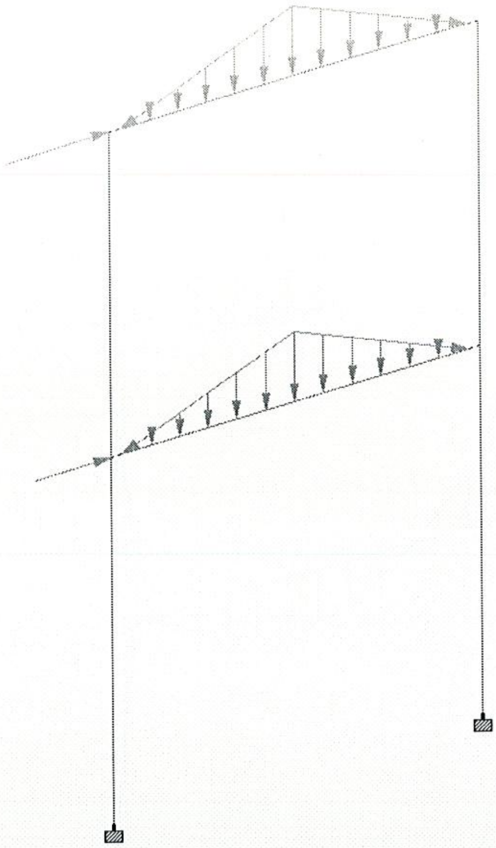


Figure 31: Loading Diagram as in STAAD-PRO

4.3 Bending Moment Diagram

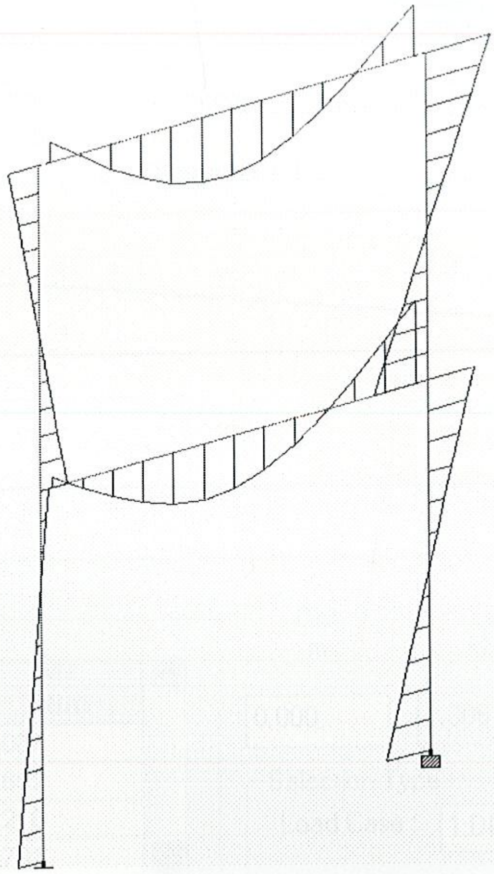
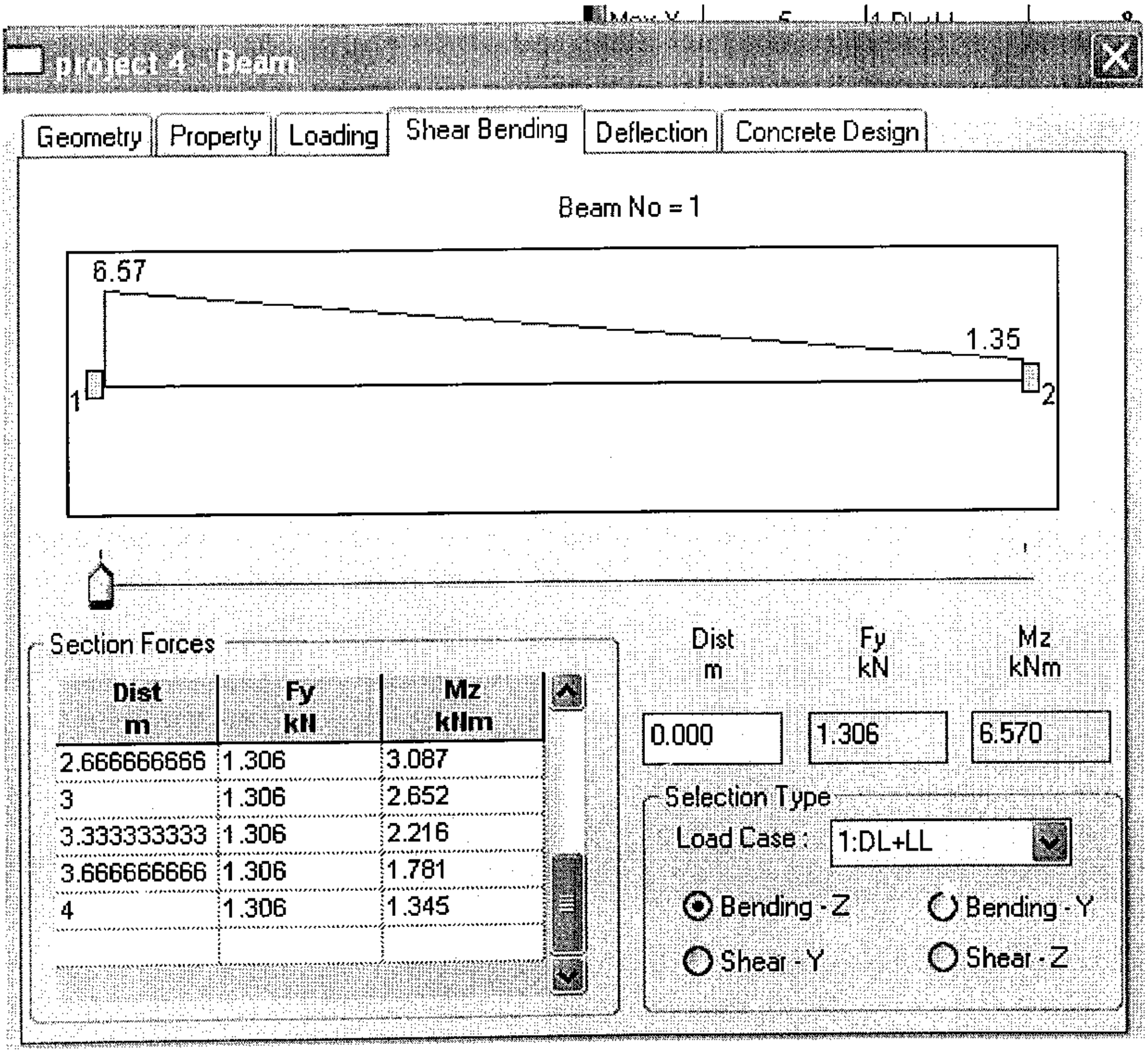
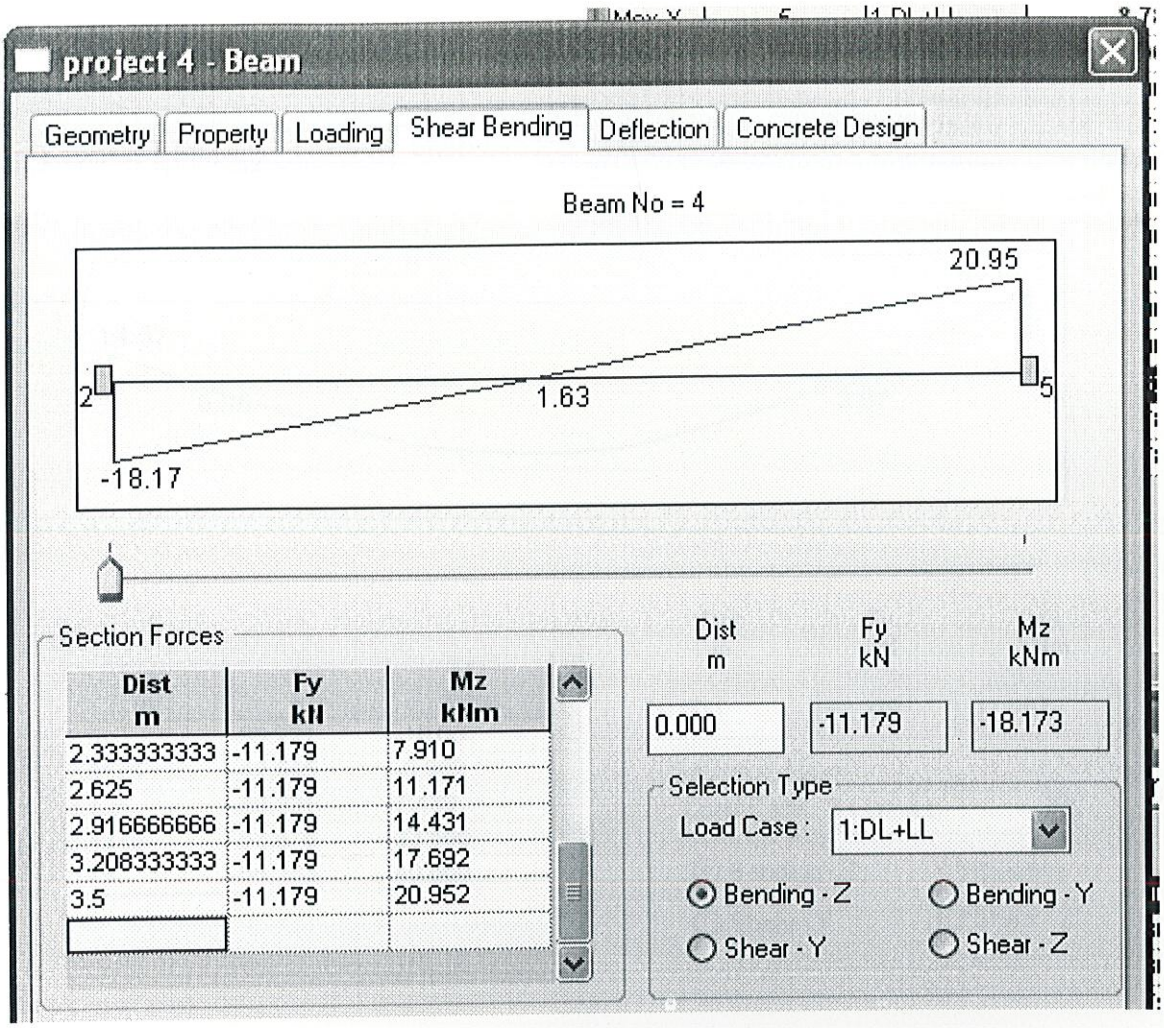


Figure 32: Bending Moment Diagram from STADD-PRO Analysis

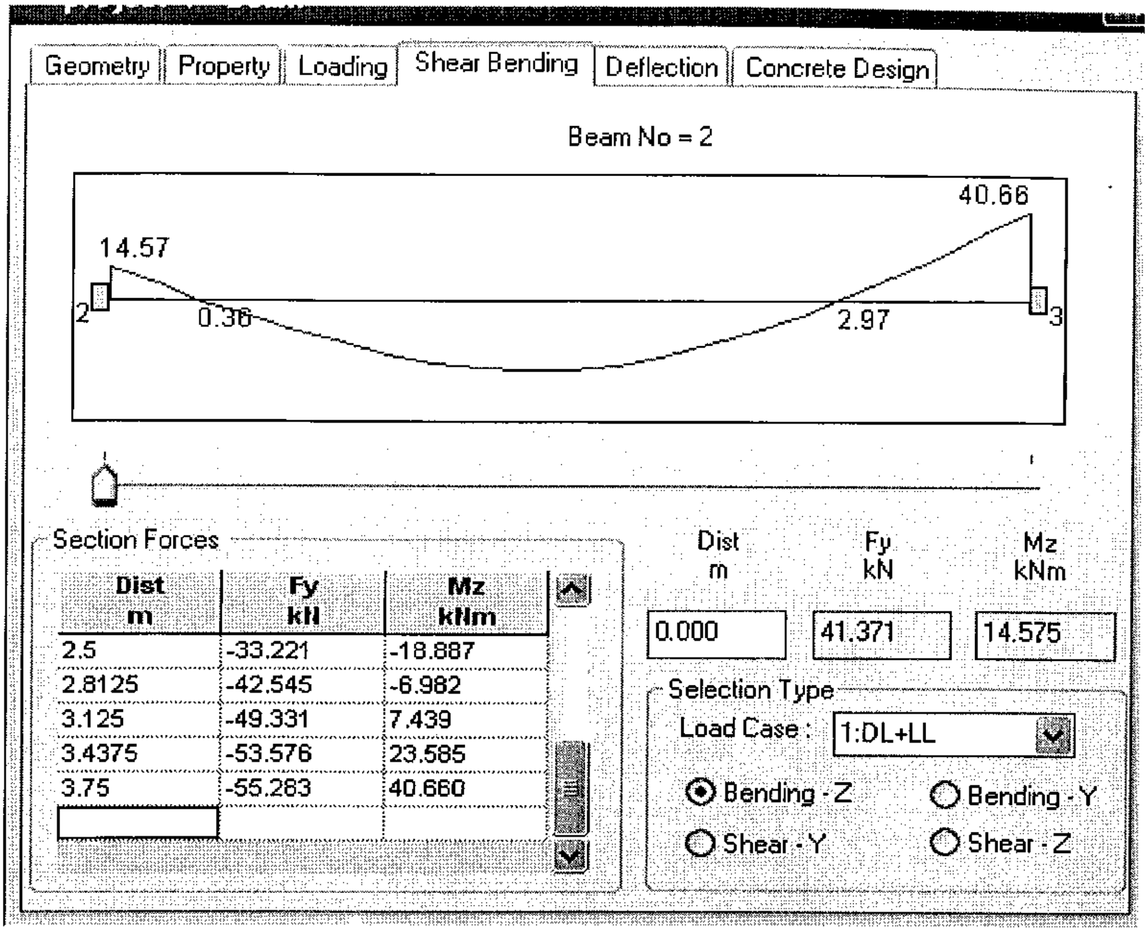
4.3.1Shear and bending moment for the columns of the first storey



Shear and bending moment for the columns of the second storey

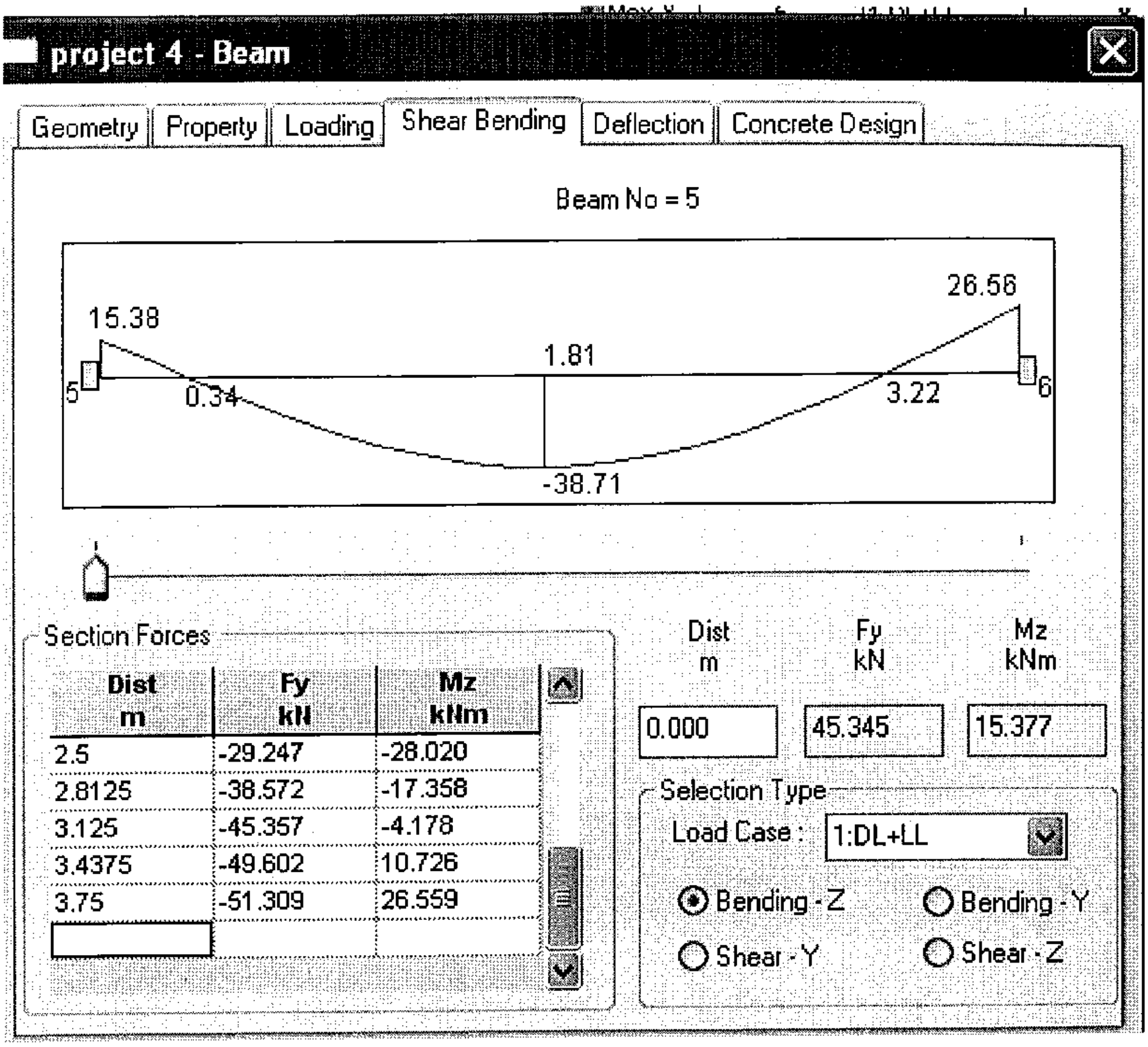


Shear and bending moment for the beams of the first storey



Dist m	Fy kN	Mz kNm
2.5	-33.221	-18.887
2.8125	-42.545	-6.982
3.125	-49.331	7.439
3.4375	-53.576	23.585
3.75	-55.283	40.660

Shear and bending moment for the beams of the second storey



Dist m	Fy kN	Mz kNm
2.5	-29.247	-28.020
2.8125	-38.572	-17.358
3.125	-45.357	-4.178
3.4375	-49.602	10.726
3.75	-51.309	26.559

4.4 Detailing of the members

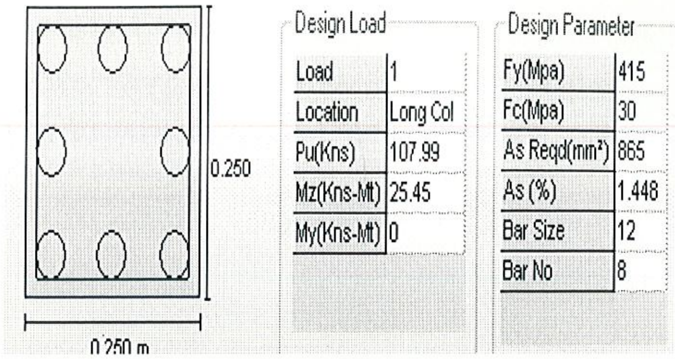


Figure 33: Detailing of the columns of the first storey

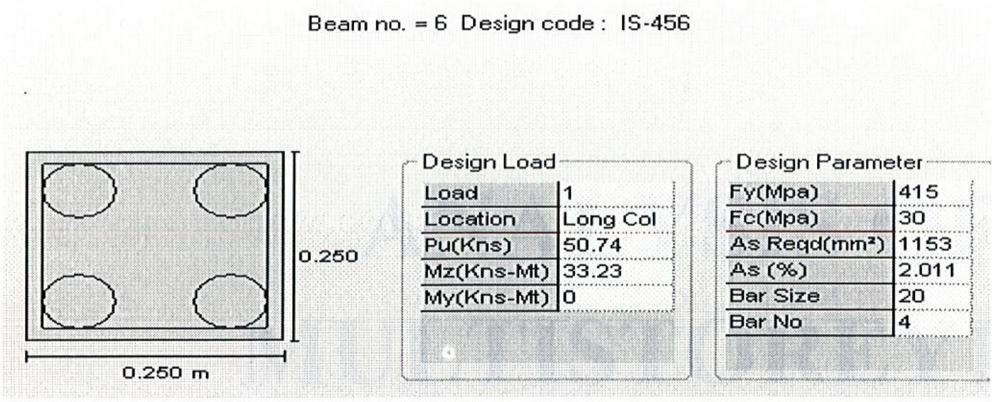


Figure 34: Detailing of the columns of the second storey

5

ANALYSIS OF A MULTISTOREYED BUILDING USING STADD-PRO

5.1 Introduction to the Problem

A multi storey building having eight storeys, bay width of 4m and the rise of each storey is 3.5m lying in seismic zone IV, having an importance factor of 1 and the building is SMRF(having a response reduction factor of 5) is analysed and designed using STAAD-PRO.

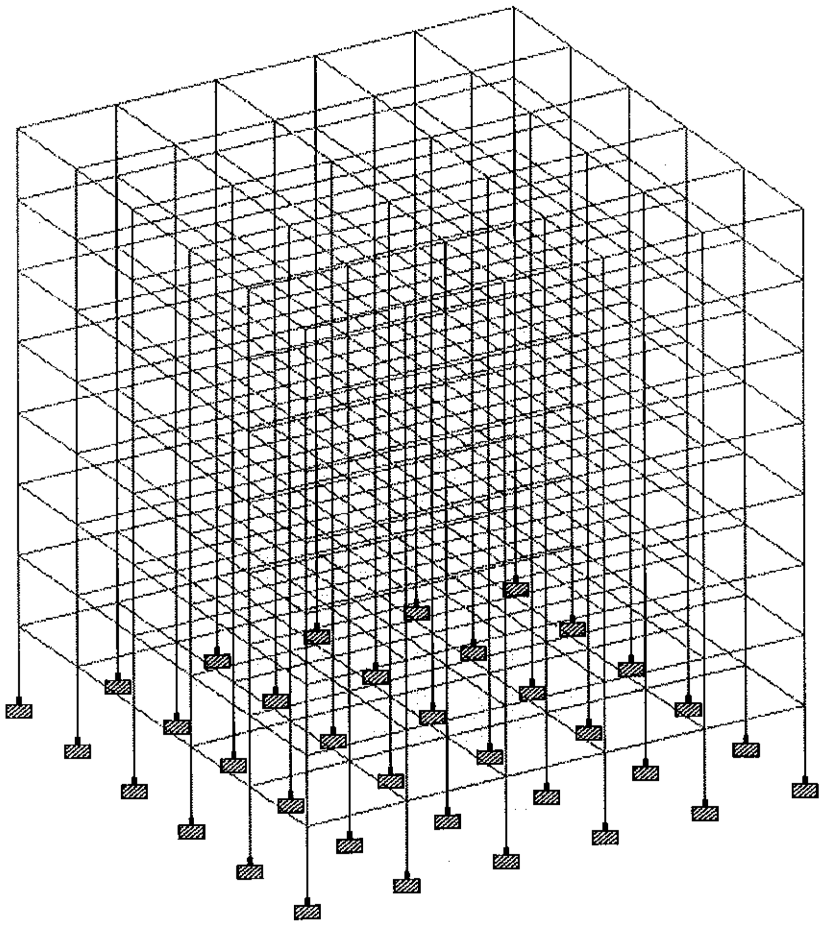


Figure 35 Frame of a eight storey building

5.2 Analysis using STAAD-PRO

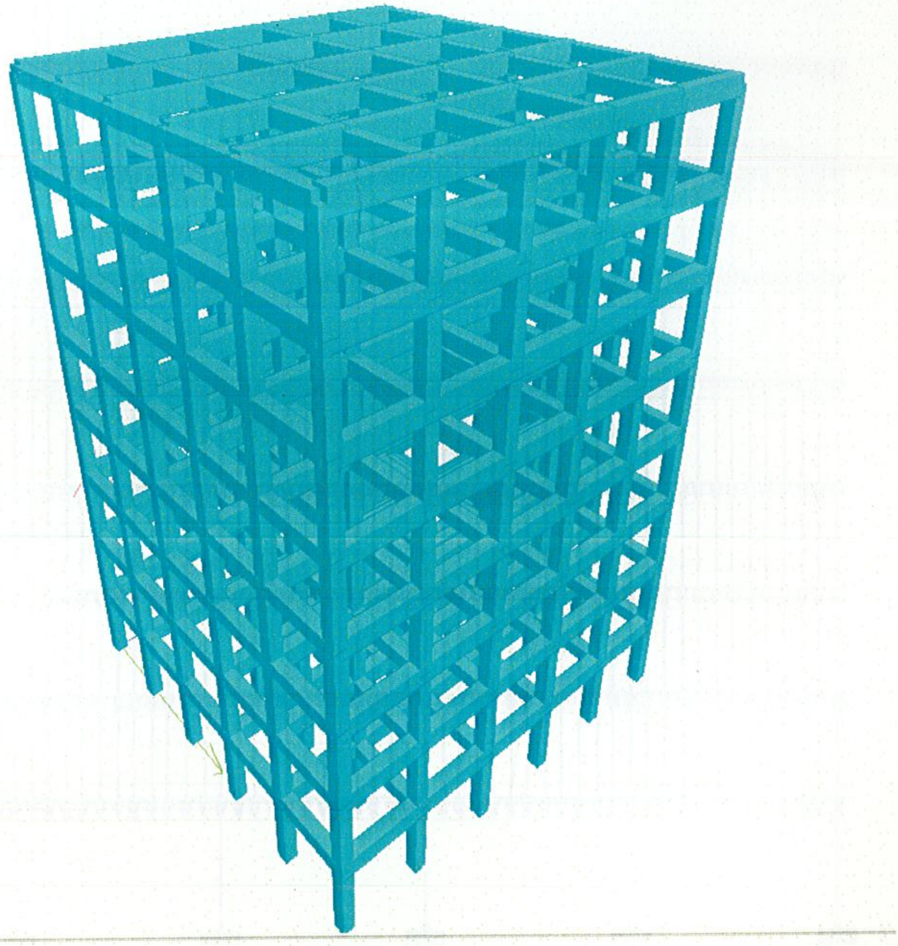


Figure 36: 3D view of the building

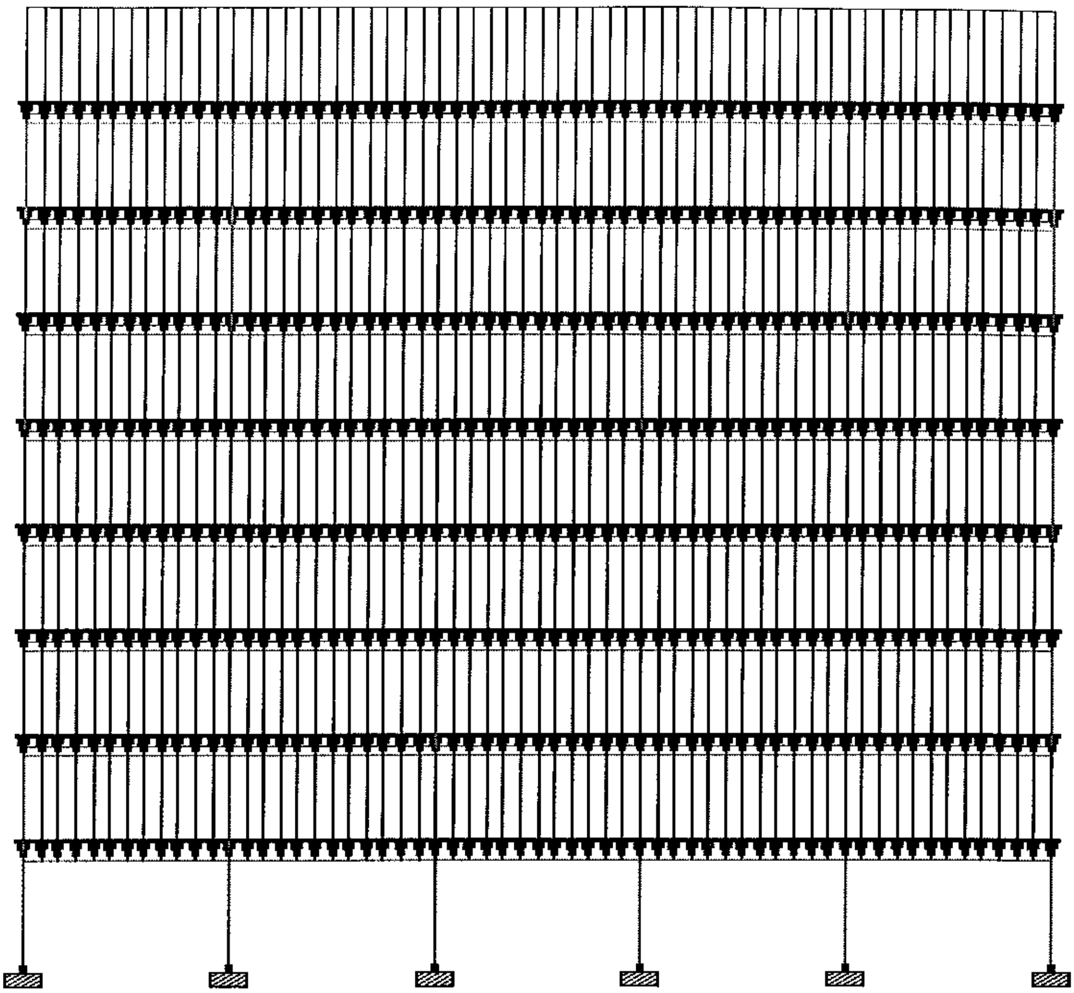


Figure 37: Live Load Diagram on the building

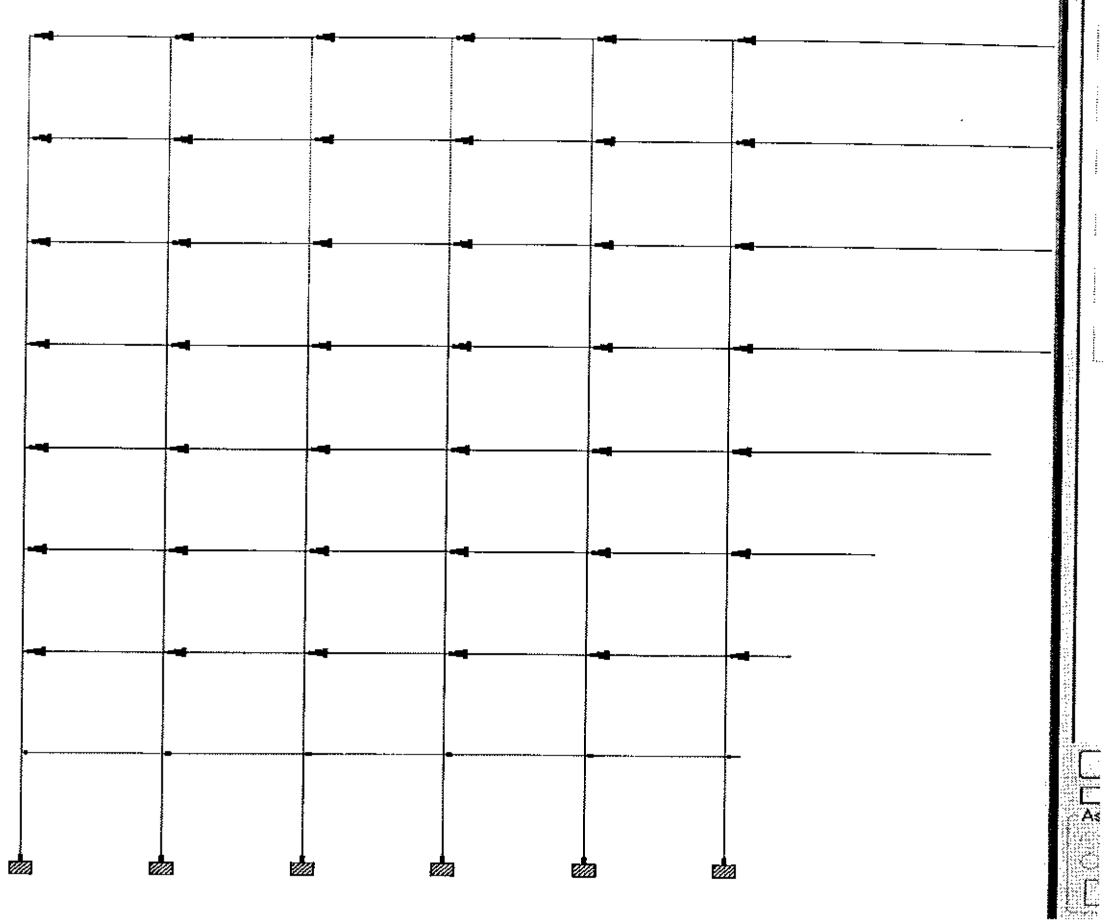


Figure 38: Earthquake forces on the structure

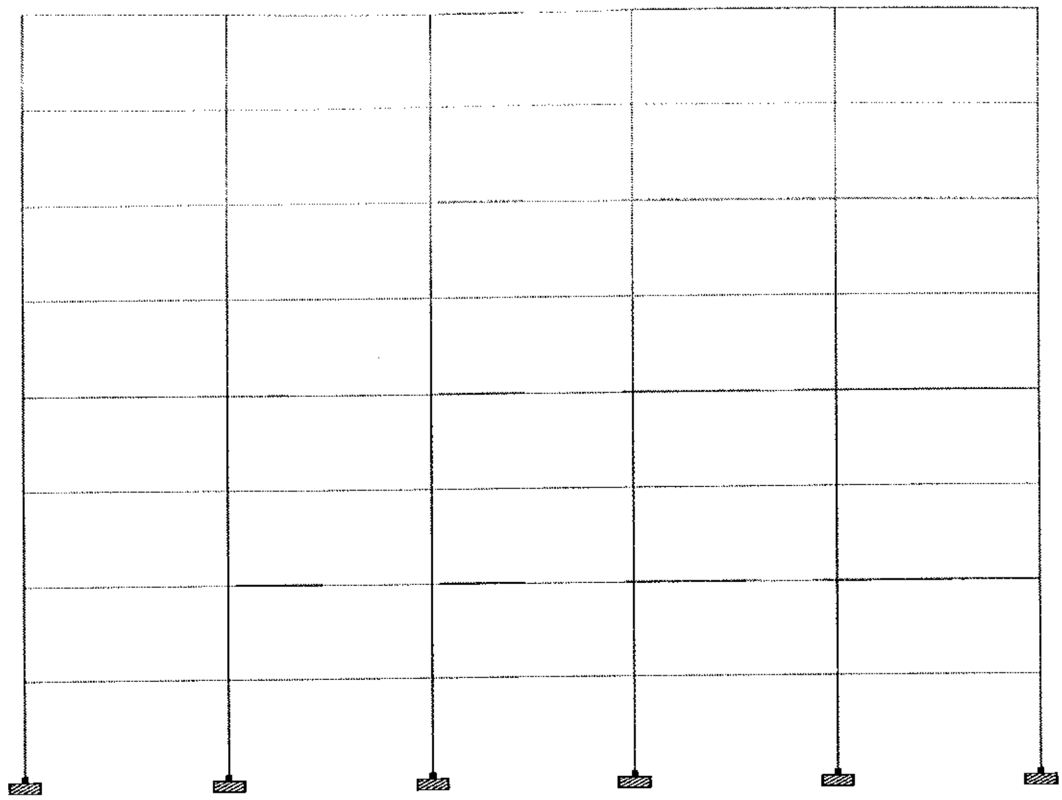


Figure 39: Frame from the above multi-storeyed building

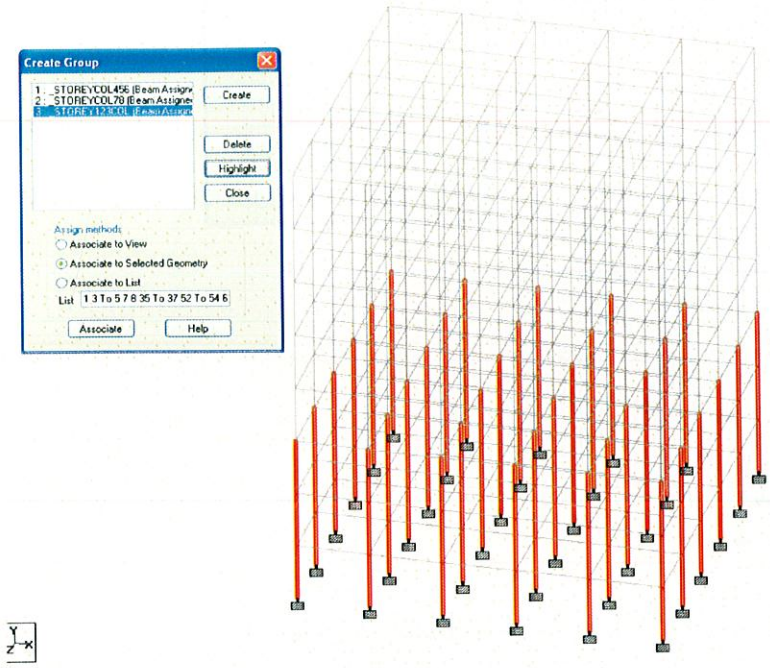


Figure 40: Columns of 1^{st},2^{nd} and 3^{rd} storey designed as same

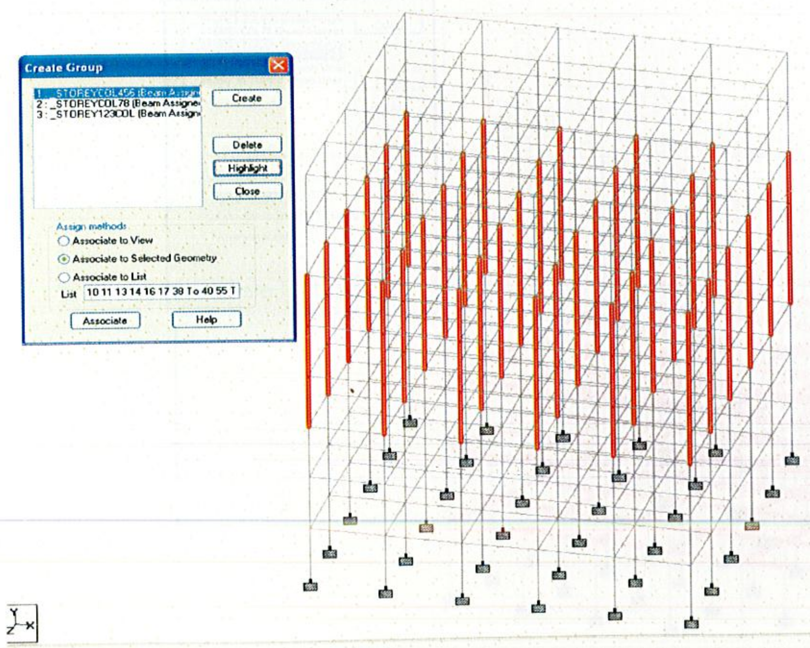


Figure 41:Columns of 4^{th},5^{th} and 6^{th} storey designed as same

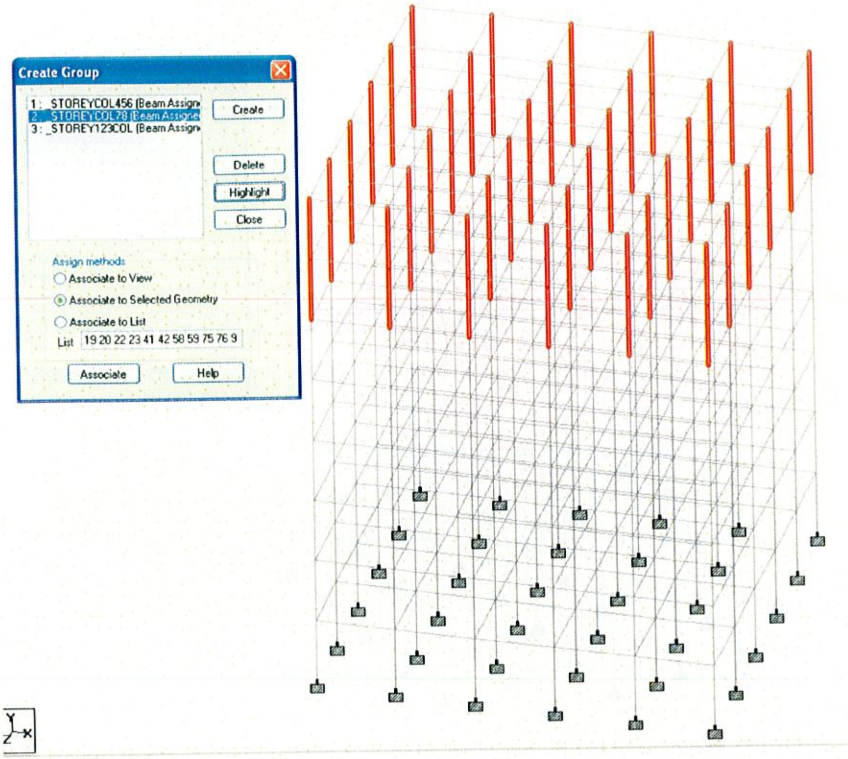


Figure 42:Columns of 7th and 8th storey designed as same

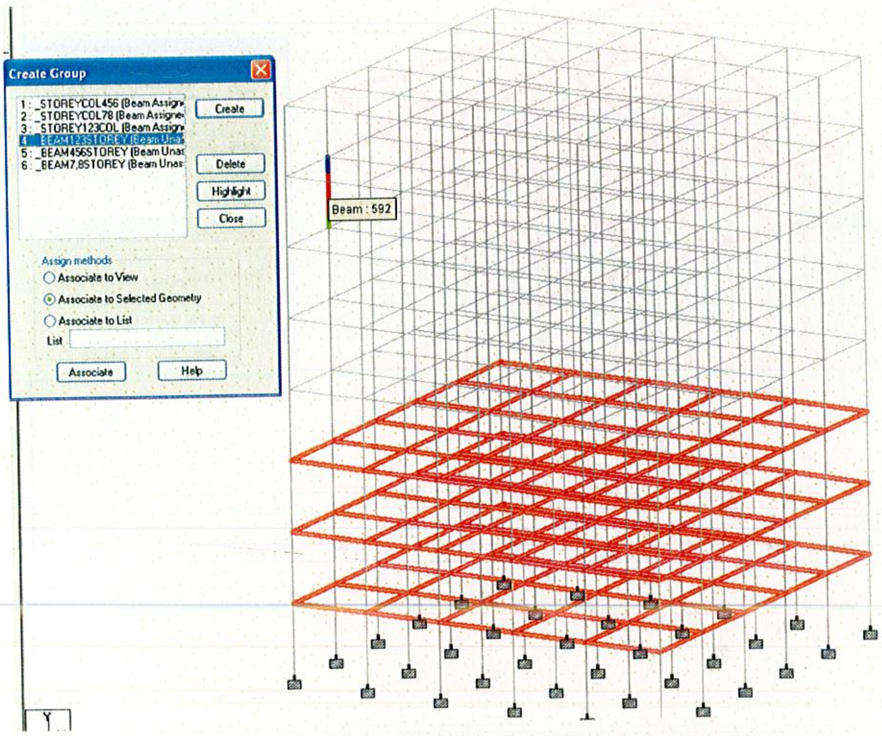


Figure 43: Beams of 1st ,2nd and 3rd storey designed the same

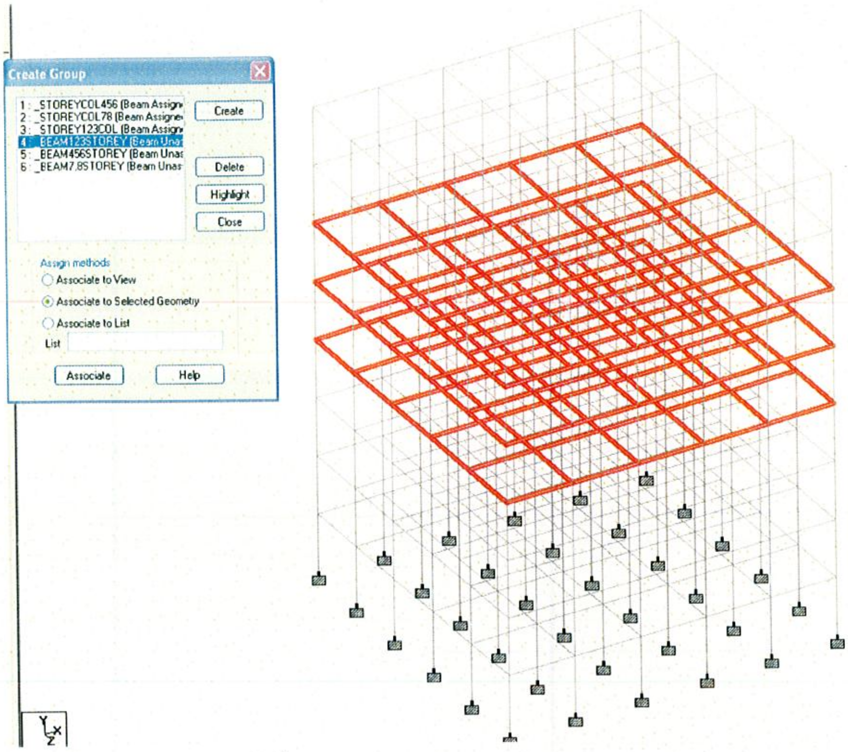


Figure 44:Beams of 4th ,5th and 6th storey designed the same

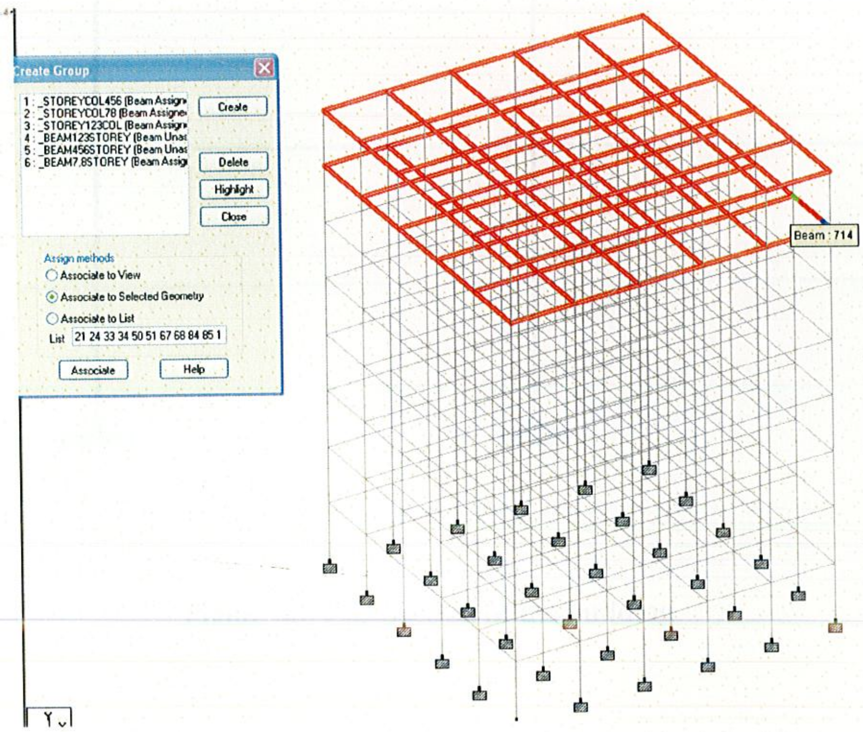


Figure 45: Beams of 4th ,5th and 6th storey designed the same

As the above section is symmetrical by grouping it may be reduced to the following and the whole building may be designed same as for the following members .The result of the analysis of these members is given in the following sections.

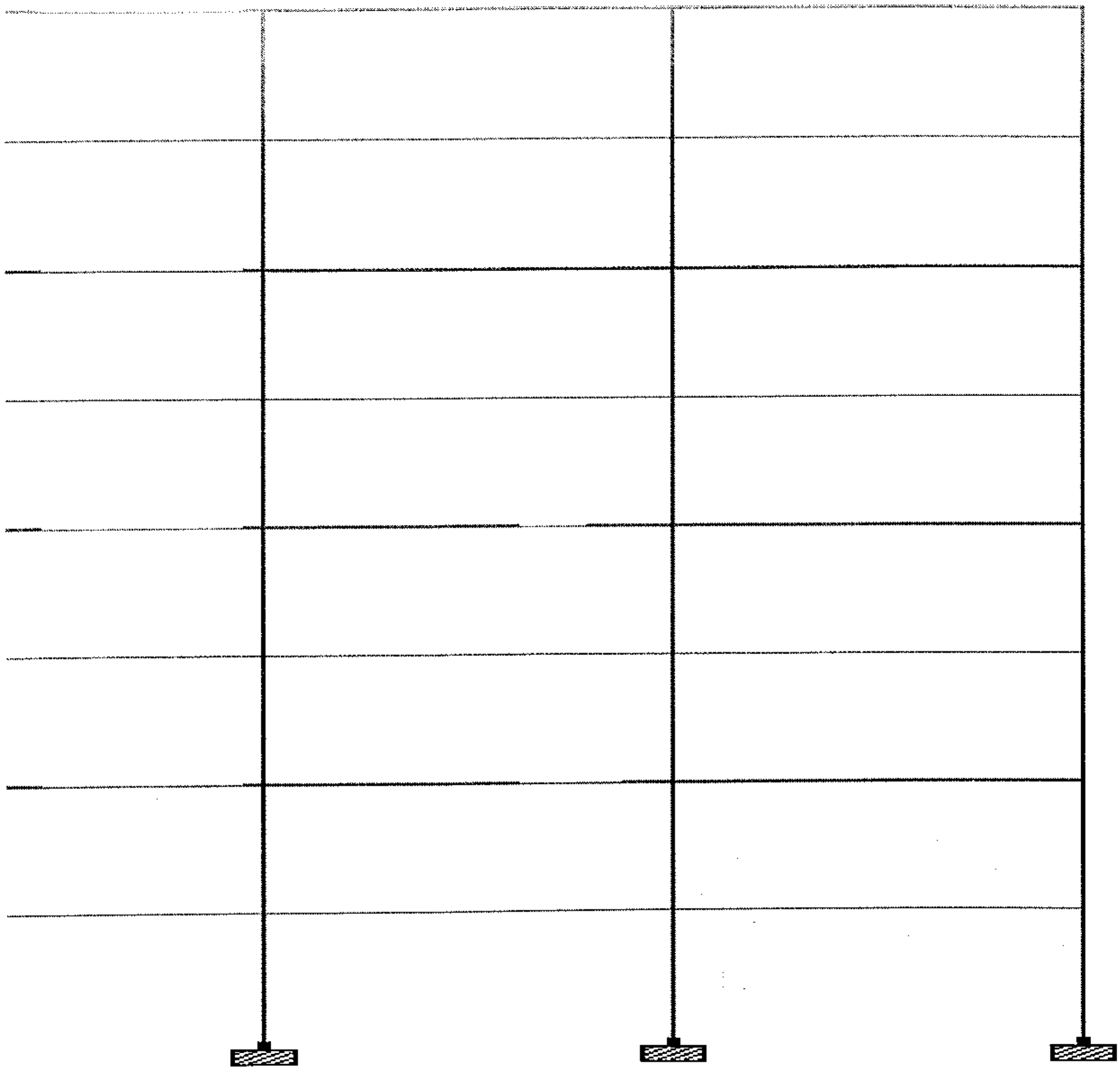


Figure 46: Cut-Section of the building

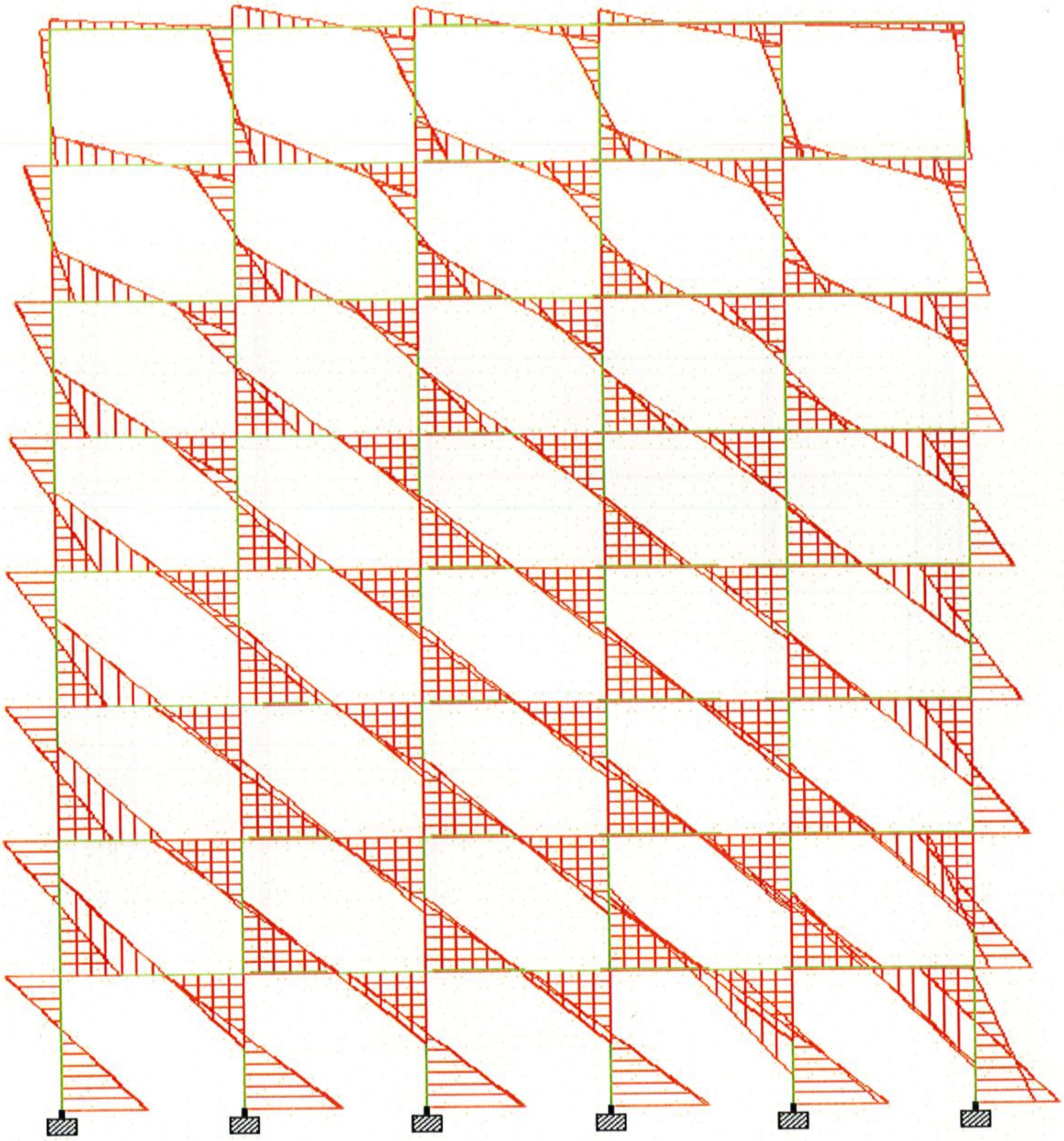


Figure 47: Bending Moment in Z direction

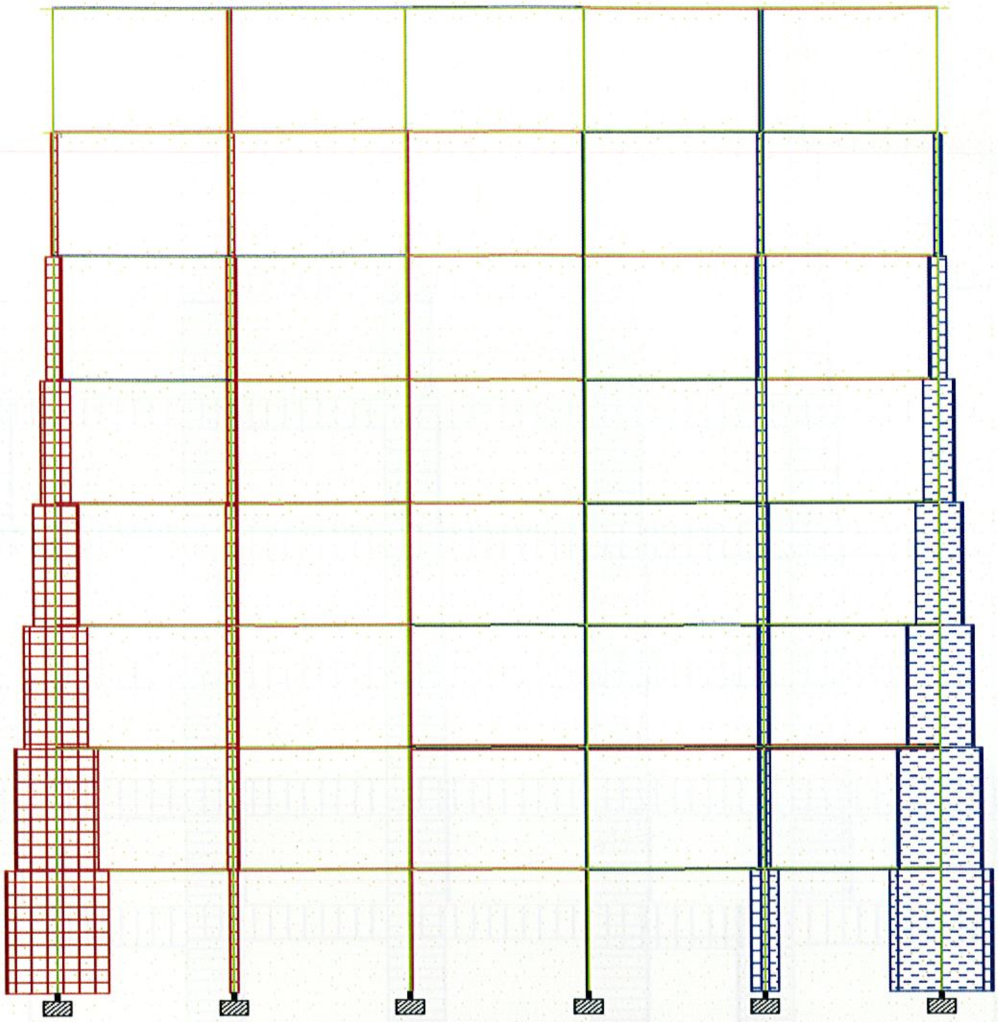


Figure 48: Axial Force Diagram

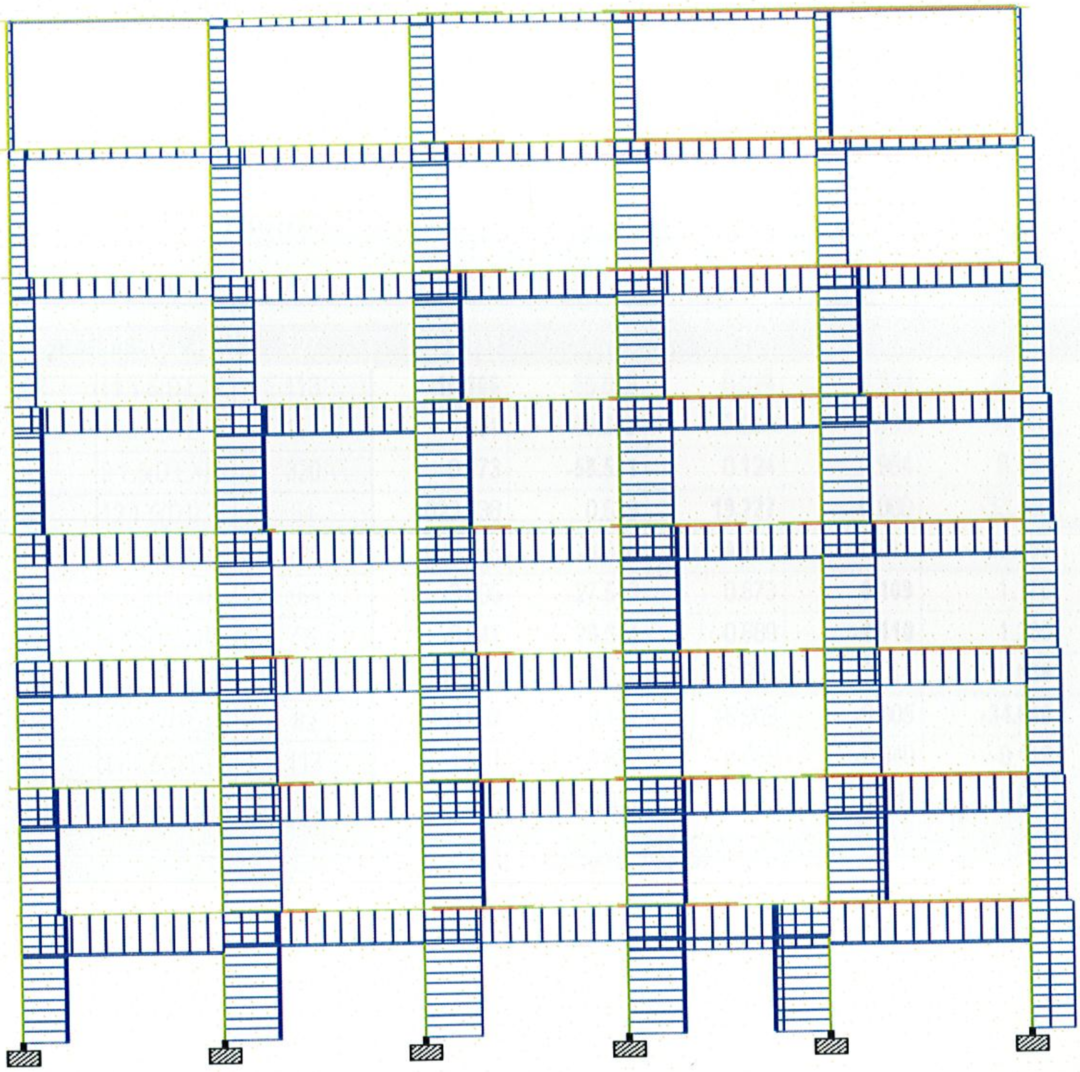


Figure 49: Shear force diagram in Y direction

5.3 Summary of the maximum member forces and moments

All / Summary / Envelope

	Beam	L/C	Node	Fx kN	Fy kN	Fz kN	Mx kNm	My kNm	Mz kNm
Max Fx	322	9 1.5(D.L.+E.L	127	**1393.455**	17.275	0.126	0.001	-0.010	32.516
Min Fx	295	11 1.5(D.L.-E.	113	**-10.906**	55.839	0.024	-0.939	-0.050	61.141
Max Fy	301	11 1.5(D.L.-E.	117	-1.031	**59.672**	0.055	-0.940	-0.119	70.808
Min Fy	791	9 1.5(D.L.+E.L	320	-0.973	**-58.501**	0.124	0.954	0.283	68.200
Max Fz	198	12 1.5(D.L.-E.	84	1023.738	0.639	**19.227**	0.000	-33.440	1.039
Min Fz	580	10 1.5(D.L.+E.	221	865.485	-8.886	**-19.292**	0.010	33.562	-15.099
Max Mx	379	6 1.2(D.L.+L.L	164	-3.605	-27.513	0.673	**6.109**	1.176	18.461
Min Mx	237	6 1.2(D.L.+L.L	56	-3.641	26.544	-0.689	**-6.110**	1.235	16.139
Max My	574	10 1.5(D.L.+E.	217	1143.366	-3.724	-16.955	0.014	**35.036**	-4.454
Min My	196	12 1.5(D.L.-E.	82	1369.067	0.117	16.909	-0.005	**-34.680**	0.015
Max Mz	301	11 1.5(D.L.-E.	117	-1.031	59.672	0.055	-0.940	-0.119	**70.808**
Min Mz	499	9 1.5(D.L.+E.L	203	797.323	20.802	-0.453	-0.002	-0.821	**-36.781**

5.3 Detailing of Members

The detailing of the members is done similar for the members of the 1st,2nd and the 3rd storey.

Similarly for the 4th ,5th and the 6th storey similar detailing is followed and same is done for 7th and the 8th storey for the purpose of ease to the site engineer and economy.

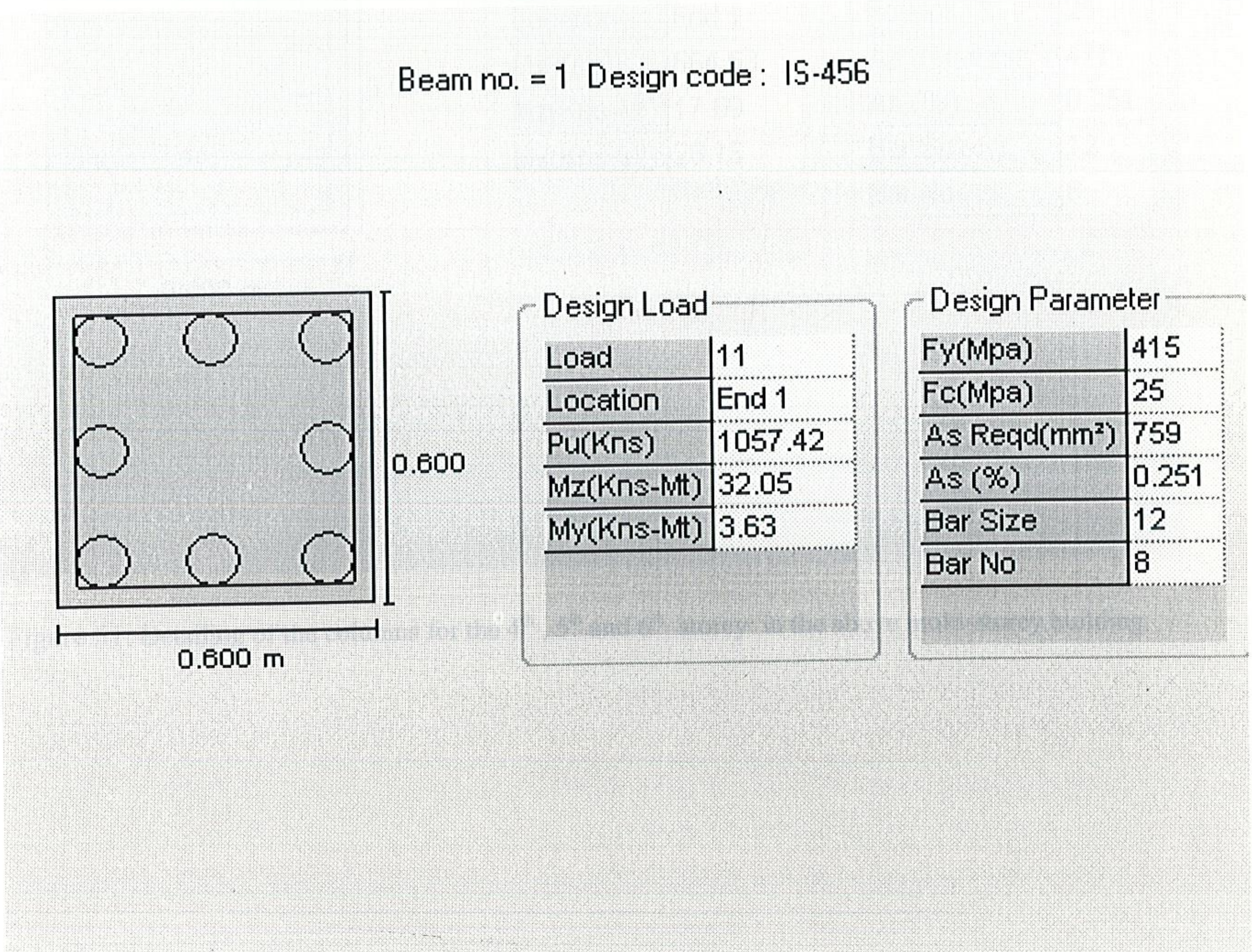
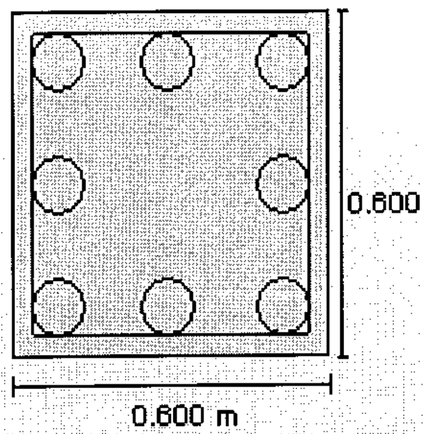


Figure 50: Detailing of the columns for the 1st ,2nd and 3rd storey in the above multi-storey building

Beam no. = 10 Design code : IS-456



Design Load

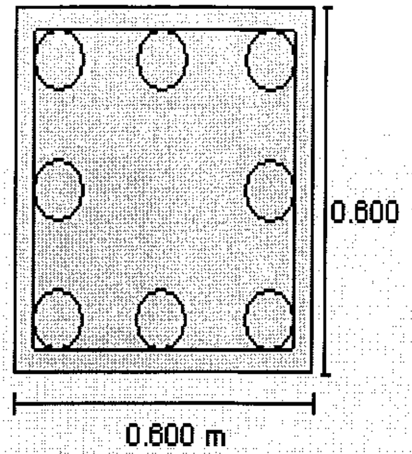
Load	12
Location	End 1
Pu(Kns)	664.53
Mz(Kns-Mt)	17.69
My(Kns-Mt)	28.15

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	25
As Reqd(mm^2)	477
As (%)	0.251
Bar Size	12
Bar No	8

Figure 51: Detailing of the columns for the 4th, 5th and 6th storey in the above multi-storey building

Beam no. = 19 Design code : IS-456



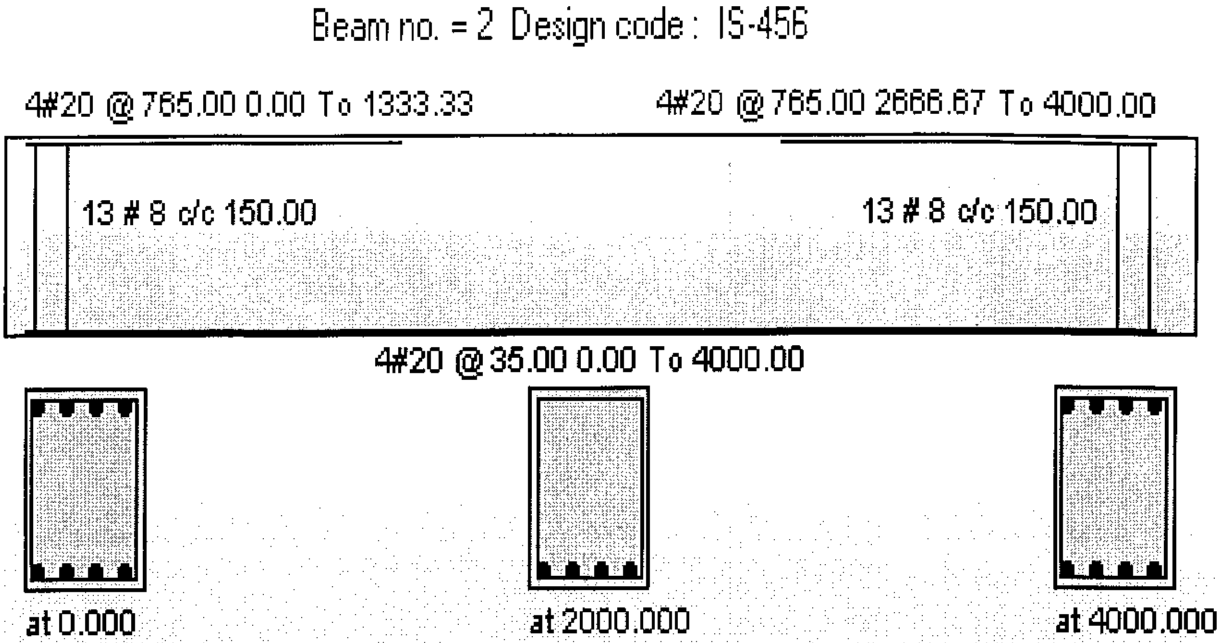
Design Load

Load	12
Location	End 1
Pu(Kns)	254.53
Mz(Kns-Mt)	21.94
My(Kns-Mt)	21.75

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	25
As Reqd(mm²)	183
As (%)	0.251
Bar Size	12
Bar No	8

Figure 52: Detailing of the columns for the 7th and 8th storey in the above multi-storey building



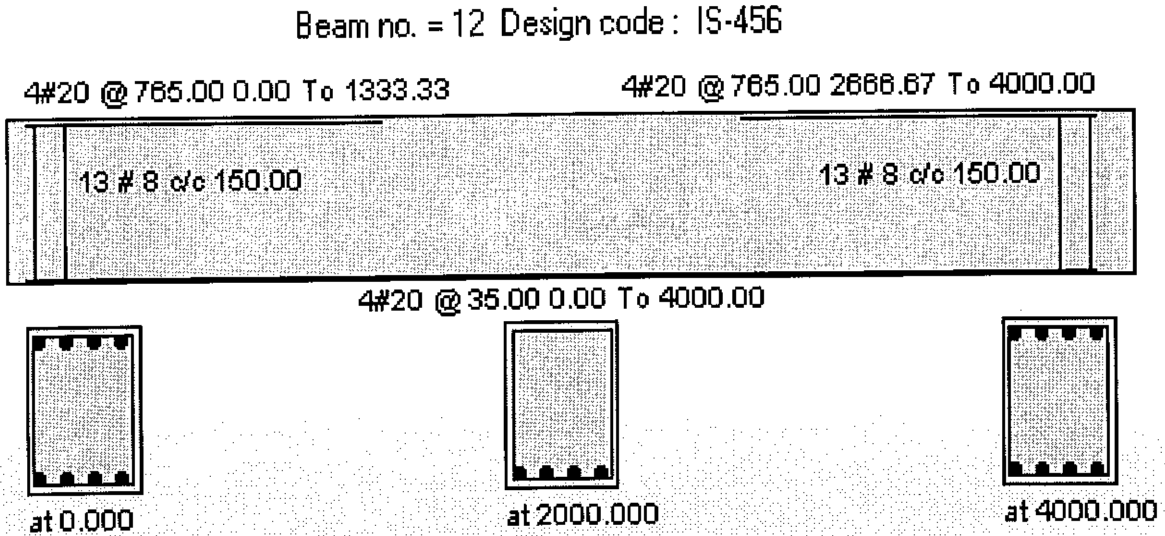
Design Load

Mz Kn Met	Dist Met	Load
26.84	1	9
-60.21	0	11
-48.17	4	9

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	25
Depth(m)	0.800000011
Width(m)	0.600000023
Length(m)	4

Figure 53: Detailing of the beams for the 1st ,2nd and 3rd storey in the above multi-storey building



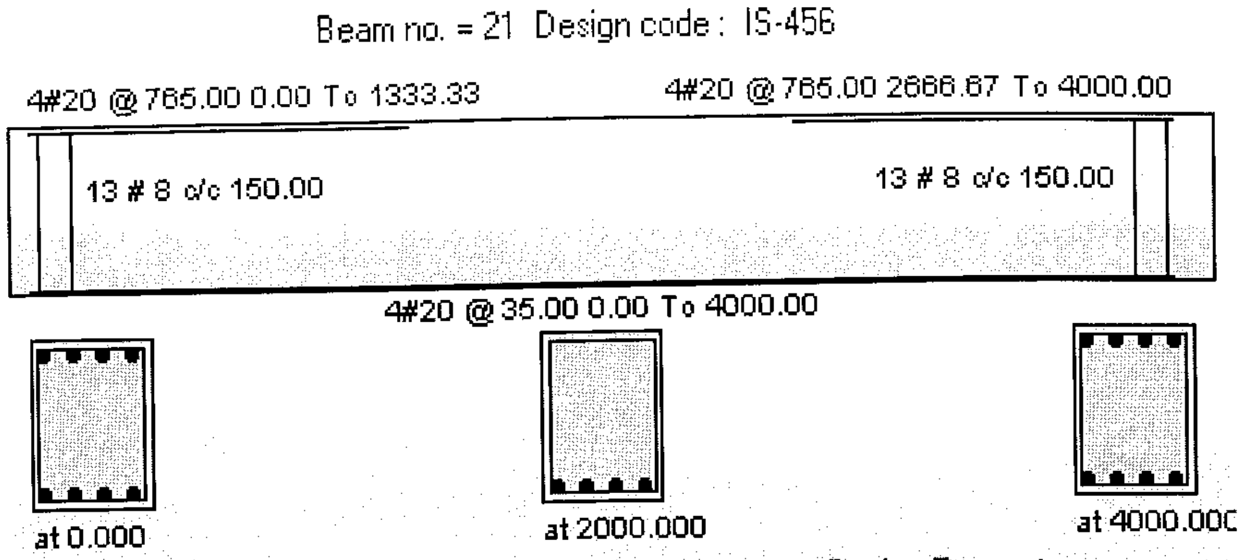
Design Load

Mz Kn Met	Dist Met	Load
24.75	3.3	11
-69.52	0	11
-26.46	4	9

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	25
Depth(m)	0.800000011
Width(m)	0.600000023
Length(m)	4

Figure 54: Detailing of the beams for the 4th , 5th and 6th storey in the above multi-storey building



Design Load

Mz Kn Met	Dist Met	Load
20.84	3	11
-57.54	0	11
-4.78	4	13

Design Parameter

Fy(Mpa)	415
Fc(Mpa)	25
Depth(m)	0.800000011
Width(m)	0.600000023
Length(m)	4

Figure 55: Detailing of the beams for the 4th , 5th and 6th storey in the above multi-storey building

6
CONCLUSION

CONCLUSIONS

This project helped us in understanding the concept of analysis and design of a building using STAAD Pro. The earthquake load on a two storey industrial building and a multi-storey building lying in the seismic zone IV has been calculated. The seismic load calculation gives step by step determination of all the lateral forces which in return helps us in determining the various moments and shear forces for the safe design of the building against the earthquake.

The complete analysis of the structure resulted in the safe design of the building. The exact amount of concrete and steel to be used in the building was also determined. After the design, it was found that the building is safe from earthquake according to the guidelines given in IS 1893(Part I):2002.

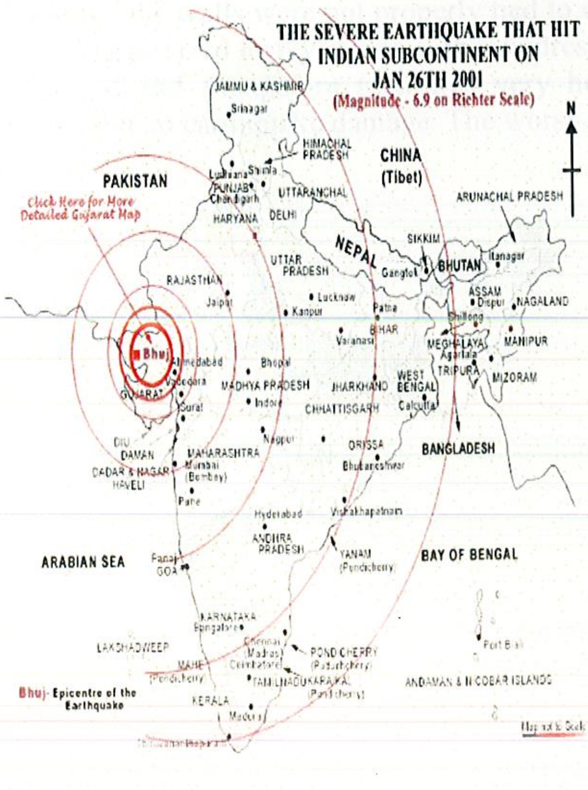
This project helped in gaining the knowledge of how to analyze and design of any structure using STAAD Pro considering the earthquake forces.

Annexure A

The Bhuj Earthquake(2001)

(This article was published in The CEC magazine of our University)

A powerful earthquake struck the Kutch region in Gujarat at 8:46 am on 26 January 2001(magnitude 7.9 on Richter scale) has been the most damaging earthquake in the past 5 decades in India. The epicenter of the earthquake was located at 50 km northeast of the town of Bhuj. The earthquake was felt over a large part of the country, and as far away as Nepal, Delhi, Calcutta (1900 km to the east), Bombay (590 km), and Chennai(1500 km). The greatest damage
due to the earthquake occurred in the region of Kutch, which is spread over an area of 45 930zkm2 and covers about 22% of the area of Gujarat State. Of the total of 884 villages located in this region, 518 suffered significant damage, 178 were completely destroyed, and another 165 damaged to the extent of 70% or more.The official Government of India figures place the death toll at 19,727 and the number of injured at 166,000. Indications are that 600,000 people were left homeless, with 348,000 houses destroyed and an additional 844,000 damaged. The Indian State Department estimates that the earthquake affected, directly or indirectly, 15.9 million people out of a total population of 37.8 million. More than 20,000 cattle are reported killed. Government estimates place direct economic losses at $1.3 billion. Other estimates indicate losses may be as high as $5 billion.



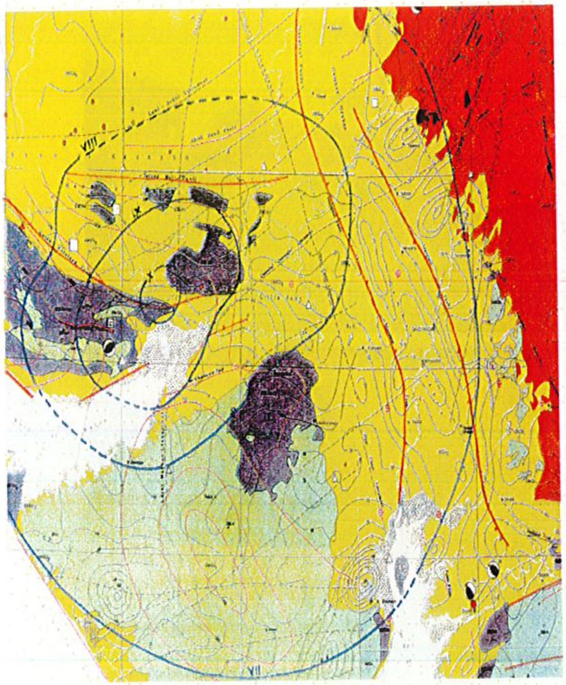


Figure 1: The epicenter of the earthquake

Figure 2: Isoseismal map of Bhuj earthquake

Damages to the structures

Load bearing masonry structures

Load bearing masonry buildings in Ahmadabad (which was located 300 km from the epicenter) performed quite well. The performance of the buildings in Kutch region was very poor due one more of the following reasons. No reinforcement had been provided to the building, the walls were not properly tied to each other and the roofs and the floor, due to the use of large sized heavy stones ,either undressed of roughly dressed and the roof construction of wood and Mangalore tiles was very heavy .These factors made the buildings more vulnerable to earthquake damage. The worst-affected towns were Anjar, Bhachau and Rapar.

Figure 2: Damages to masonary structures during Bhuj earthquakes at Kutch

Reinforced Concrete Frame Buildings

A large number of reinforced concrete buildings which were located at Ahmadabad suffered serious damage. The damages in these buildings can be attributed to the following reasons. Many buildings were founded on the deep sediments deposited by the Sabarmati river, which may have amplified the earthquake motions experienced by these buildings. Another factor responsible for the failure of RC buildings war the use of open ground storey buildings(soft storey building-shown in Figure 4) coupled with poor detailing and inappropriate construction practices.

Examples of some vulnerable structures

Some other features vulnerable to earthquakes are :-

(1) The building having short columns(where the columns are restrained in one direction but unrestrained in the other direction.

(2) If the two buildings are connected by staircases.

(3) Water tank placed at the roof level on short reinforced concrete columns.

(4) Complex architectural configurations of the buildings.

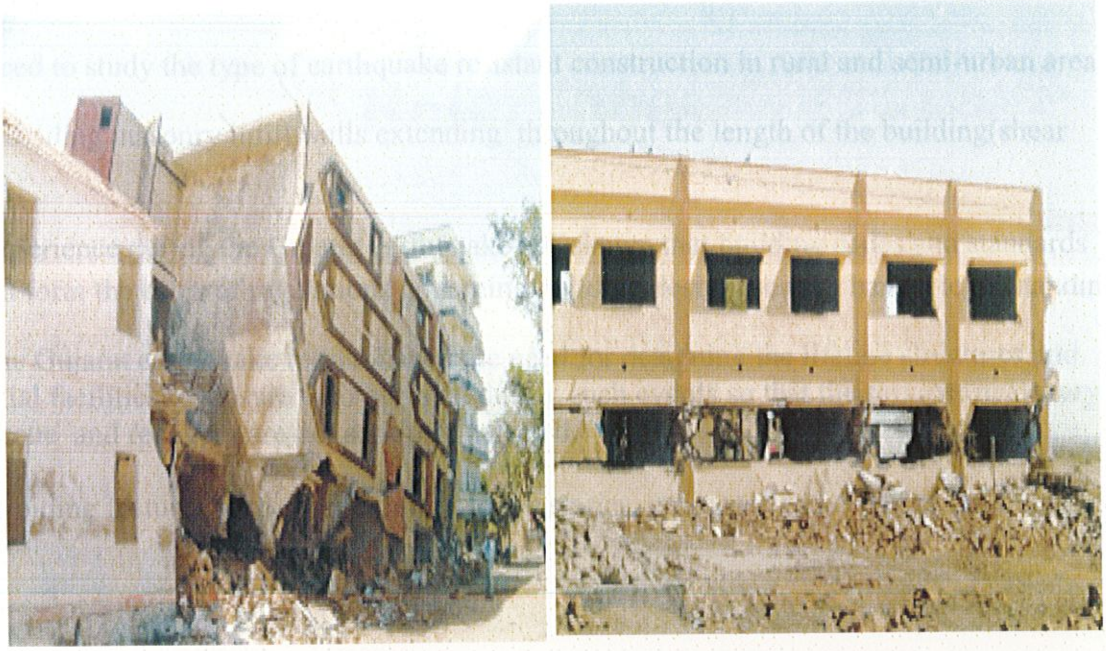


Figure 3: Short column and Open storey failures during the Bhuj earthquake (2001)

Important conclusions drawn from Bhuj earthquake to minimize any future damages due to earthquakes:-

(1) Need to study the type of earthquake resistant construction in rural and semi-urban areas.

(2) Providing masonry infill walls extending throughout the length of the building(shear walls).

(3) Experience during the Gujarat earthquake has shown that building codes and standards should form the basis of regulations governing building design, so they have a legal standing.

(4) The Gujarat earthquake reestablished the need for designing the lifeline structures and essential facilities to ensure their survival during such events so that the services necessary for rescue and recovery are not seriously affected.

(5) Avoiding features such short columns, open stories, staircases and complex architectural features.

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2) S S Bhavikatti, Structural Anaysis, Vikas Publication House

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