ABSTRACT

Every year thousands of buildings are damaged and collapse, thousands of people become homeless due to the natural calamity earthquake, which occurs with intensities not less than 3 on the seismic scale. In the present era, the low rise to high rise buildings is constructed due to limited space. Once this earthquake occurs, its effects these structures most of which causes huge property loss and human loss. To control this, some precautions and codes for seismic resistant building construction are assigned by various countries. In India, IS 1893-2016 provides the rules and precautions for various types of building construction that is seismic -resistant. Buildings such as Conventional RC Frame structures are common in practice. But due to highly advanced technologies, beamless slab called Flat slab are in use these days.

In the present work the comparison of Dynamic behaviour of Conventional slab, Flat slab and Post Tension slab is made, using ETABS software. The characteristics of seismic behaviour of these buildings such as Storey Displacement, Storey Shear, Overturning Moment, and Storey Drift are evaluated using dynamic analysis. The Performance of the buildings is evaluated using Response spectrum analysis. To study the variation in behaviour of different slab systems buildings with respect to height, 4 storey, 8 storey and 12 storey models of zone 2 are created to perform dynamic and non-linear analyses. The Flat slab buildings and buildings with Post tensioning slabs even though have many advantages with respect to architectural aspects, it was found they are much vulnerable with respect to seismic behaviour.

Keywords: - Storey Displacement, Storey Shear, Overturning Moment, Response Spectrum.

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SYMBOLS

L_x	-	Shorter span of slab (m)
L_y	-	Longer span of slab (m)
L_n	-	Clear span of flat slab (m)
W	-	Load (kN)
W_u	-	Factored load (kN)
M	-	Moment (kN-m)
M_u	-	Ultimate moment (kN-m)
M_{ux}	-	Ultimate moment in X- direction (kN-m)
M_{uy}	-	Ultimate moment in Y- direction (kN-m)
X_u	-	depth of Neutral axis (mm)
$X_{u \cdot max}$	-	Maximum depth of Neutral axis (mm)
f_{ck}	-	characteristic Compressive strength of concrete (eg. M_{20} , M_{25} , M_{30})
F_y	-	Yield stress of steel (eg. Fe250 , Fe415, Fe500 , Fe550)
Φ	-	Diameter of Reinforcement steel bar (mm)
α_x	-	Coefficient of Moment for shorter span of slab
α_y	-	Coefficient of Moment for longer span of slab
RSP	-	Response spectrum

CHAPTER-1

INTRODUCTION

1.1. General

Urban areas due to the scarcity of space vertical construction have developed such as low-rise, medium-rise and high-rise buildings. These types of buildings utilize frame structures as Conventional RC frame structure and Flat slab frame structure. Conventional RC frame structure possesses a Conventional slab used for the construction that accomplishes a system where a slab is supported by beam and beam supported by the column. This may be called the Beam –Slab Load Transfer method, a technique that is common practice all over the world. The other form of frame structure is called Flat Slab, where slab directly rests on the column. This is also called a Beamless Slab as there would be no beams in this frame structure. In multi-storey shopping malls, offices, warehouses, public community halls the aesthetic view is improved by using Flat Slab in place of the conventional slab.

The usage of Flat slab for residential buildings is also in practice provided span not more than 6m. Both conventional and flat slab frame systems are subjected to vertical as well as lateral loads. Lateral loads influence buildings such as the height of the building increases, the effect of lateral load increases. The effect of Lateral loads is much stronger than vertical loads. These Lateral loads include Wind loads and Seismic loads. The Lateral forces tend to sway the building frame. As such, the building frame tends to act as a cantilever. Many seismic prone areas, the buildings are prone to collapse if construction is not abated by proper measures. All these studies make studying the effect of earthquake loads as important. A different earthquake occurs with different intensities, magnitudes at different places. It is quite essential to study various seismic aspects such as story displacement, base shear etc. Seismic Analysis is, therefore, necessary to study the seismic response of buildings; the design of buildings without seismic analysis is not preferred especially in earthquake-prone zones.

1.2. Conventional Slab

The slab which is supported on Beams and columns is called a conventional slab. In this kind, the thickness of the slab is small whereas the depth of the beam is large, and load is transferred to beams and then to columns. It requires more formwork when compared with the flat slab. In the conventional type of slab there is no need for providing column caps. The thickness of conventional slab is 4″ or 10cm. 5″ to 6″ inches is recommended if the concrete will receive occasional heavy loads, such as motorhomes or garbage trucks.

Conventional concrete slabs are square in shape and have a length of 4m. Reinforcement is provided in conventional slab and the bars which are set in horizontal are called Main Reinforcement Bars and bars which are set in vertical are called Distribution bars.

Based on the length and breadth of Conventional Slab is classified into two types:

1. One-Way Slab
2. Two-Way Slab

1. One Way Slab:

One way slab is supported by beams on the two opposite sides to carry the load along one direction. The ratio of longer span (l) to shorter span (b) is equal or greater than 2, considered as One-way slab. In this type, the slab will bend in one direction i.e in the direction along its shorter span. However minimum reinforcement known as distribution steel is provided along the longer span above the main reinforcement to distribute the load uniformly and to resist temperature and shrinkage stresses.

$$\frac{longer\ span}{Shorter\ span} \geq 2$$

In general, the length of the slab is 4m. But in one way slab, one side length is 4m and another side length is more than 4m. So, it satisfies the above equation. Main reinforcement is provided in shorter span and distribution reinforcement is provided in the longer span. Main bars are cranked to resist the formation of stresses.

Example: Generally, all the Cantilever slabs are one Way slab. Chajjas and verandahs are a practical example of one-way slab.

2. Two Way Slab:

Two-way slab is supported by beams on all the four sides and the loads are carried by the supports along with both directions, it is known as a two-way slab. In a two-way slab, the ratio of longer span (l) to shorter span (b) is less than 2. The slabs are likely to bend along both the directions to the four supporting edges and hence distribution reinforcement is provided in both the directions.

$$\frac{longer\ span}{Shorter\ span} < 2$$

In this kind of slab, the length and breadth of the slab are more than 4m. To resist the formation of stresses distribution bars are provided at both the ends in a two way slab.

Fig. 1.1-Conventional slab

1.3. Flat Slab

The flat slab is a reinforced concrete slab supported directly by Concrete columns or caps. Flat slab doesn't have beams, so it is also called a beamless slab. They are supported on columns itself. Loads are directly transferred to columns. In this type of construction, a plain ceiling is obtained thus giving an attractive appearance from an architectural point of view. The plain ceiling diffuses the light better and is considered less vulnerable in the case of fire than the traditional beam slab construction. The flat slab is easier to construct and requires less framework. This is one of the types of concrete slabs.

The thickness of the Flat slab is minimum 8″ or 0.2m**.**

Components of the flat slab are as following:

1. Column head
2. Drop

1. Column head

Generally, in Flat Slab, the columns are supported with the head of wide enlargement called column head or capitals. Column head resists the negative moment that is transferred to the column from a slab-column junction.

2. Drop

The thickened part of the slab above columns the heavy load on the column is called Drop. It provides resistance to Punching shear which is predominant at the junction of column and slab.

Flat slab buildings are significantly more flexible than the conventional RC frame buildings during earthquakes. The Flat slab thus satisfies Architectural demand by some highlighting features such as better illumination, simple formwork, and maximum vision with the optimum use of available space hence leading to an admired concept in the field of Structural Engineering.

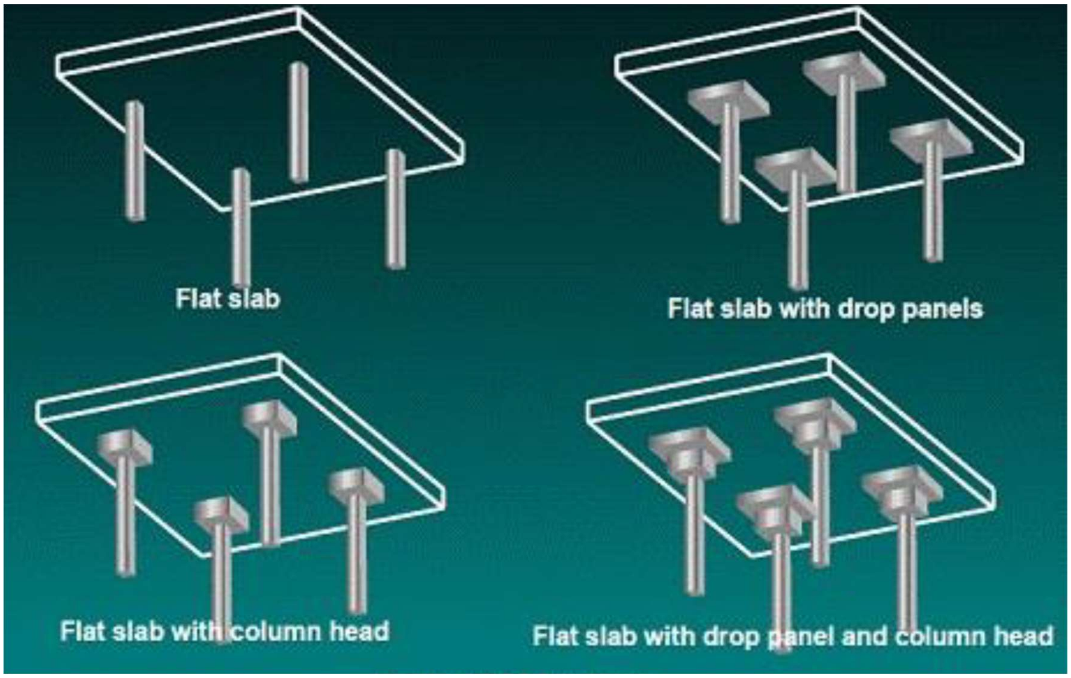


Fig.1.2- Types of flat slabs

Disadvantages of Flat slab:

1. In a flat plate system, it is not possible to have a large span.
2. Not suitable for supporting brittle (masonry) partitions.
3. Higher slab thickness.

1.4. Post Tensioning Slab

Post tension slab is a combination of conventional slab reinforcement and additional protruding high-strength steel tendons, which are consequently subjected to tension after the concrete has set. This hybridization helps achieve the formation of a much thinner slab with a longer span devoid of any column-free spaces.

1.4.1. Working Principle of PT Slab

We all know that concrete has a high compressive strength and steel has a high tensile strength, and when their combination is used to bear loads, the efficiency increases manifold.

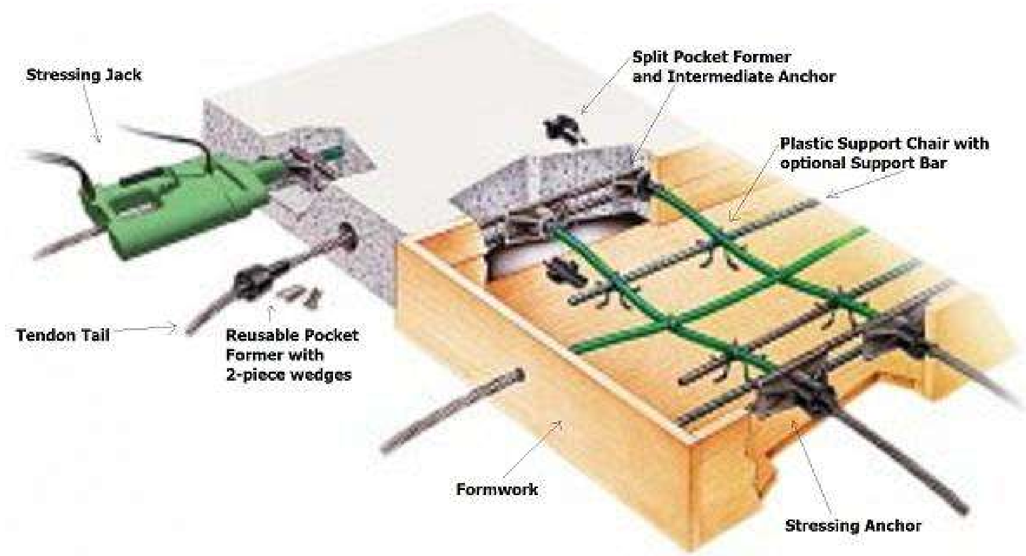


Fig.1.3. Typical details of PT slab

When a heavy live load is brought upon a structure, its concrete slab undergoes tension, which leads to the formation of cracks and ultimately deformation occurs. To mitigate this problem, post tensioned steel tendons are inserted at the time of concreting and tensioned after concreting with conventional rebars.

When these post tensioned steel tendons are stressed, the concrete is squeezed, in other terms, the concrete is compacted which increases the compressive strength of the concrete and at the same time the steel tendons that are pulled increase the tensile strength. As a result, the overall strength of the concrete increases.

1.4.2. Components of Post Tensioning Slab

- Ducts
- Tendons
- Anchors

Ducts

Thin sheet metal pipes with claw coupling or welded overlapped seam supplied in lengths of 5 and 6 m respectively are used as a standard. Ducts are connected to each other by an external screw coupling and sealed with PE tape. Plastic ducts are also available in the market these days which are watertight, frictionless and fatigue resistant.

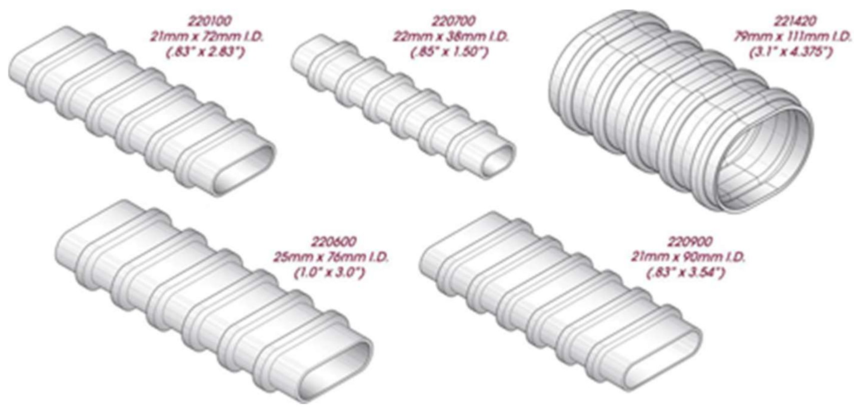


Fig. 1.4. Type of Ducts Used Encased Steel Tendons

Tendons

The basic element of a post-tensioning system is called a tendon. A post-tensioning tendon is made up of one or more pieces of pre-stressing steel, coated with a protective coating, and housed inside a duct or sheathing.

The basic element of a post-tensioning system is called a tendon. A post-tensioning tendon is made up of one or more pieces of pre-stressing steel, coated with a protective coating, and housed inside a duct or sheathing.

Figure 1.5: Steel Tendons Used In PT Slab

The pre-stressing steel is manufactured as per the requirements of ASTM A-416 and typical strand sizes are 0.50 and 0.60 inch in diameter. A typical steel strand used for post-tensioning will yield about 243,000 psi. In contrast, a typical piece of rebar will yield about 60,000 psi.

Anchors

Anchors are used to anchor the tendons into the concrete while terminating or joining two tendons. Main function of anchorage is to transfer the stressing force to the concrete once the stressing process is completed.

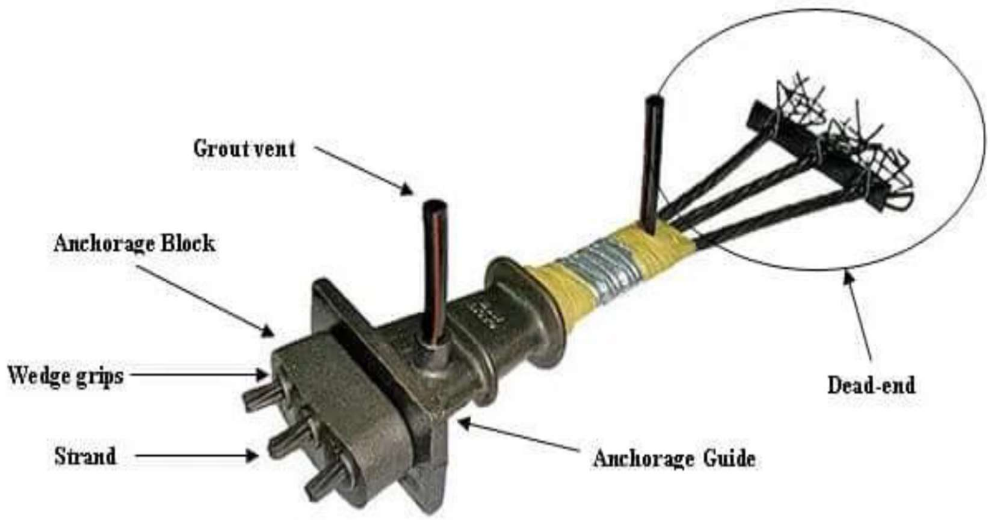


Figure 1.6: Slab Anchor

1.5. Need of the Study

The Bhuj earthquake of January 26, 2001, in Gujarat, caused the destroyed many modern 4 to 10 storey buildings. After this earthquake, doubts arose about our professional practices, building by-laws, construction materials, building codes and education for civil engineers and architects. It led to revision of the seismic code Initiation of the national program on earthquake engineering education.

It was found that most of the buildings that were analysed for lateral seismic analysis were observed to ignore the response spectrum analysis subjected to dynamic loading which is the most important response of the system. Response spectrum analysis is done to find out the maximum deflection or displacement of structure involving response or behaviour spectral curve generated for possible seismic events by incorporating previous seismic records.

The target of the study is to keep the maximum displacement within the allowable limit. So, by this analysis a sustainable structure can be designed during possible seismic events. With RSA we can review the response of the structure how it may behave during earthquake before constructing it. Much research has been done on conventional slab and flat slab systems in seismic areas, but limited research work was done on post tensioning slab system. Therefore, in this study the three slab systems namely, conventional,

flat slab and post tensioned slab analysed and compared using response spectrum and push over analyses.

1.6. Objectives

1. Evaluation of seismic parameters (max. storey displacement, storey shear, storey drift, overturning moment) of multistory buildings with different slab systems under static loading.
2. Evaluation of static analysis of normal slab system compared with flat slab system & Post tensioned slab system.

1.7. Scope of the Study

The scope of the present study is to evaluate the dynamic behaviour of R.C buildings with a conventional slab, flat slab, PT slab systems (designed according to Indian standard codes). The performance-based seismic evaluation technique known has linear dynamic behaviour analysis procedure has been carried out using ETABS.

The results of analysis are compared in terms of base shear, top Storey displacements, overturning moments through response spectrum analysis, the buildings were design to meet the performance level and performance check is done by checking the hinges at nodes and drift ratio of building.

The focus of the present work is to assess the seismic response of structure in ETABS for multistorey RC buildings with different slab systems and to determine the seismic parameters (max. storey displacement, storey shear, storey drift, overturning moment) and find out the of performance level of the buildings for various storey levels through non-linear static process.

The preliminary building data required for analysis assumed are presented in the Table 1.1

Table-1.1: Assumed Preliminary Data Required for the Analysis of Structural Models.

Sl.no.	Variable	Data
1	Type of structure	Ordinary moment resisting frame (OMRF)
2	No. of stories	4, 8 and 12
3	Floor height	3m
4	Bottom storey height	3m
5	Imposed load	3 KN/m^2
6	Material	Concrete =M_{30}, F_y=550N/mm^2
7	Thickness of Conventional slab	150 mm
8	Thickness of Flat slab	400 mm
9	Thickness of Drop	300 mm
10	Plan dimension	20mx15m
11	Zone	2
12	Importance factor	1
13	Response reduction factor	3
14	Type of soil	Medium

CHAPTER-2
LITERATURE REVIEW

2.1. General

The literature shows the considerable working and study on a different slab building and its behavior under the seismic excitation. Several experimental and numerical analyses were performed on the different slab building structures by various authors.

These works are reviewed keeping in view the methodology, principle and various aspects and behavior of different slab building under the earthquake forces. Some of the related works are discussed below.

2.2. Overview

Pradip S. Lande, Ankith B.Raut (2015)

The flat plate system has been adopted in many buildings construction taking advantage of the reduced floor height to meet the economical and architectural demands. Flat slab RC buildings exhibit several advantages over conventional beam column building. However, the structural effectiveness of flat-slab construction is hindered by its alleged inferior performance under earthquake loading. Although flat-slab systems are widely used in earthquake prone regions of the world, unfortunately, earthquake experience has proved that this form of construction is vulnerable to more damage and failure, when not designed and detailed properly. Therefore, careful analysis of flat slab building is important.

In the present study a parametric investigation was carried out to identify the seismic response of systems

a. flat slab building
b. flat slab with per metric beams
c. flat slab with shear walls
d. flat slab with drop panel.
e. Conventional building the hypothetical systems were studied for two different storey heights located in zone v. and analyzed by using ETABS Nonlinear version 9.7.3. Linear

dynamic analysis i.e., response spectrum analysis is performed on the system to get the seismic behavior.

Thummala spoorthy (2018)

Every year thousands of buildings are damaged and collapsed and thousands of people become homeless due to the natural calamity Earthquake, which occurs with intensities not less than 3 on the seismic scale. In the present era, the low rise to high rise buildings is constructed due to limited space. Once, this earthquake occurs, its effects these structures most. Huge property loss and human loss occur. In order, to control this some precautions and codes for seismic resistant building construction are assigned by various countries. In India, IS 1893-2002 provides the rules and precautions for various types of building construction that is seismic resistant. Buildings such as Conventional RC Frame structures are common in practice. but due to highly advanced technologies, beamless slab called Flat slab is in use these days. T Hough flat slab possess many advantages over conventional buildings when dealing with seismicity, the flat slab is far less potentially strong to resist for seismic conditions. In the present work the comparison of Conventional building and Flat slab with Drop in different zones, using ETABS software. Therefore, the characteristics of a seismic behavior of Flat slab and Conventional RC frame building measures for guiding the concept and design of these structures and for improving the performance of buildings during seismic loading. In Present work, a good amount of information regarding parameters such as Storey Displacement, Storey Shear, Overturning Moment, and Storey Drift for Flat Slab and Conventional Slab is provided and its variation of these parameters in different zones is also details.

Manu KV (2015)

Recently, Flat slab buildings are commonly used for the construction because use of flat slab building provides many advantages over conventional RC Frame building in terms of economical use of space, easier formwork, architectural flexibility, and importantly shorter construction time. The structural efficiency of the Flat slab construction is most difficult by its poor performance under earthquake loading. It is necessary to analyze seismic behaviour of buildings for various heights to see what changes are going to occur for the conventional RC frame building, flat slab building with and without drops. The analysis is done with ETabs V9.7.4 software. The characteristics seismic behavior of conventional RC frame building, flat slab buildings suggest that additional measures for guiding the conception and design of these structures in seismic regions are needed and to improve the performance of building having conventional RC building, flat slabs under seismic loading. The object of the present study covers the behavior of multi storey buildings having conventional RC frame building, flat slabs and to study the effect of height of the building on the performance of these types of buildings under seismic forces. Present study covers information on the parameters story drift, lateral displacement, seismic base shear, natural time period.

Mohammed Fatir (2016)

Recently there has been a considerable increase in the number of tall buildings, both residential and commercial, and the modern trend is towards taller structures. Flat slab is the most widely used system in reinforced concrete construction in offices, residential and industrial buildings in many parts of the world. The flat plate system, in which columns directly support floor slabs without beams. To improve the performance of buildings having flat slabs under seismic loading, provision of flat slab with drop is proposed. The object of the present work is to compare the behaviour of multi-storey buildings having flat slabs with drops with that of conventional beam column framing so called grid slab system under linear dynamic analysis (Response spectrum analysis) with different masonry infills i.e. shear wall and concrete bracing in two different zones i.e. zone III and zone IV with medium soil type conditions. Software ETABS is used for this purpose. The parameters studied are Time Period, Base shear, Displacements and Story Drift. And it is found that the structure with infills shows better performance in comparison with structures without infills. In addition to this the structure with shear wall reduced max displacement and storey drift and time period of different types of structures in both the zones in comparison with structure with concrete bracing.

Kumar Vanshaj (2017)

A popular form of concrete building construction uses a flat concrete slab (without beams) as the floor system. This system is very simple to construct and is efficient in that it requires the minimum building height for a given number of stories. The flat slab system is currently widely used in construction. It permits flexibility in architecture, more clear space, low building height, easier formwork, and shorter construction time. However, Flat slab building structures are significantly more flexible than traditional concrete structures as beams are not present. They are more vulnerable to earthquakes.

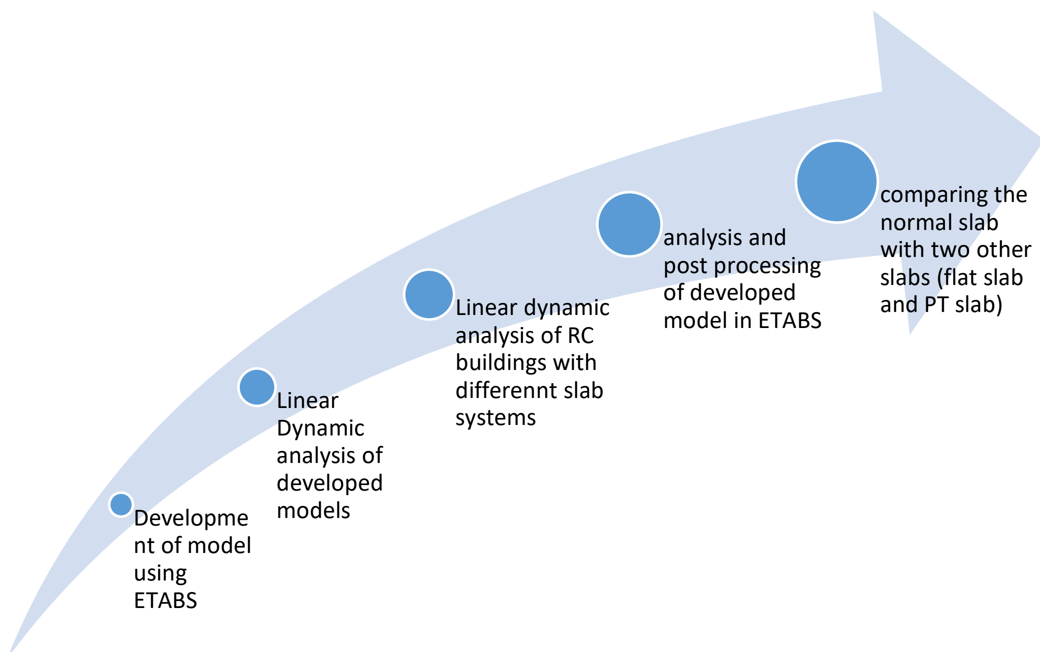
The objective of this research is to investigate the behavior of flat slab multistory G+19 building in four different cases as I) flat slab structure without shear wall. II) Flat slab structure with shear wall at core of the building. III)Flat slab structure with shear wall at corners of the building IV). Flat slab structure with shear wall at side centers of the perimeter boundary of the building. The lateral behavior of a typical flat slab building is evaluated by means of dynamic analysis through linear time history analysis method using ETABS software. The efficiency and serviceability under Indian standard code in seismic zone “V” been observed for each defined model and compared the values with international codes.

CHAPTER-3
METHODOLOGY

3.1. General

It begins with the evaluation of the considered building in Etabs for linear dynamic Response spectrum analysis and ends with finalizing a suitable technique beneficial for the RC buildings with different slab systems.

3.2. Flow chart of the work



3.3 Seismic Analysis

It is a subset of structural analysis and is the calculation of the response of a structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent. The earliest provisions for seismic resistance were the requirement to design for a lateral force equal to a proportion of the building weight (applied at each floor level). This approach was adopted in the appendix of the 1927 Uniform Building Code (UBC), which was used on the west coast of the United States. It later became clear that the dynamic properties of the structure affected the loads generated during an earthquake.

Seismic analysis is a tool for the estimation of structural response in the process of designing earthquake resistant structures and/or retrofitting vulnerable existing structures. In principle, the problem is difficult because the structural response to strong earthquakes is dynamic, nonlinear, and random. All three characteristics are unusual in structural engineering, where the great majority of problems are (or at least can be adequately approximated as) static, linear and deterministic. After computers became widely available, i.e., in the late 1960s and in 1970s, a rapid development of procedures for seismic analysis and supporting software was witnessed. Nowadays, due to tremendous development in computing power, numerical methods, and software, there are almost no limits related to computation.

Earthquake engineering has developed a lot since the early days, with the development of advanced software to perform the analysis and design with accuracy, thus simplifying the process and achieving effectiveness and detailed study in a less time frame. Some of the more complex designs now use special earthquake protective elements either just in the foundation (base isolation) or distributed throughout the structure. Analyzing these types of structures requires specialized computer software and can be done by finite element computer code, which divides time into very small slices and models for precision. Structural analysis methods can be divided into the following five categories.

1. Linear static analysis
2. Response spectrum analysis
3. Linear dynamic analysis
4. Nonlinear static analysis (Pushover analysis)
5. Nonlinear Time History Analysis.

1. Linear Static Analysis

In linear static analysis it is assumed that the material used in the structure obeys the Hooke's law (stress directly proportional to strain) and the rigidity and the stiffness value remain the same. The proportional relationship between loads and deformation is translated into an equal proportion between deformation and deformation rate, and between deformation rate and stress. This allows the use of the superposition method to predict performance under various conditions. Linear static analysis is used for designing the beams and columns.

2. Response Spectrum Analysis

The concept of response spectra was first incorporated into the United States building codes in the late 1950's by means of the coefficient C in the lateral force equation V=KCW by the Structural Engineers Association of California (SEAOC, 1960), where V is the total lateral force, K is a structural systems coefficient of 1.33, 1.0 or 0.67, and W is the total dead load. Over the decades, response spectra have been playing an increasing role in the development of earthquake design criteria. Much of this is due to research and the vast data obtained from recording earthquake motion from earthquakes in California, such as 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge, as well as from earthquakes worldwide.

The paper traces the development of building code provisions and the relationship to response spectra. Response spectra used for design tend to be smooth curves, whereas response spectra obtained from ground motion recordings are generally very ragged with sharp spikes and valleys. The effects of these differences are discussed along with recommendations on how to graphically smooth out the curves. In general, response spectra are used to analyse structures that respond within elastic-linear limits. The paper presents methods of using response spectra to evaluate structural response in the inelastic-nonlinear range. This includes easy to use graphical methods that compare the seismic demand represented by a response spectrum to the capacity of the structure represented by pushover force-displacement curves. Such methods are the capacity spectrum method (CSM) developed by the author (Freeman et al., 1975) as well as modifications (ATC, 1996; FEMA, 2005; Freeman, 2006), and procedures presented by others (Fajfar, 1998; Priestley et al., 1996). Other uses of response spectra include the development of an earthquake engineering intensity scale (EEIS) that extends the TriNet instrumental intensity scale (Wald et al., 1999) to estimate damage levels for a variety of building types.

3.3.1. Introduction to Response Spectra

Response spectra provide a very handy tool for engineers to quantify the demands of earthquake ground motion on the capacity of buildings to resist earthquakes. Data on past earthquake ground motion is generally in the form of time-history recordings obtained from instruments placed at various sites that are activated by sensing the initial ground motion of an earthquake. The amplitudes of motion can be expressed in terms of acceleration, velocity, and displacement.

Although useful to express the relative intensity of the ground motion (i.e., small, moderate or large), the PGA does not give any information regarding the frequency (or period) content that influences the amplification of building motion due to the cyclic ground motion. In other words, tall buildings with long fundamental periods of vibration will respond differently than short buildings with short periods of vibration. Response spectra provide these characteristics. Picture a field of lollipop-like structures of various heights and sizes stuck in the ground. The stick represents the stiffness (K*) of the structure and the lump at the top represents the mass (M*). The period of this idealized single-degree-of-freedom (SDOF) system is calculated by the equation:

$$T = 2 (M^* / K^*)^{1/2} \qquad (1)$$

If the peak acceleration (Sa) of each of these SDOF systems, when subjected to an earthquake ground motion, is calculated and plotted with the corresponding period of vibration (T), the locus of points will form a response spectrum for the subject ground motion. Thus, if the period of vibration is known, the maximum acceleration can be determined from the plotted curve. When calculating response spectra, a nominal percentage of critical damping is applied to represent viscous damping of a linear-elastic system, typically five percent.

Response spectra can be plotted in a variety of formats. A format commonly used in the 1960s was the tripartite logarithmic plot, where the vertical scale is spectral velocity (Sv) and the horizontal scale is T in seconds or frequency (f) in Hertz. On diagonal lines are designated Sa and spectral displacement (Sd). An example is shown in Figure 3.1.

Mathematical relationships between the components of response spectra are given by the following equations:

$$S_v = (T / 2) S_a \qquad (2)$$

$$S_d = (T / 2) S_v \qquad (3)$$

$$S_d = (T / 2) S_v = S_a (T / 2)^2 \qquad (4)$$

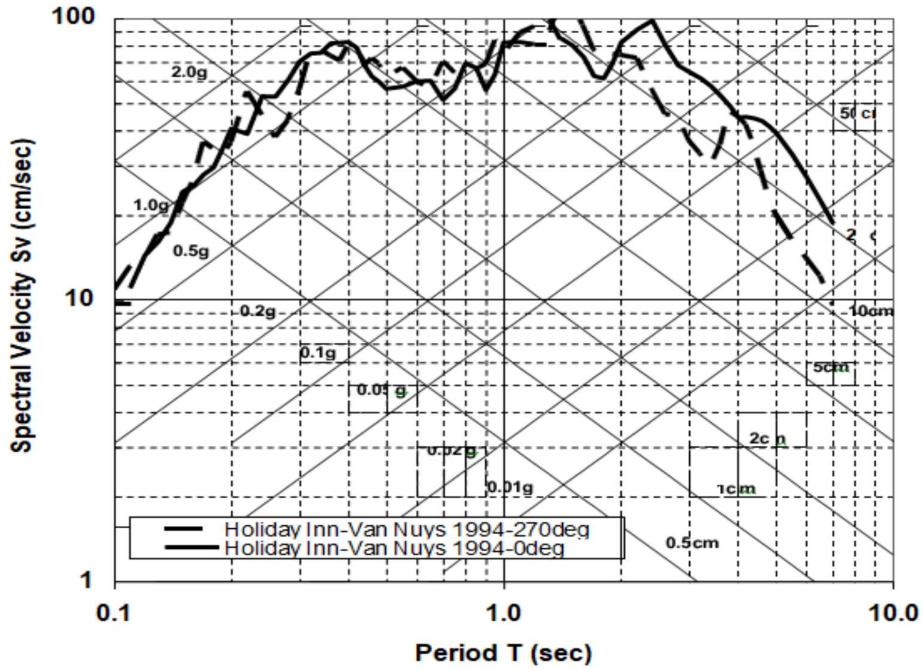


Figure 3.1: Tripartite (Logarithmic) Response Spectra

3.3.2. Factor Influencing Response Spectra

The response spectral values depend upon the following parameters,

1. Energy release mechanism

2. Epicentral distance

3. Focal depth

4. Soil condition

4. Richter magnitude

5. Damping in the system

6. Time period of the system.

3.3.3. Errors in evaluation of Response spectrum

The following errors are introduced in evaluation of response spectra (Nigam and Jennings, 1969),

1. **Straight line Approximation: -** In the digital computation of spectra, the actual earthquake record is replaced by linear segments between the points of digitization. This is a minor approximation provided that the length of the time intervals is much shorter than the periods of interest.

2. Truncation Error: - In general, a truncation error exists in numerical methods for integrating differential equations. For example, in third order Runge-Kutta methods the error is proportional to (Δti)4.

3. **Error Due to Rounding the Time Record: -** For earthquake records digitized at irregular time intervals, the integration technique proposed in this report requires rounding of the time record and the attendant error depends on the way the rounding is done. For round-off to 0.005 sec, the average error in spectrum values is expected to be less than 2 percent.

4. Error Due to Discretization: - In any numerical method of computing the spectra, the response is obtained at a set of discrete points. Since spectral values represent maximum values of response parameters which may not occur at these discrete points, discretization introduces an error which gives spectrum values lower than the true values. The error will be a maximum if the maximum response occurs exactly midway between two discrete points as shown in Figure 4.1. An estimate for the upper bound of this error is shown in Table 1 by noting that at the time of maximum displacement or velocity, the response of the oscillator is nearly sinusoidal at a frequency equal to its natural frequency. Under this assumption the error can be related to the maximum interval of integration, Δti and the period of the oscillator as shown in Figure 3.2.

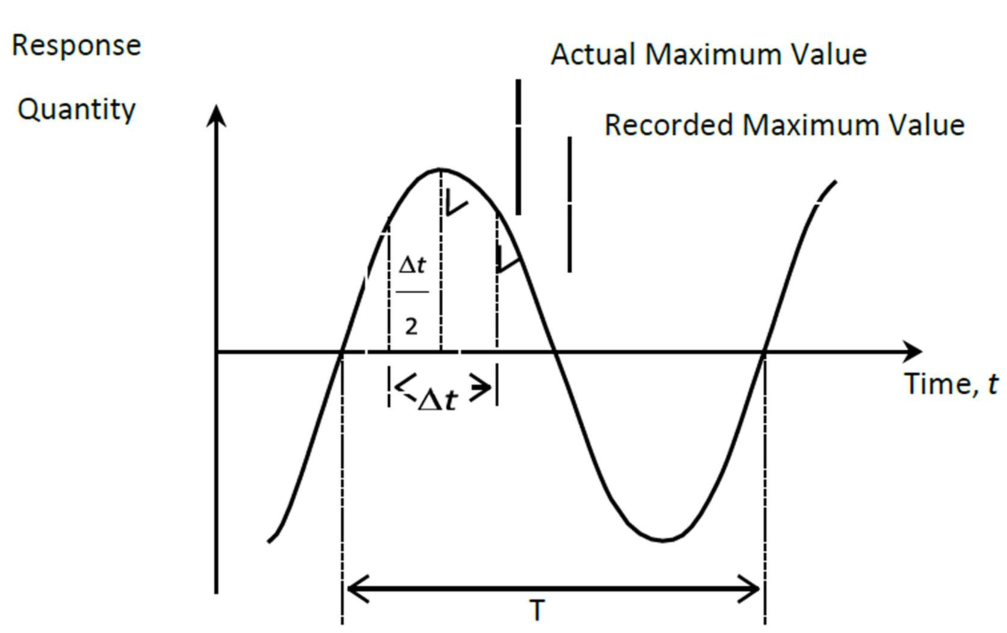


Figure 3.2: Error in Response Spectra Due to Discretization

Table 3.1: Variation of Percentage Error in Response Quantity with Time Step Chosen

Δt_i	Maximum Error (%)
$\leq$ T/10	$\leq$ 4.9
$\leq$ T/20	$\leq$ 1.2
$\leq$ T/40	$\leq$ 0.3

3.4. Response Spectrum Method for MDOF Systems

3.4.1. Response Analysis of MDOF Systems

Multi degree of freedom (MDOF) systems are usually analysed using Modal Analysis. A typical MDOF system with "*n*" degree of freedom is shown in Figure (4.8). This system when subjected to ground motion undergoes deformations in number of ways. These deformed shapes are known as modes of vibration or mode shapes. Each shape is vibrating with a particular natural frequency. Total unique modes for each MDOF system are equal to the possible degree of freedom of system. The equations of motion for MDOF system is given by

$$[m]\{x''(t)\}+[c]\{x'(t)\} + [k]\{x(t)\} = - [m]\{r\}x_g''(\mathrm{t}) \qquad (5)$$

where, $[m]$ = Mass matrix ($n \times n$); $[k]$ = Stiffness matrix ($n \times n$); $[c]$ = Damping matrix ($n \times n$); $\{r\}$ = Influence coefficient vector ($n\times1$); $\{x(t)\}$ = relative displacement vector; $\{x'(t)\}$ = relative velocity vector, $\{x''(t)\}$ = relative acceleration vector, and x_g''(t) =earth quake ground acceleration.

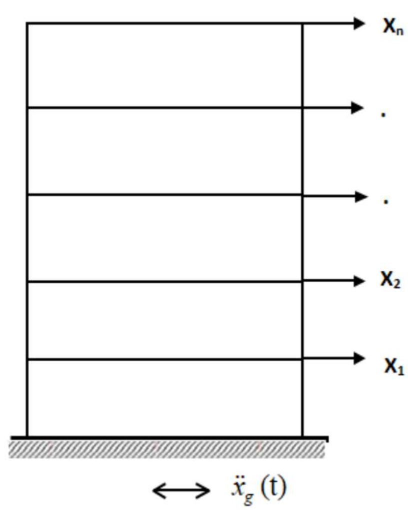


Figure 3.3: MDOF System with "N" Degree-of-Freedom

The undamped eigen values and eigen vectors of the MDOF system are found form the characteristic equation

$\{[k] - \omega_i^2 [m]\} \Phi i = 0$ (6)

i = 1, 2, 3……n

$\det | \{[k] - \omega_i^2 [m]\} | = 0$ (7)

Where;

ω_i^2 = eigen values of the i^{th} mode

Φi = eigen vector or mode shape of the i^{th} mode

ωi = natural frequency in the i^{th} mode.

Let the displacement response of the MDOF system is expressed as

$\{x(t)\} = [\Phi] \{y(t)\}$

where $\{y(t)\}$ represents the modal displacement vector, and $[\Phi]$ is the mode shape matrix given by

$[\Phi]= [\Phi_1, \Phi_2, ... \Phi_n]$

Substituting $\{x\} = [\Phi]\{y\}$ in equation 5 and pre-multiply by $[\Phi]^T$

$[\Phi]^T[m] [\Phi] \{y''(t)\}+[\Phi]^T [c][\Phi]\{y'(t)\}+[\Phi]^T [k][\Phi]\{y(t)\}=-[\Phi]^T[m]\{r\}x_g''(t)$

The above equation is reduced to

$[M_m]\{y''(t)\}+[Cd]\{y'(t)\}+[K_d]\{y(t)\}= -[\Phi]^T[m]\{r\}x_g''(t)$

Where;

$[\Phi]^T [m][\Phi] =[M_m]$= generalized mass matrix. $[\Phi]^T[c][\Phi] = [C_d]$ = generalized damping matrix

$[\Phi]^T [k][\Phi] = [K_d]$ = generalized stiffness matrix.

3.5. Design of Earthquake Structure Based on Codal Provisions

General principles and design philosophy for design of earthquake-resistant structure are as follows:

1. The characteristics of seismic ground vibrations at any location depends upon the magnitude of earthquake, its depth of focus, distance from epicentre, characteristic of the path through which the waves travel, and the soil strata on which the structure stands. Ground motions are predominant in horizontal direction

2. Earthquake generated vertical forces, if significant, as in large spans where differential settlement is not allowed, must be considered.

3. The response of a structure to the ground motions is a function of the nature of foundation soil, materials size, and mode of construction of structures, and the duration and characteristic of ground motion.

4. The design approach is to ensure that structures possess at least a minimum strength to withstand minor earthquake (DBE), which occur frequently, without damage; resist moderate earthquake without severe damage though some non-structural damage may occur, and aims those structures withstand major earthquake (MCE) without collapse. Actual forces that appeared on structures are much greater than the design forces specified here, but ductility, arising due to inelastic material behaviour and detailing, and over strength, arising from the additional reserve strength in structures over and above the design strength are relied upon to account for this difference in actual and design lateral forces.

5. Reinforced and pre-stressed members shall be suitably designed to ensure that premature failure due to shear or bond does not occur, as per IS:456 and IS:1343.

6. In steel structures, members and their connections should be so proportioned that high ductility is obtained

7. The soil structure interaction refers to the effect of the supporting foundation medium on the motion of structure. The structure interaction may not be considered in the seismic analysis for structures supporting on the rocks.

8. The design lateral forces shall be considered in two orthogonal horizontal directions of the structures. For structures, which have lateral force resisting elements in two orthogonal directions only, design lateral force must be considered in one direction at a time. Structures having lateral resisting elements in two directions other than orthogonal shall be analysed according to clause 2.3.2 IS 1893 (part 1): 2002. Where both horizontal and vertical forces are considered, load combinations must be according to clause 2.3.3 IS 1893 (part 1): 2002.

9. When a change in occupancy results in a structure being re-classified to a higher importance factor (I), the structure shall be confirmed to the seismic requirements of the new structure with high importance factor.

3.6. Design Criteria

To determining the design seismic forces, the country (India) is classified into four seismic zones (II, III, IV, and V). Previously, there were five zones, of which Zones I and II are merged into Zone II in fifth revision of code. The design horizontal seismic forces coefficient Ah for a structure shall be determined by following expression.

$$A_h = \frac{ZIS_a}{2Rg} \qquad (8)$$

Z = zone factor for the maximum considerable earthquake (MCE) and service life of the structure in a zone. Factor 2 in denominator is to reduce the MCE to design basis earthquake (DBE).

I = importance factor, depending on the functional purpose of the building, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value , or economic importance.

R = response reduction factor, depending upon the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations however the ratio I/R shall not be greater than 1.

Sa /g = average response acceleration coefficient.

For rocky, or hard soil sites;

$$\frac{S_a}{g} \begin{cases} 1+15T & (0.00 \leq T \leq 0.10) \\ 2.50 & (0.10 \leq T \leq 0.40) \\ 1.00/T & (0.4 \leq T \leq 4.00) \end{cases}$$

For medium soil sites;

$$\frac{S_a}{g} \begin{cases} 1+15T & (0.00 \leq T \leq 0.10) \\ 2.50 & (0.10 \leq T \leq 0.55) \\ 1.36/T & (0.55 \leq T \leq 4.00) \end{cases}$$

For soft soil sites;

$$\frac{S_a}{g} \begin{cases} 1+15T & (0.00 \leq T \leq 0.10) \\ 2.50 & (0.10 \leq T \leq 0.67) \\ 1.67/T & (0.67 \leq T \leq 4.00) \end{cases}$$

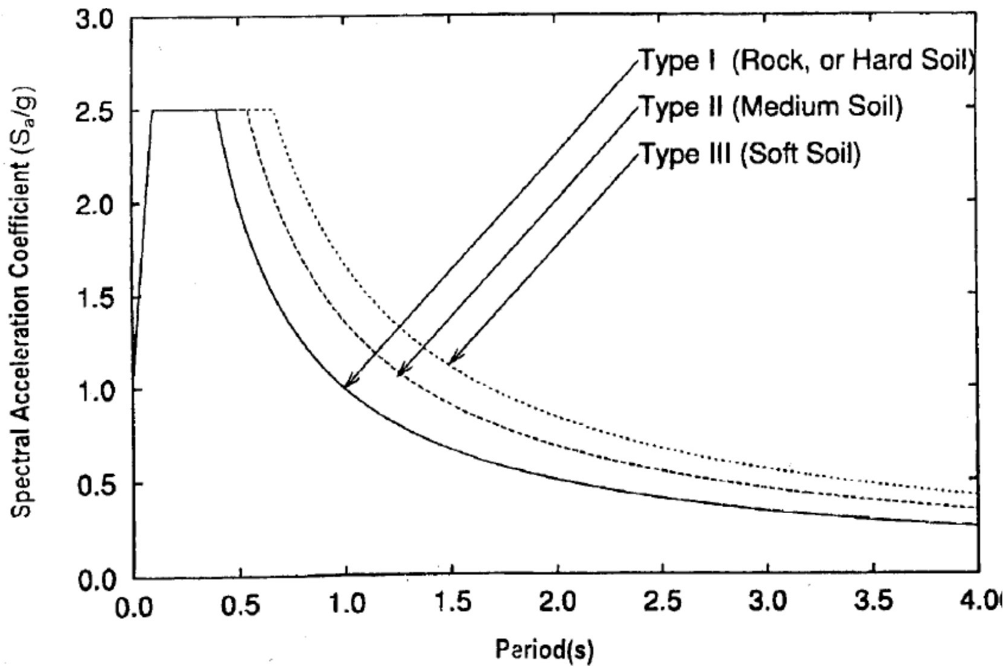


Figure 3.4: Design response spectra curve as per IS:1893-2002 code

3.6.1. Design Lateral Force

The total design lateral force or design seismic base shear (Vb) along any principal direction of the building shall be determined by the following expression

$$V_b = A_h W \qquad (9)$$

where Ah is the horizontal seismic forces coefficient (refer equation (8) and W is the seismic weight of building.

3.6.2. Seismic Weight

The seismic weight of each floor is its full dead load plus appropriate amount of imposed load as specified. While computing the seismic weight of each floor, the weight of columns and walls in any storey shall be equally distributed to the floors above and below the storey.

The seismic weight of the whole building is the sum of the seismic weights of all the floors. Any weight supported in between the storey shall be distributed to the floors above and below in inverse proportion to its distance from the floors.

- **fundamental Natural Period**

The fundamental natural time period as mentioned in clause 7.6 IS 1893 (part 1): 2002 for moment resisting RC frame building without brick infill walls and moment resisting steel frame building without brick infill walls, respectively is given by

$$Ta = 0.075h^{0.75} \quad (10)$$

$$Ta = 0.085h^{0.75} \quad (11)$$

where, h = height of the building in 'm' excluding basement storey if it relates to the ground floor decks or fitted in between the building column.

If there is brick filling, then the fundamental natural period of vibration, may be taken as

$$T_a = \frac{0.09h}{\sqrt{d}} \quad (12)$$

where, h = height of the building in m, as defined above, and d = base dimension of the building at the plinth level, in meter, along the considered direction of the lateral force.

3.7. Distribution of Design Force

The design base shear, Vb computed above shall be distributed along the height of the building as per the following expression,

$$Q_i = \frac{W_i \times h_i}{\sum_{i=1}^{n} W_j \times h_j^2} \quad (13)$$

Where;

Q_i = design lateral force at i^{th} floor

W_i = seismic weight of i^{th} floor

h_i= height of i^{th} floor measured from base, and

= numbers of storey in the building are the number of the levels at which the masses are located

In case of buildings whose floors can provide rigid horizontal diaphragm action, the total shear in any horizontal plane shall be distributed to the various vertical elements of lateral force resisting system, assuming the floors to be infinitely rigid in the horizontal plane.

In case of building whose floor diaphragms cannot be treated infinitely rigid in their own plane, the lateral shear at each floor shall be distributed to the vertical elements resisting the lateral forces, considering the in plane flexibility of the diaphragms.

3.8. Response Spectrum Method (Dynamic Analysis)

General Codal Provision

Dynamic analysis should be performed to obtain the design seismic force, and its distribution to various levels along the height of the building and to various lateral load resisting elements, for the following buildings:

- **Regular buildings-** Those are greater than 40 m in height in zone IV, V and those are greater than 90 m height in zones II, III, and
- **Irregular buildings-** All framed buildings higher than 12 m in zone IV and V, and those are greater than 40 m in height in zone II and III.

Dynamic analysis may be performed either by time history method or by the response spectrum method. However, in either method, the design base shear V_b shall be compared with a base shear V b calculated using a fundamental period Ta... When V_b is less than V ball response quantities shall be multiplied by V_b / V_b

3.8.1. Modes to be Considered

The number of modes to be considered in the analysis should be such that the sum of the total modal masses of all modes considered is at least 90% of the total seismic mass and the missing mass correction beyond 33%. If modes with natural frequency beyond 33 Hz are to be considered, modal combination shall be carried out only for modes up to 33 Hz.

3.8.2. Computation of Dynamic Quantities

Buildings with regular, or nominally irregular plan configuration may be modelled as a system of masses lumped at the floor levels with each mass having one degree of freedom, that of lateral displacement in the direction of consideration. In such a case, the following expressions shall hold in computations of various quantities.

1. Modal mass

$M_{ik} = \frac{\sum_{i=1}^{n} W_i \emptyset_{ik}}{\sum_{i=1}^{n} W_i \emptyset_{ik}^2}$ (14)

where,

g = acceleration due to gravity

φik= mode shape coefficient of floor, *i* in mode *k*, and

Wi=seismic weight of floor, *i*

2. Modal Participation Factor: The factor is given by

$P_{ik} = \frac{\sum_{i=1}^{n} W_i \emptyset_{ik}}{\sum_{i=1}^{n} w_i \emptyset_{ik}^2}$ (15)

3. Design lateral force at each floor in each Mode: The peak lateral force at floor i in k^{th} mode is given by

$Q_{ik} = A_i \, \emptyset_{ik} W_i$ (16)

Where Ak= Design horizontal acceleration spectrum values using natural period of vibration

4. Storey shear force in each mode: The storey peak shear force at i^{th} storey in mode k is given by

$V_{ik} = \sum_{j=i+1}^{n} Q_{ik}$ (17)

3.9. Analysis Method

These are broadly classified as linear static, linear dynamic, nonlinear static and nonlinear dynamic as discussed in chapter 3.

Firstly, equivalent static analysis is conducted and then linear dynamic analysis (Response spectrum method) and push over analysis are performed.

3.10. Equivalent Static Analysis

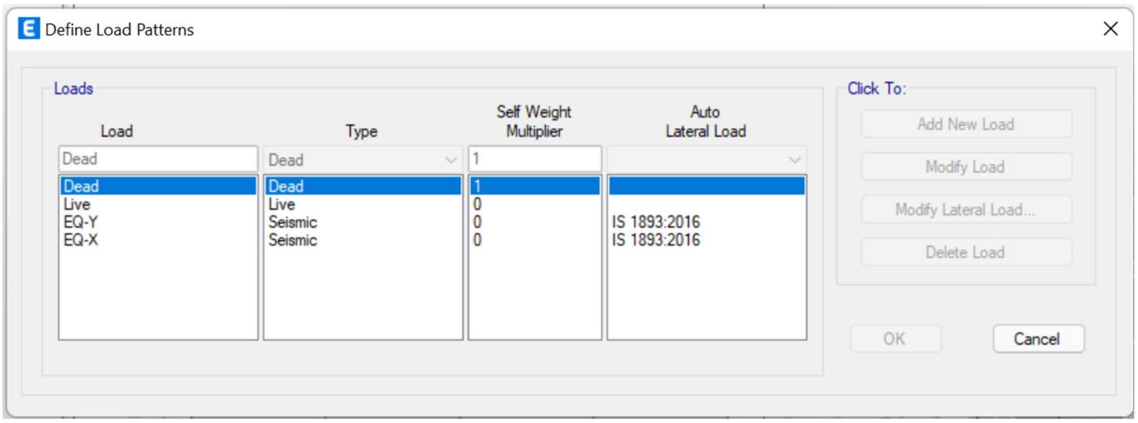


fig 3.5: Equivalent Static, Gravity, and Lateral Loads

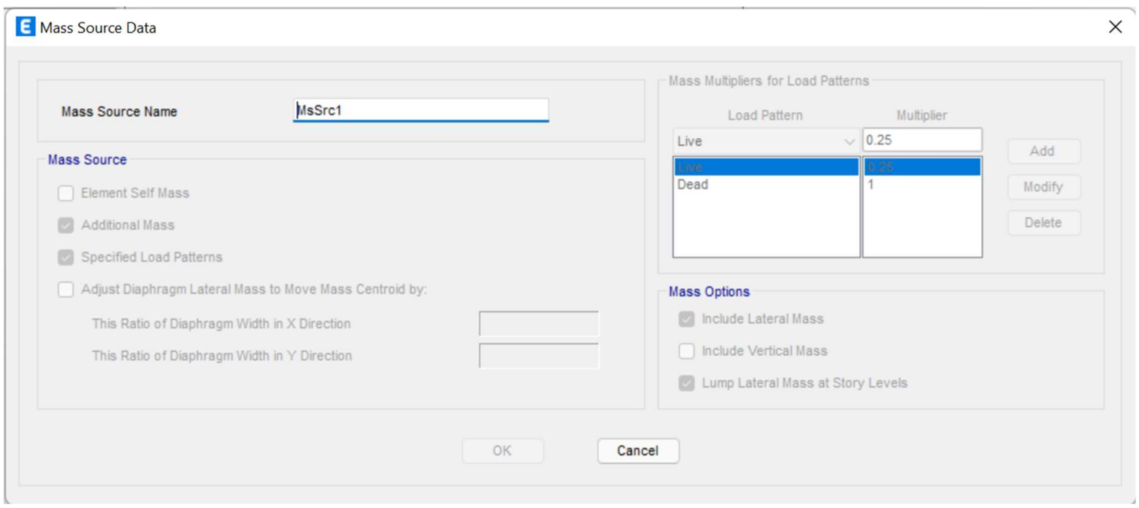


Figure 3.6: Mass Source of the Structure

3.11. Analysis Using Response Spectrum method

Analysis methods are broadly classified as linear static, linear dynamic, nonlinear static and nonlinear dynamic methods. In these the first two methods are suitable when the structural loads are small and no point, the load will reach to collapse load and are differs in obtaining the level of forces and their distribution along the height of the structure. Whereas the non-linear static and non-linear dynamic analysis are the improved methods over linear approach. During earthquake loads the structural loading will reach to collapse load and the material stresses will be above yield stresses. So, in that case material nonlinearity and geometrical nonlinearity should be incorporated into the analysis to get better results. These methods also provide information on the strength, deformation, and ductility of the structures as well as distribution of demands.

Linear dynamic analysis of the building models is performed using ETABS 18. The lateral loads generated by ETABS 18 correspond to the seismic zone 2 and 5% damped response spectrum given in IS 1893-2002 (Part 1). The fundamental natural period values are calculated by ETABS 18, by solving the eigen value problem of the model. Thus, the total earthquake load generated and its distribution along the height corresponds to the mass and stiffness distribution as modelled by ETABS 18. The response spectrum for the structure is defined in the ETABS 18 as Spec 1 (Spectrum) and the response spectrum analysis data is defined in the load cases defined. The following Fig. 4.9 & 4.10 show the details of the Response history analysis case. The response spectrum analysis is run, and the members are designed for the analysis results obtained, by IS: 456-2000 design specifications. The ETABS 18 has predefined member reinforcement details, these are overwritten by selecting the Reset all Concrete Overwrites button.

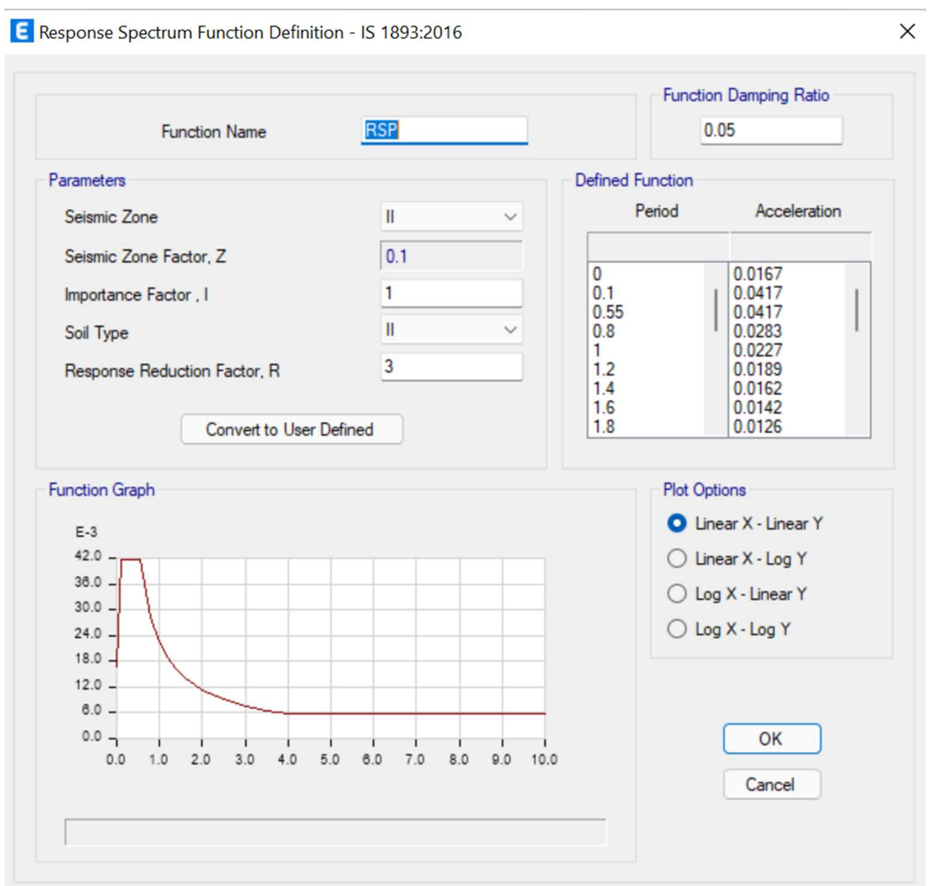


Figure 3.7: Details of the Response Spectrum Defined for Response Spectrum Analysis

Details of the Response Spectrum Defined for Response Spectrum Analysis

Following are the parameters considered for the discussion of results by seismic analysis.

- **Storey Displacement**

Story displacement is also called Lateral Displacement or Sway of the building. It is defined as Displacement taken in the Lateral direction of building due to seismic load and wind load that acts in Lateral direction on the building. Sway is directly proportional to height and slenderness of structure that is storey displacement increases as the height of building increases. Storey displacement is least at base and highest at the top storey as the height of structure increases.

- **Storey Drift**

Storey Drift is nothing, but the ratio of displacement taken place between two consecutive floors to a height of that the building. It is also defined as the Lateral Displacement of a single storey that occurs in the multistorey building. Story drift varies as parabolic path and assumes maximum at some storey in middle but not at the topmost storey.

- **Storey Shear**

A sum of reactive forces obtained due to the action of seismic forces on buildings act at the column base of building in the direction opposite to that in which they act (sum of the lateral load = base shear). As considered, it does not only act on base, indeed it acts on every story and varies with height and masses over every story and this reactive force is called Storey Shear.

- **Overturning moment**

When structures are subjected to lateral forces such as wind force and seismic forces, they undergo deflection in the lateral direction and lateral sway is also observed in one direction of the structure. This causes structure to experience overturning. Tall structures experience large lateral forces due to their height.

Therefore, they are designed in such a way that the structure can counteract the effect of overturning. When the design analysis involves the consideration of overturning effect, the stability of the structure increases up to a greater extent. If the overturning of the structure is not controlled, then it can eventually lead to structural failure. The results obtained from the analysis are formatted as graphs and the discussion is done at the end.

Table.3.2 – Beam and Column dimensions

4 Storey	8 Storey	12 Storey
Column size: 500mmx500mm, 500mmx750mm	**Column size:** 650mmx650mm, 600mmx850mm	**Column size:** 650mmx650mm, 600mmx850mm
Beam size: 350mmx550mm	**Beam size**: 350mmx650mm	**Beam size:** 350mmx650mm

3.12. Different slab models

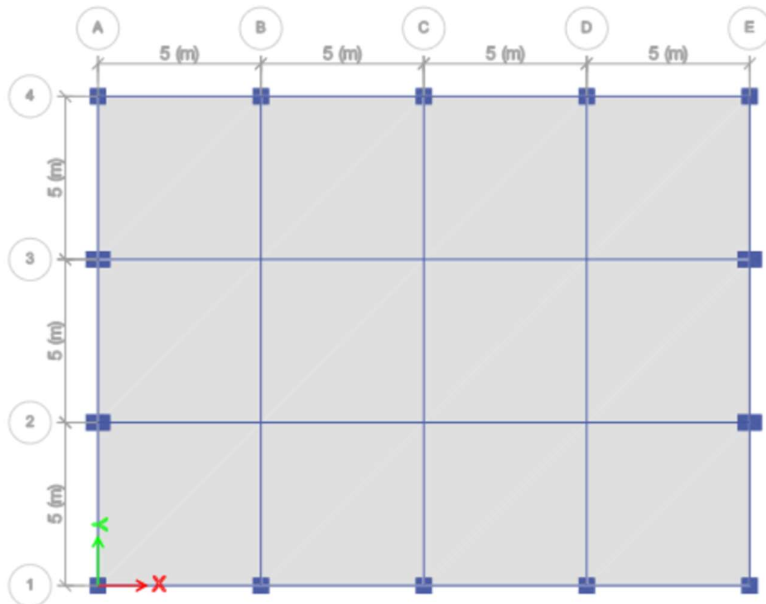


Fig. 3.8 -Plan of Conventional slab system

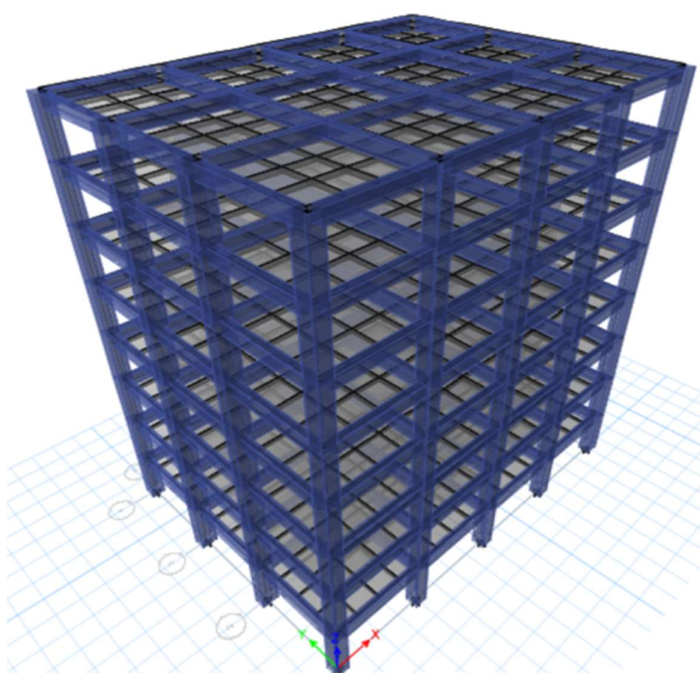


Fig.3.9. - 3D View of Conventional Slab System

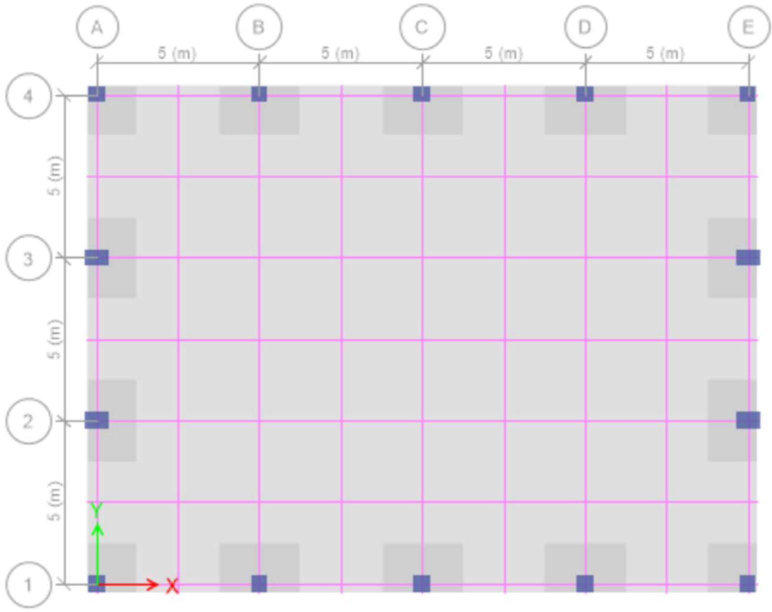


Fig.3.10. - Plan of Flat slab system with Drop

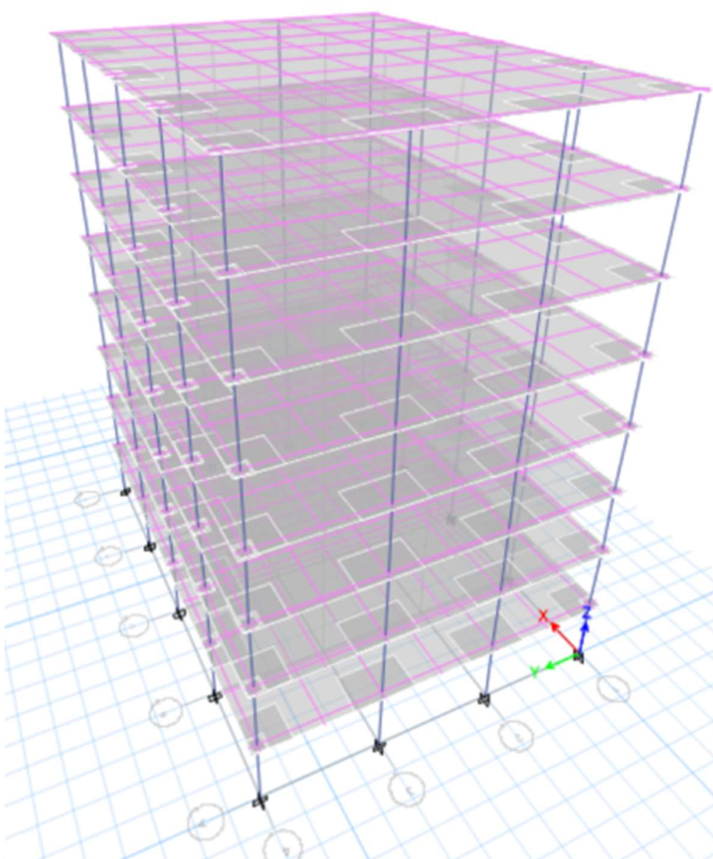


Fig.3.11. -3D View of Flat slab System (8 Storey)

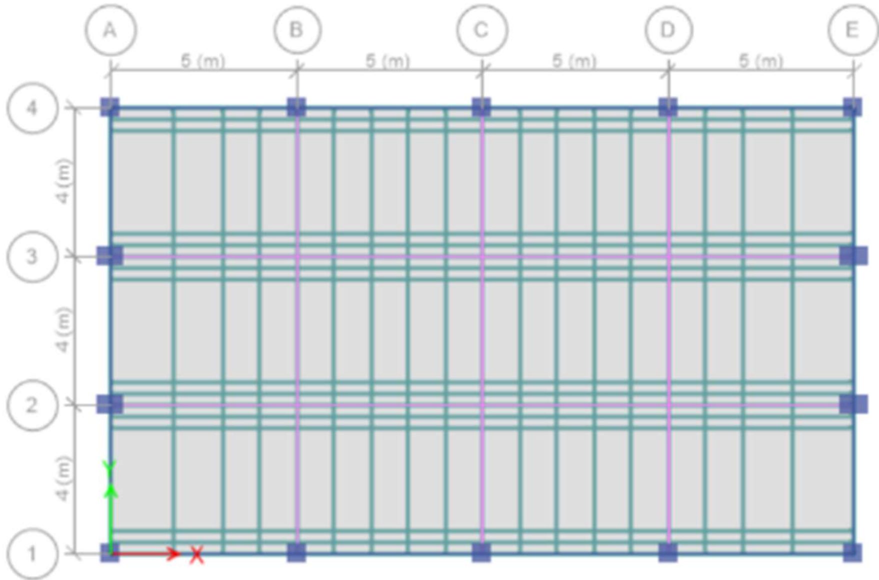


Fig 3.12 Plan view of Post Tensioned slab

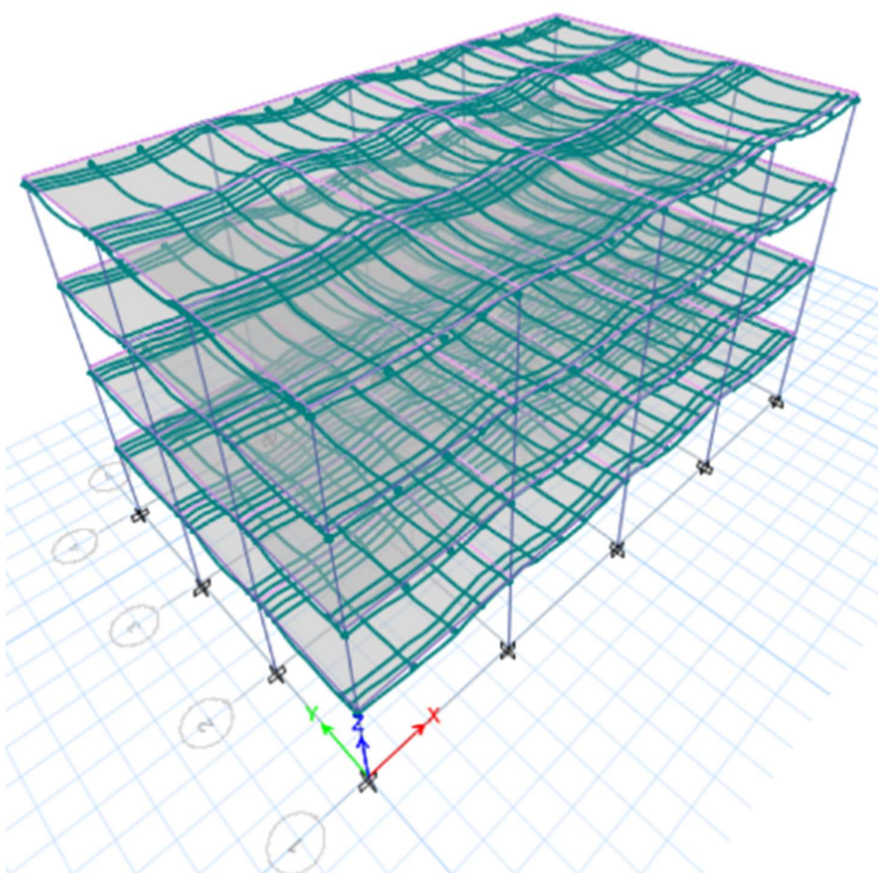


Fig. 3.13 3D view of 4-storey Post Tensioned slab

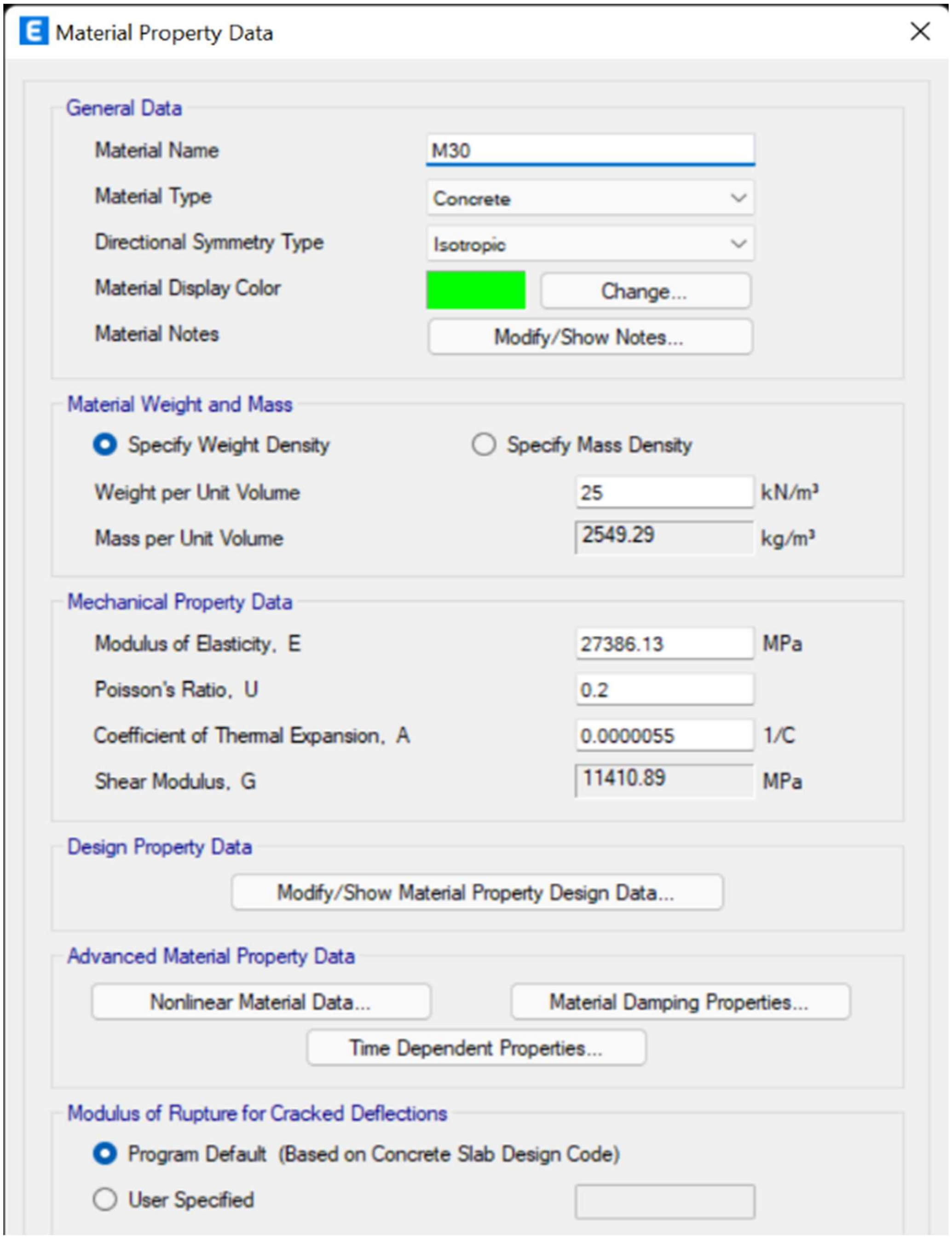


fig.3.14. Material property data– M_{30} grade of Concrete

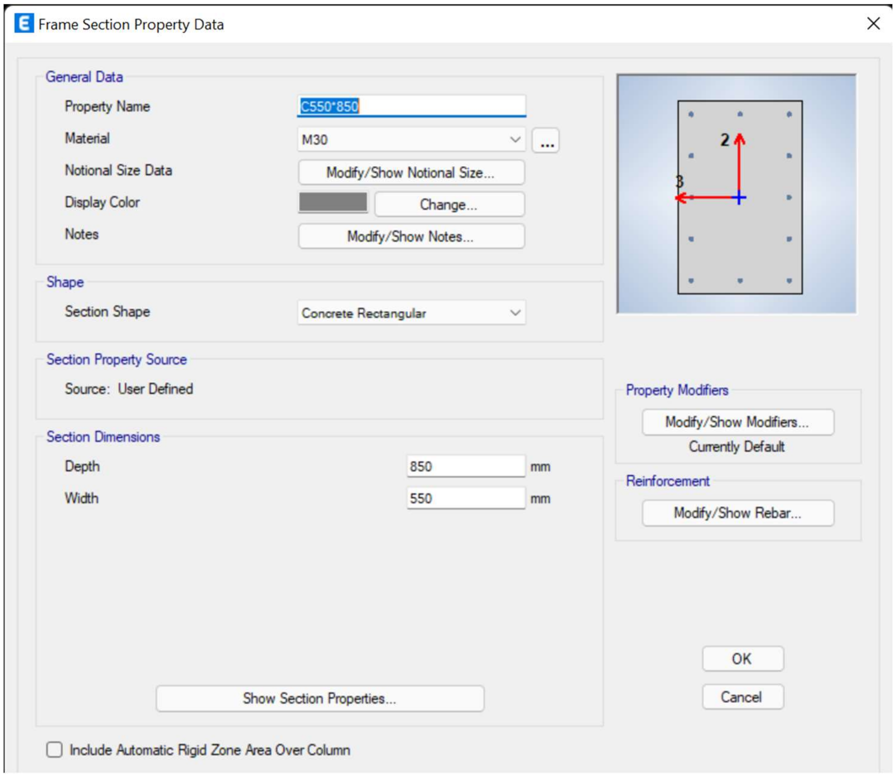


Fig.3.15. Frame Section Property data – Rectangular Column

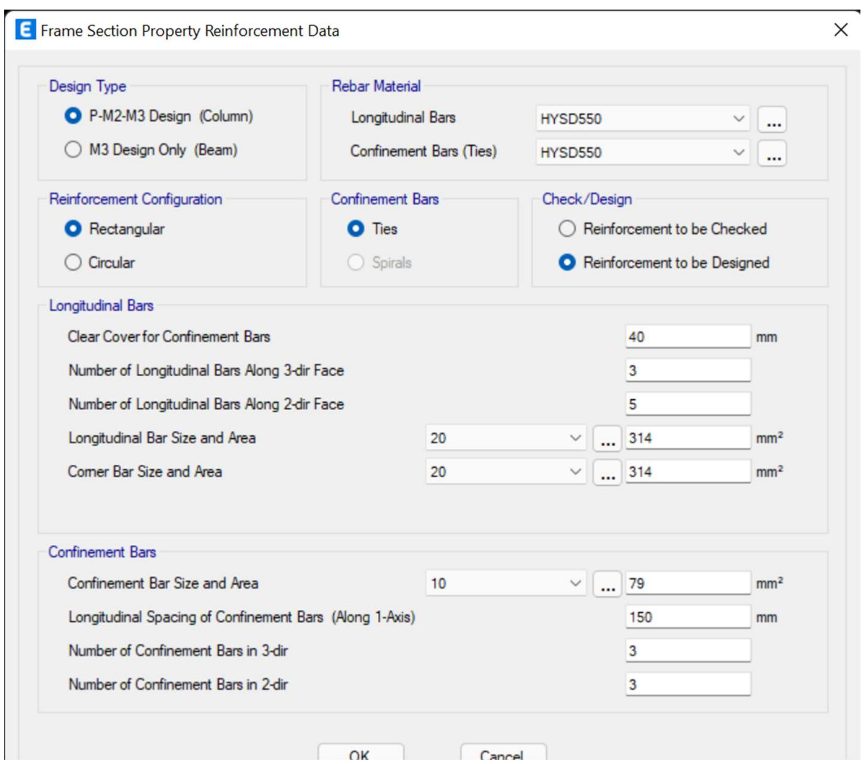


Fig.3.16. Frame section property Reinforcement data- Column

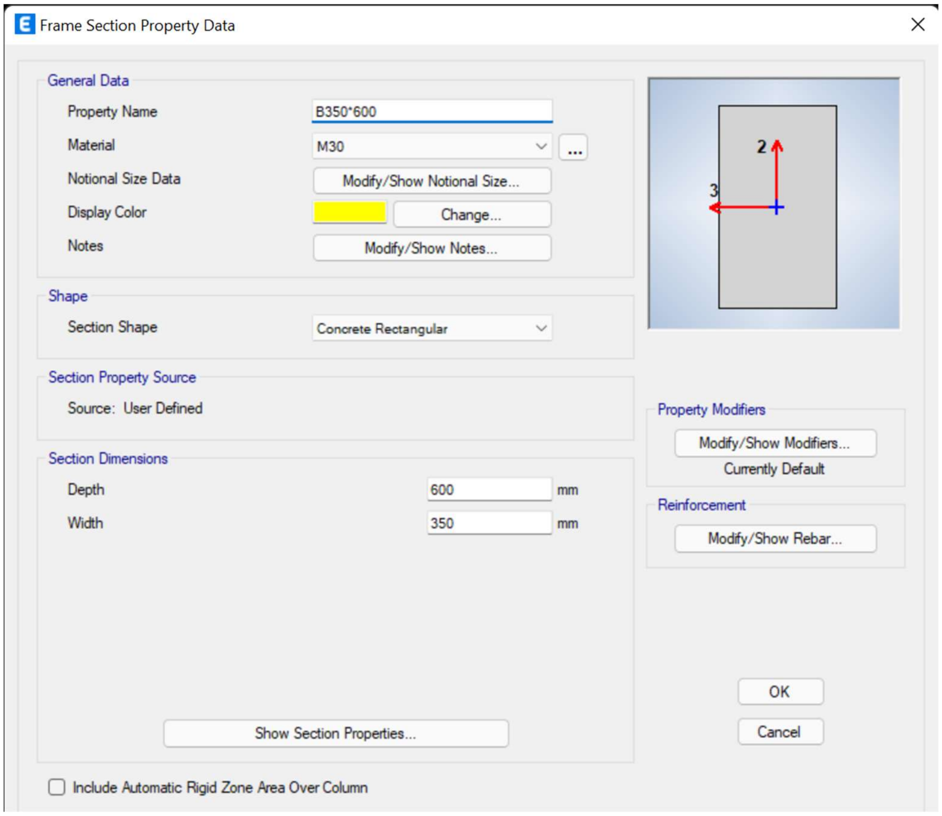


Fig.3.17. Frame Section Property data – Rectangular Beam

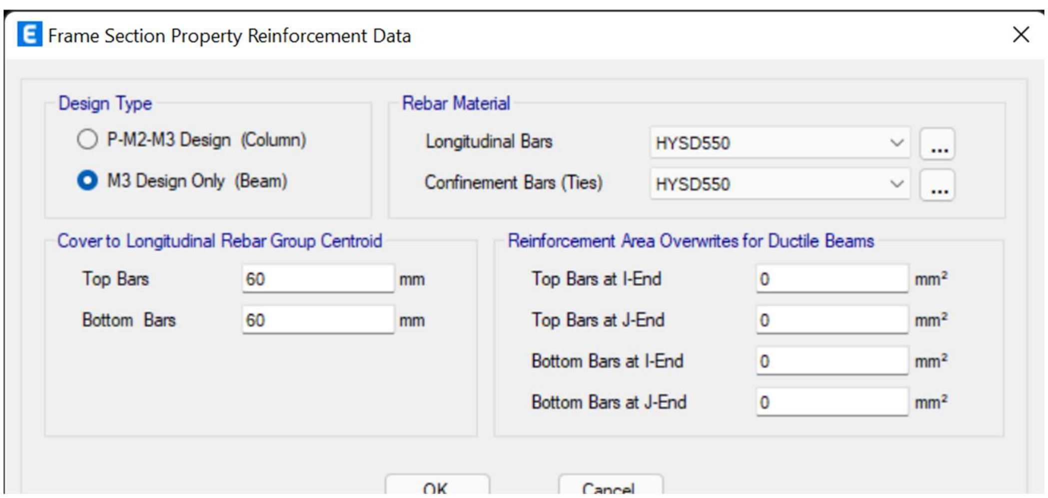


Fig.3.18. Frame section property Reinforcement data-Beam

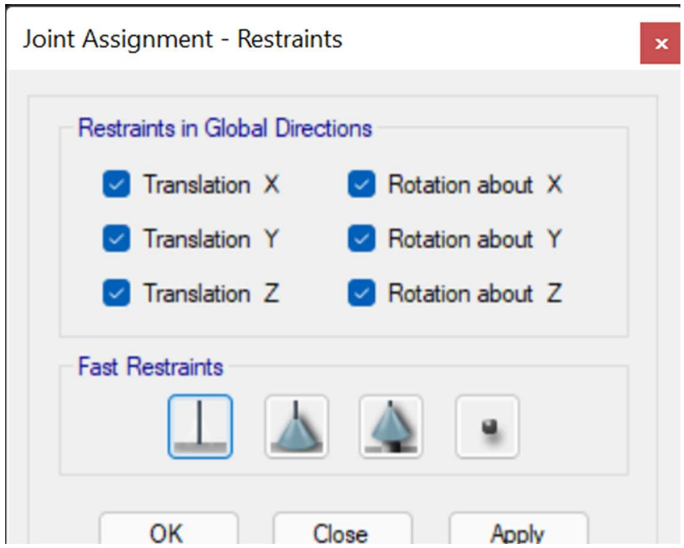


Fig.3.19. Joint assignment – Restraints

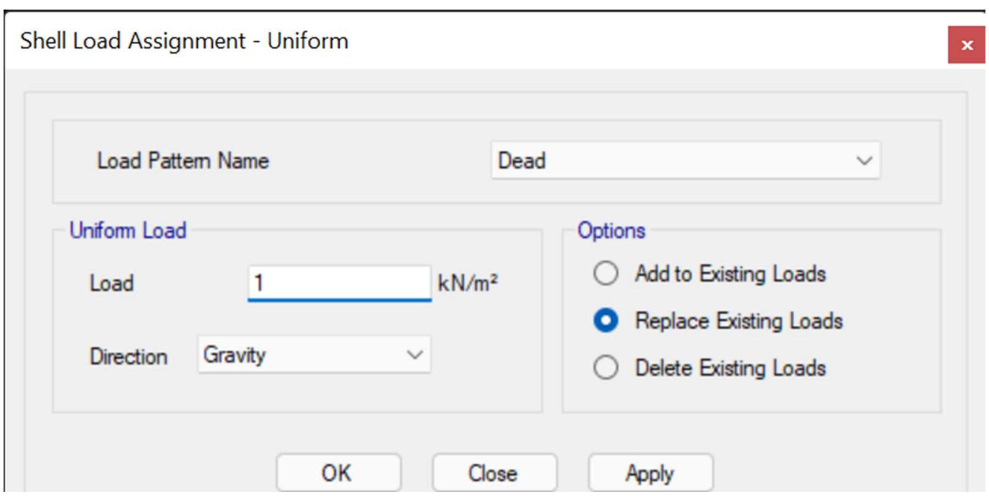


Fig.3.20. Shell load assignment (Uniform) -Dead

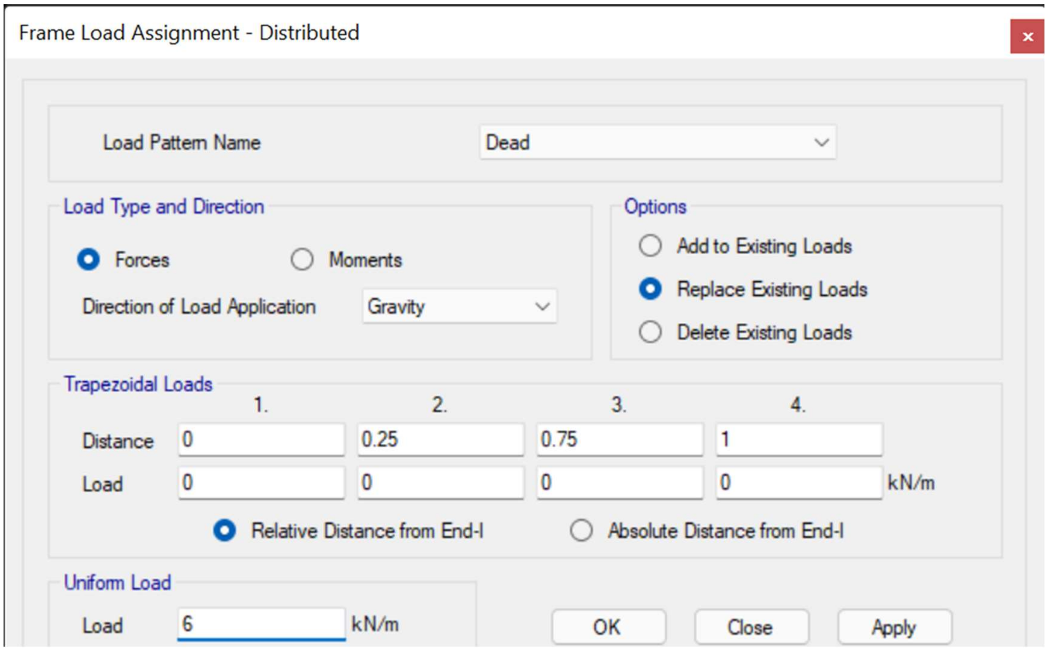


Fig.3.21. Frame load assignment (Distributed) – Dead

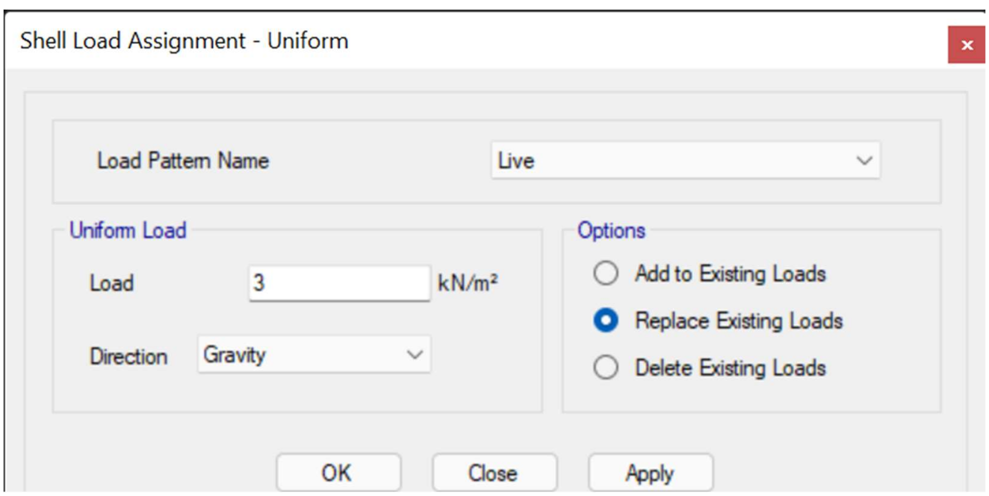


Fig.3.22. Shell load assignment (Uniform) - Live

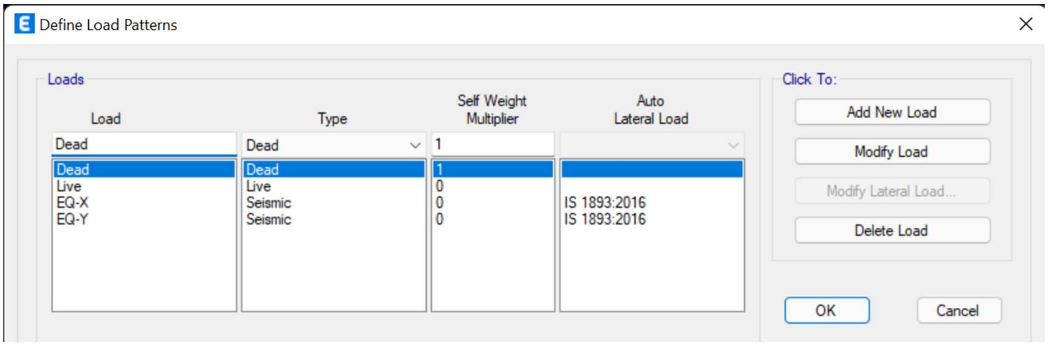


Fig.3.23. Define load patterns

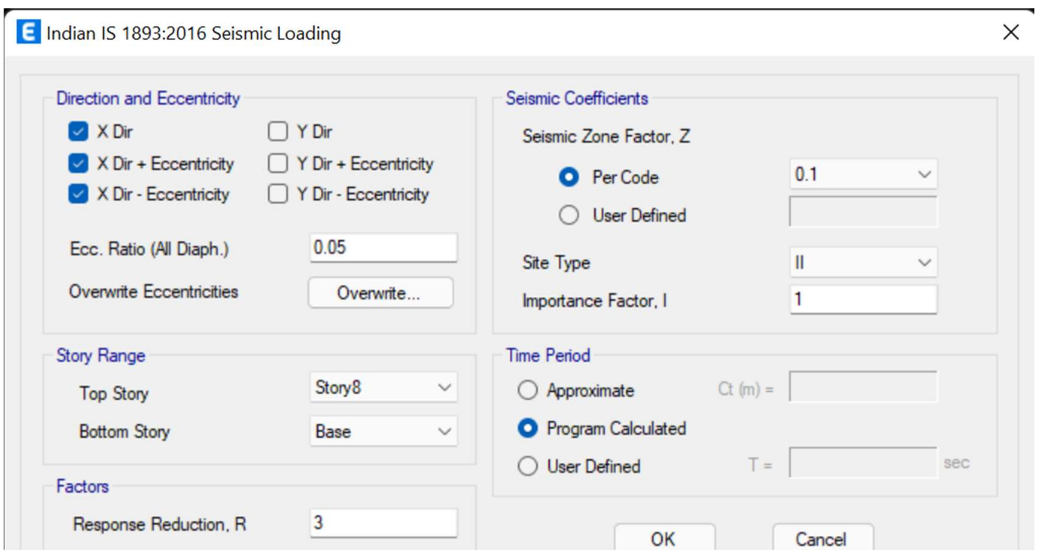


Fig.3.24. IS 1893:2016 Seismic Loading in X-direction

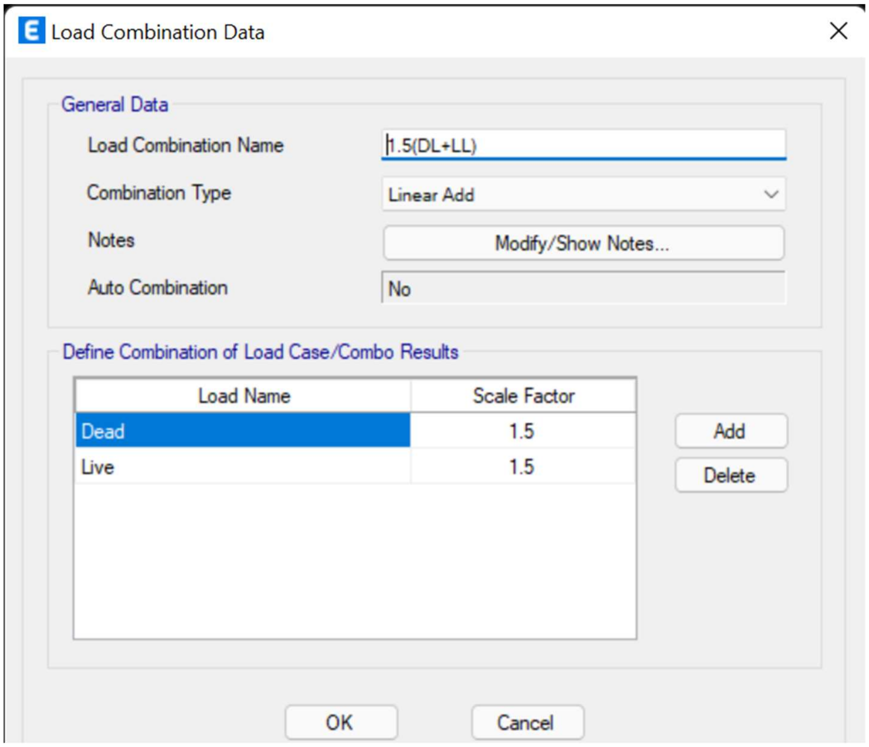


Fig.3.25 Load Combination data – Dead load and liveload

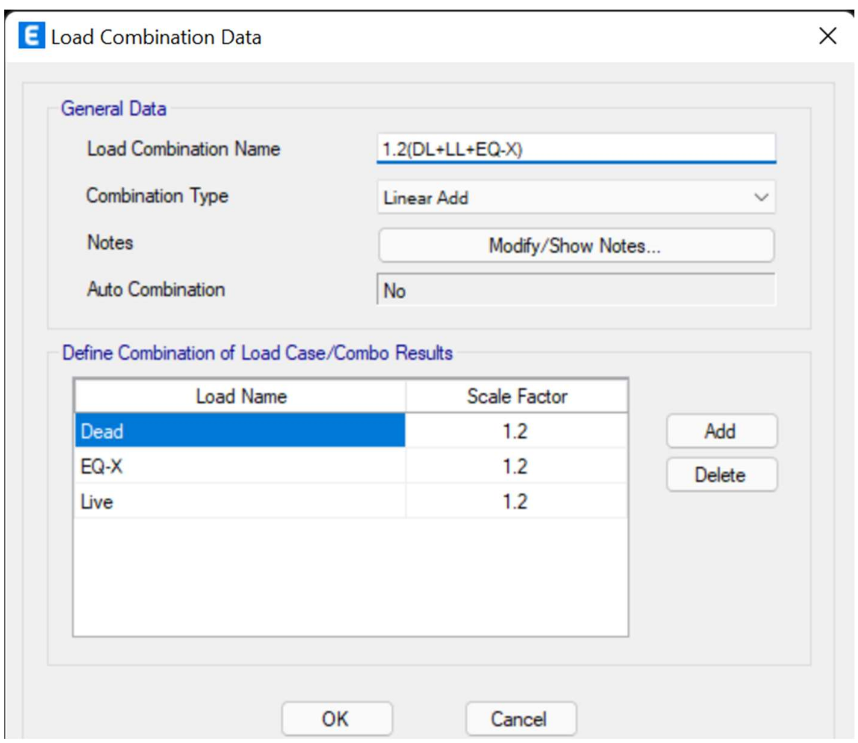


Fig.3.26 Load Combination data – Dead load, Live load and Earth quake load in X-direction

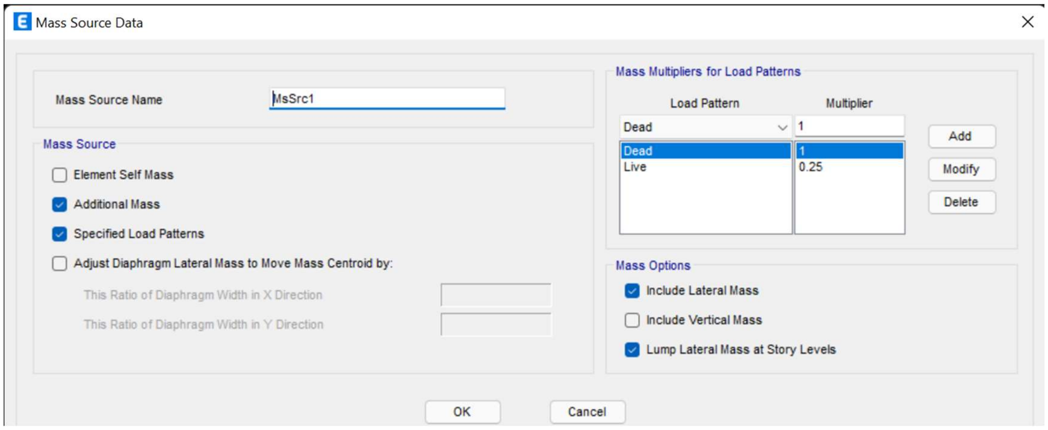


Fig.3.27. Mass Source data

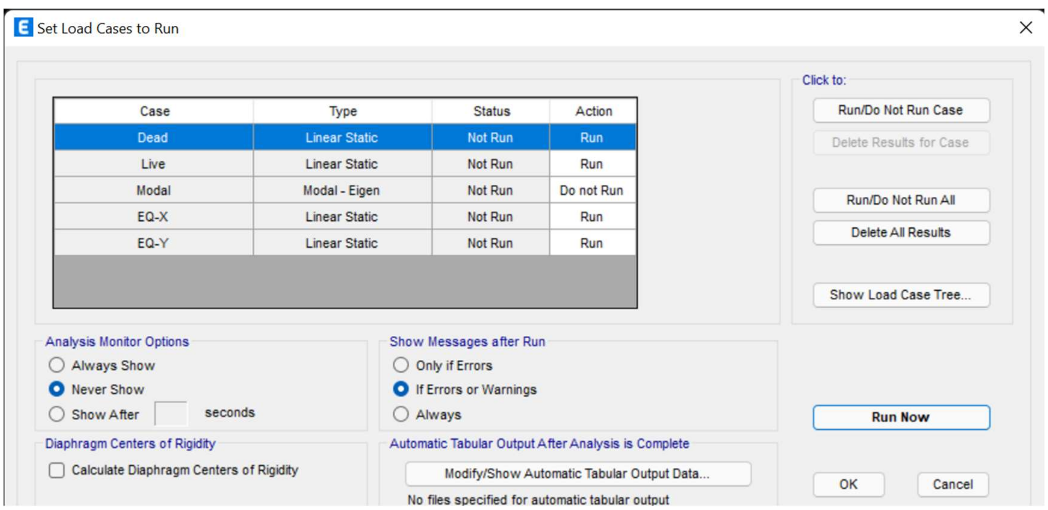


Fig.3.28. Set load Cases to Run

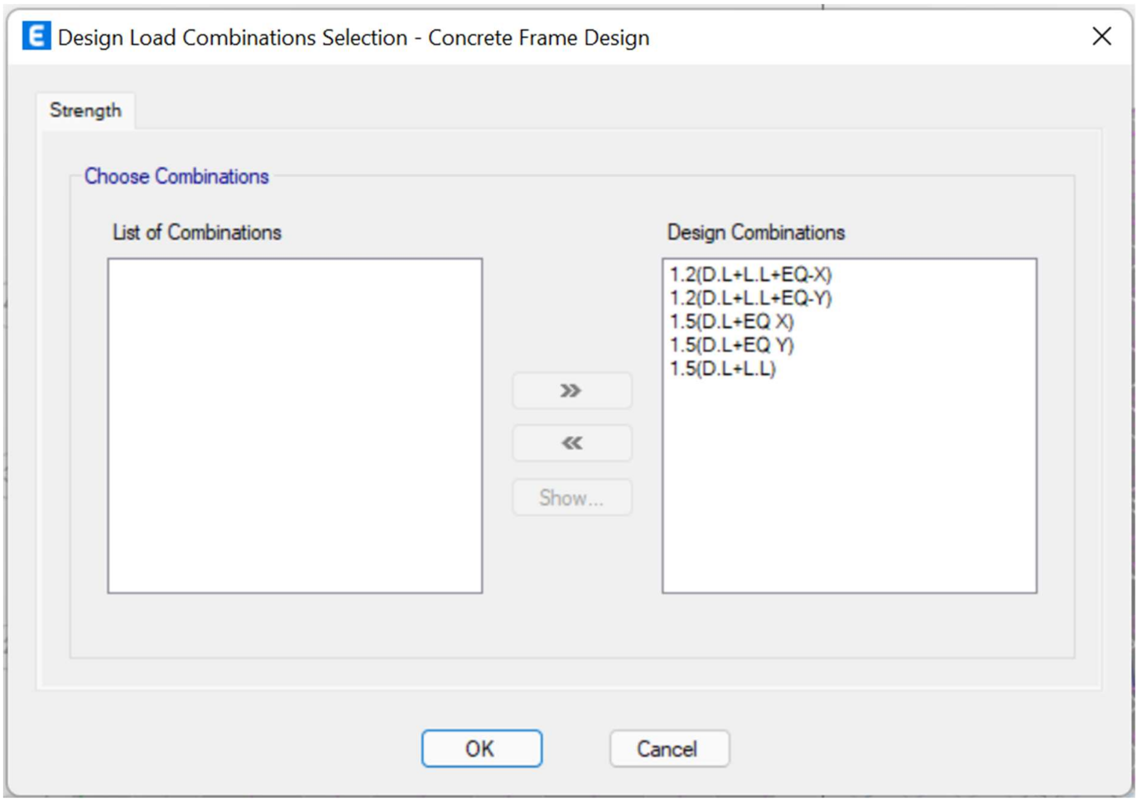


Fig.3.29. Design load combinations selection

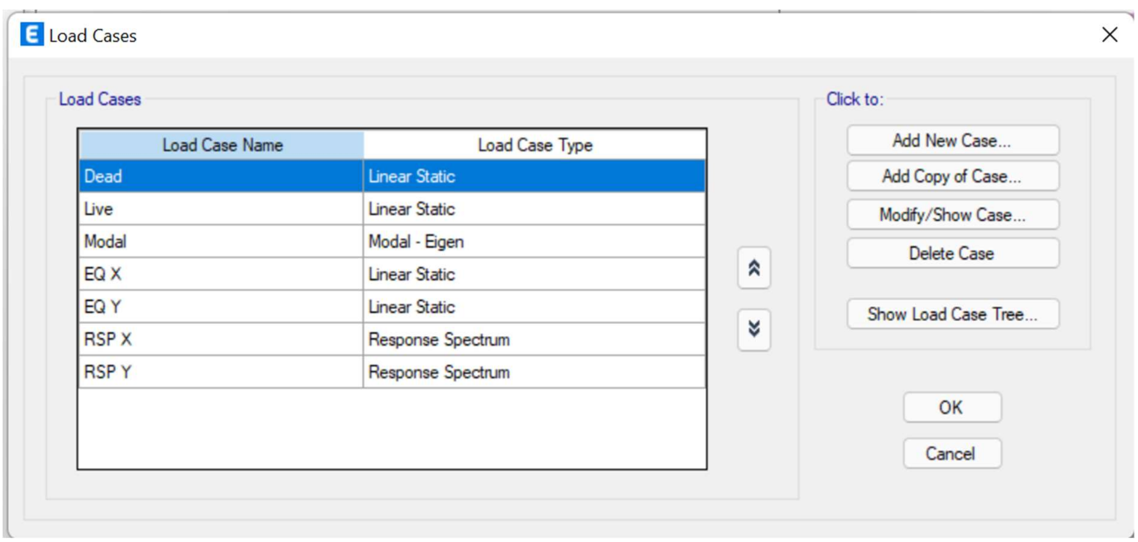


Fig.3.30. Define load cases – Response spectrum

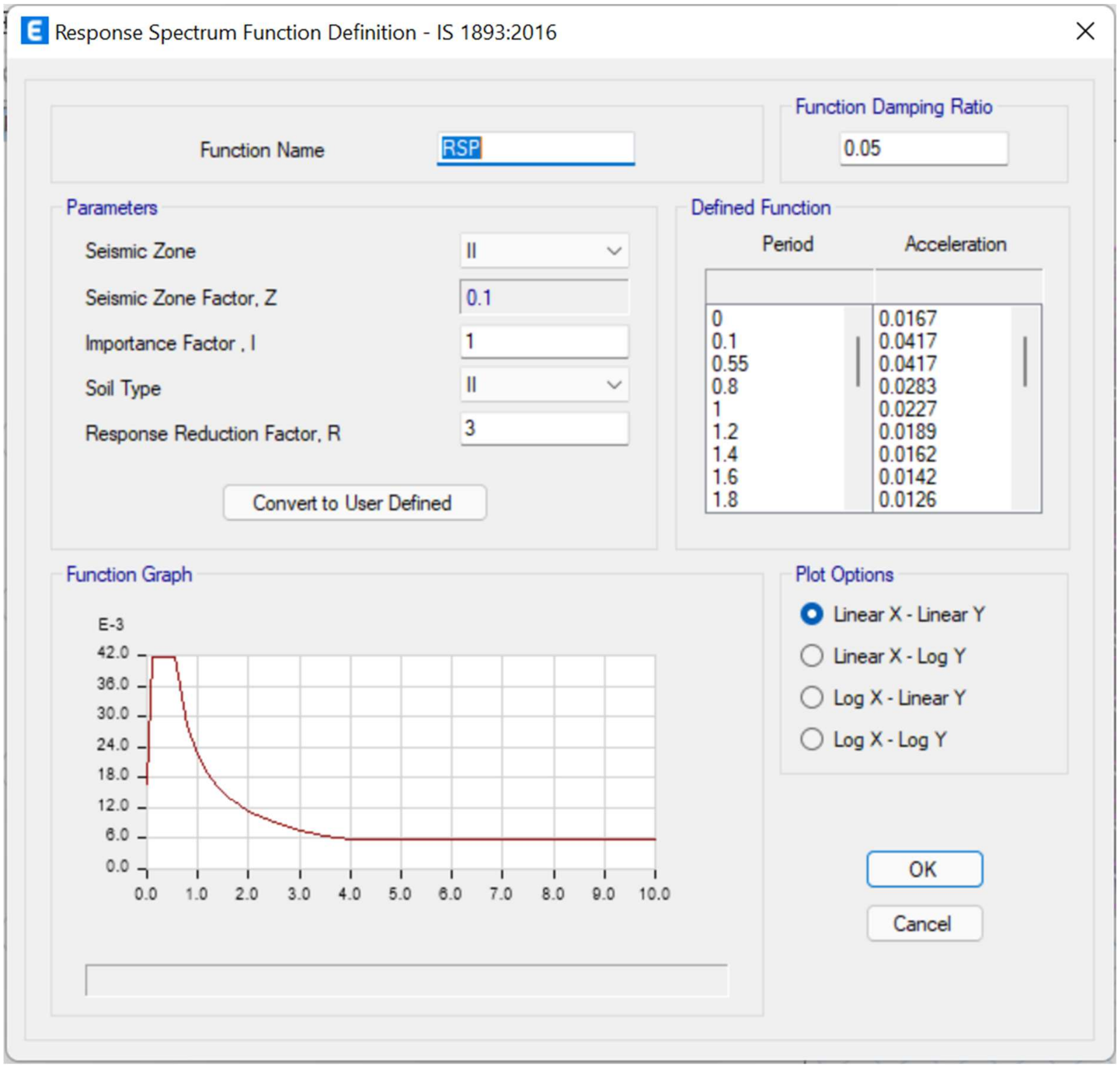


Fig.3.31. Response spectrum Function definition

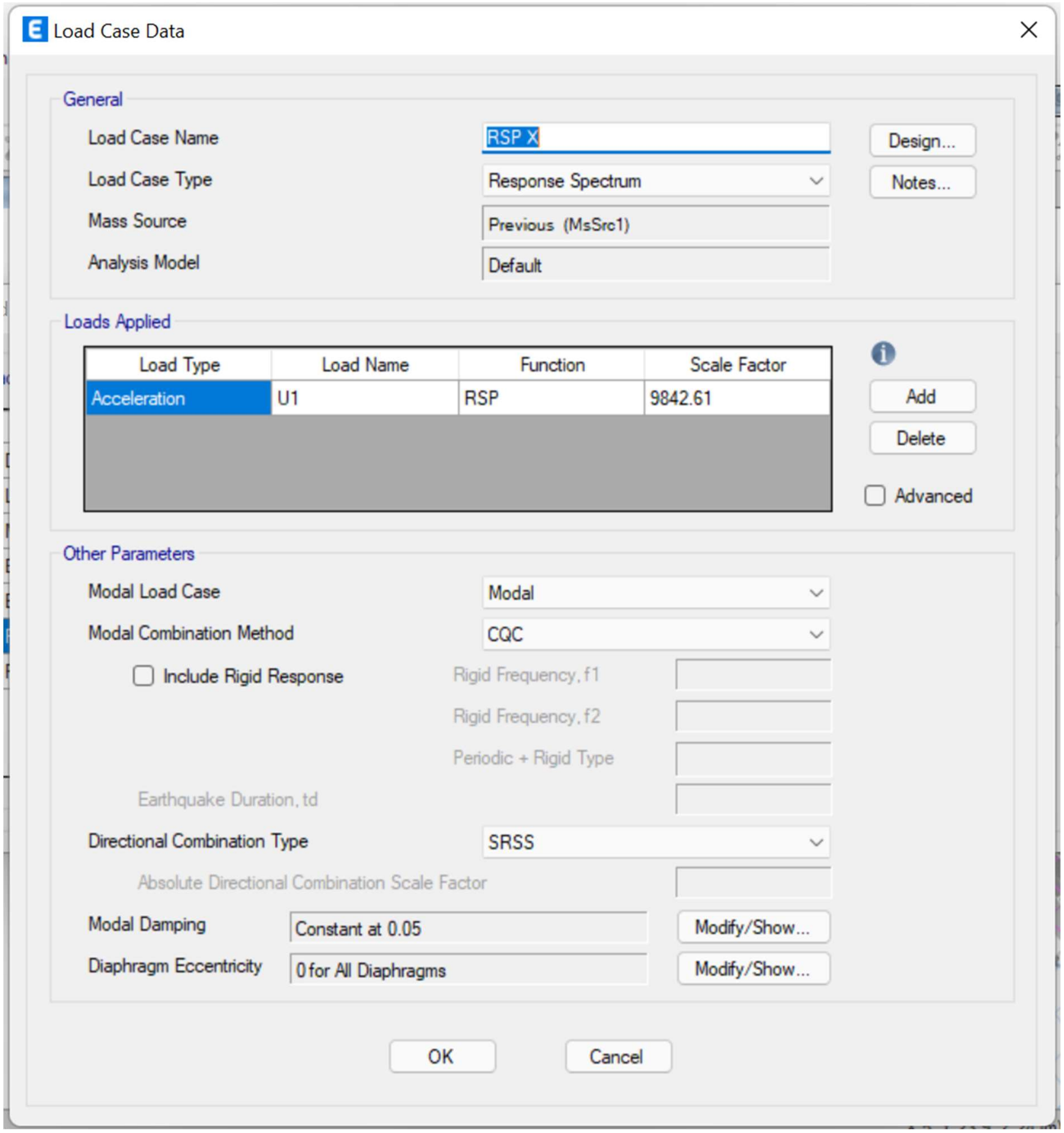
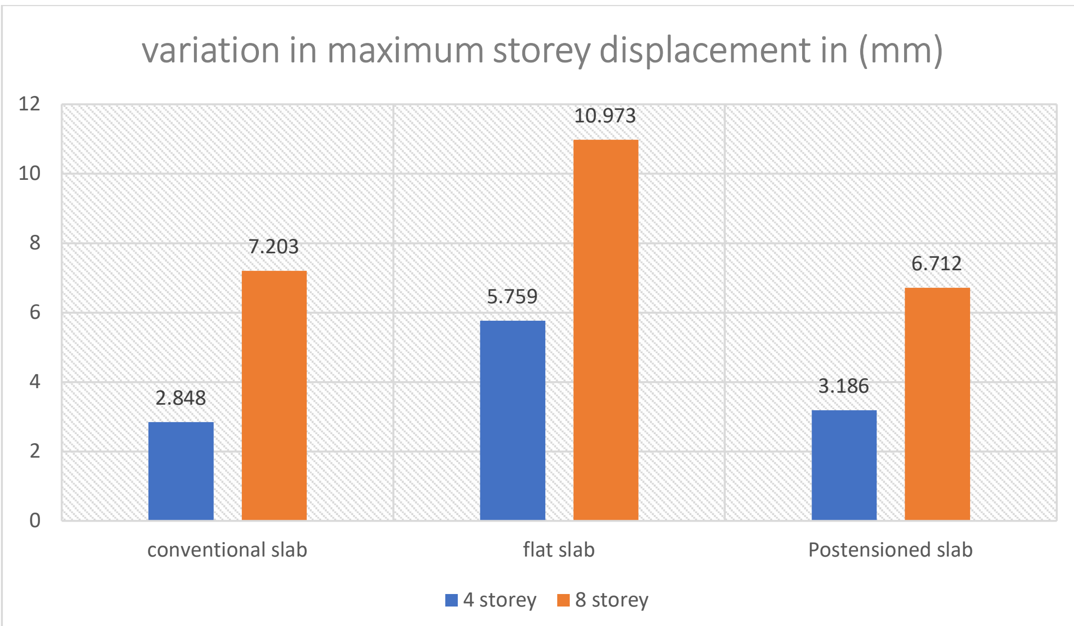


Fig.3.32. Define Load cases

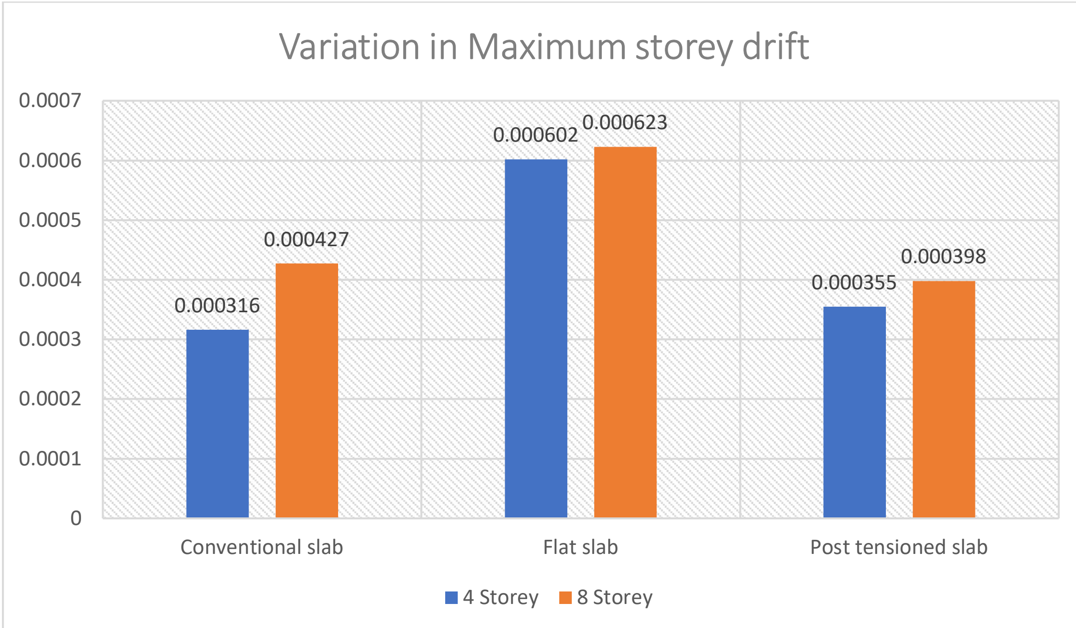
RESULTS AND DISCUSSIONS

4.1 General

In the coming papers of this chapter, the results obtained by performing linear dynamic analysis and non-linear push over analysis are discussed, followed by the calculation of suitable seismic parameters (max. storey displacement, max. storey drift, base shear, overturning moment) for RC building's with different slab systems like conventional slab, flat slab, post tensioning slab systems.



Graph.4.1. Variation in maximum storey displacement in Conv. Slab, Flat Slab and PT Slab Systems.



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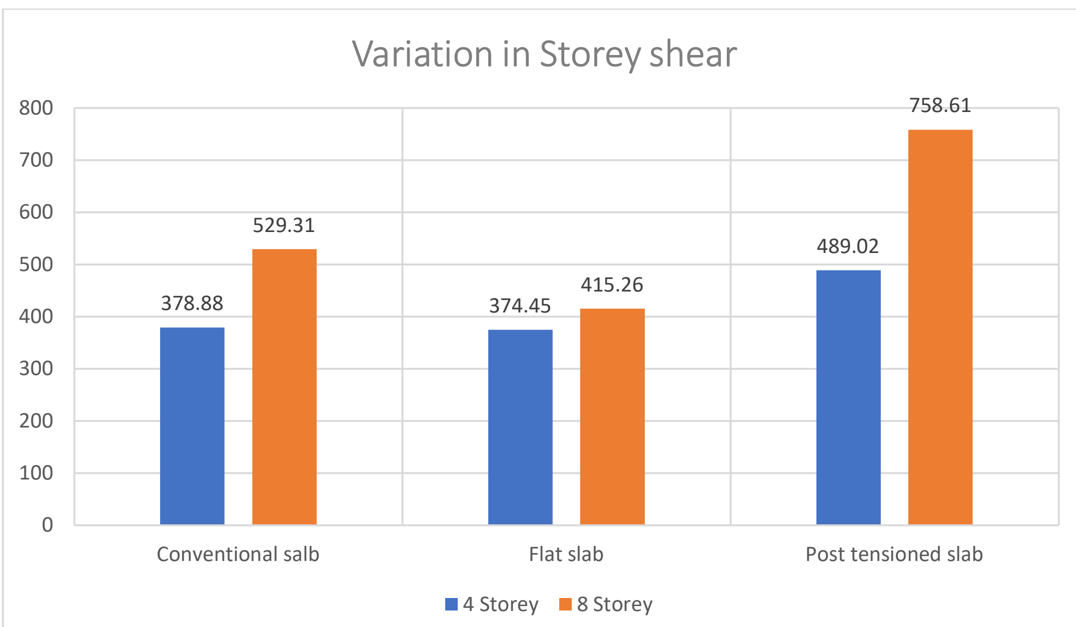
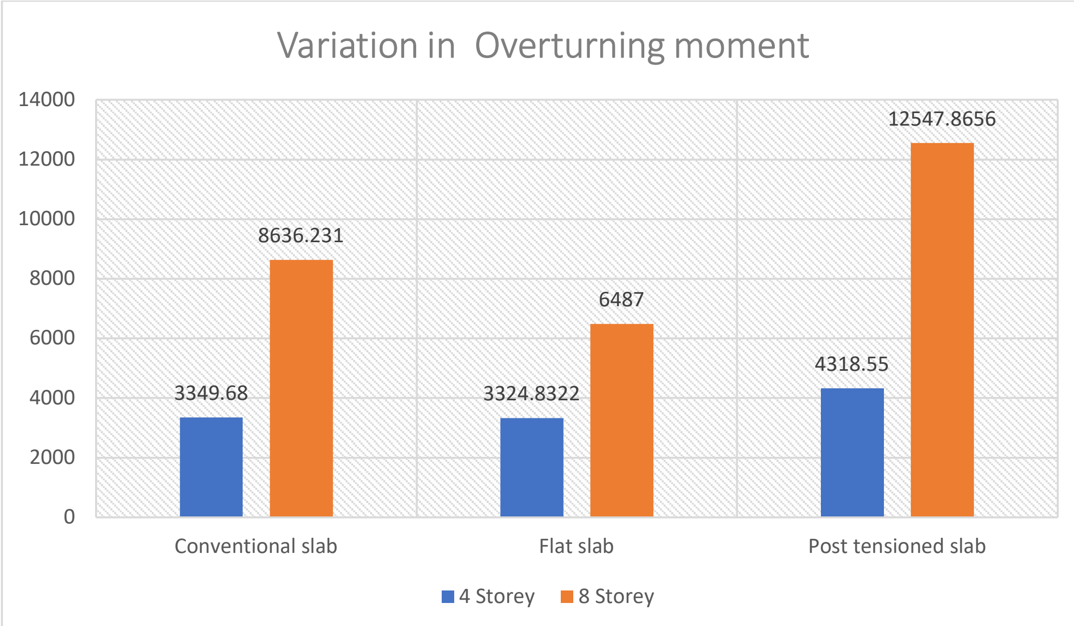
Graph. 4.2. Variation in Maximum storey drift in Conv. Slab, Flat Slab and PT Slab Systems.



Graph.4.3. Variation in Storey Shear in Conv. Slab, Flat Slab and PT Slab Systems.



Graph. 4.4. Variation in Overturning moment in Conv. Slab, Flat Slab and PT Slab Systems.

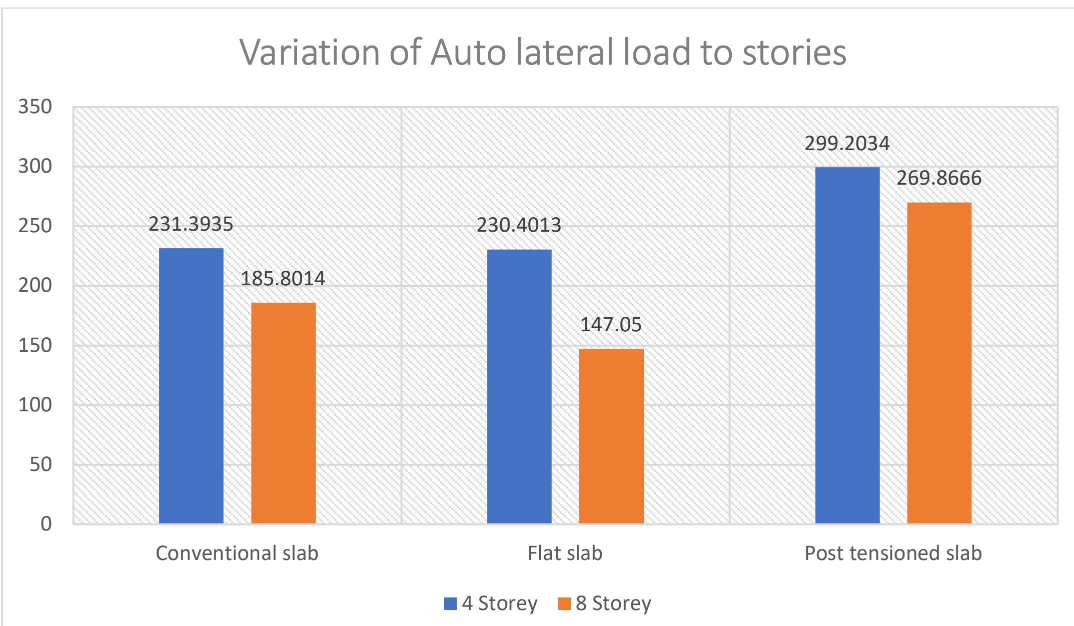


Fig.4.5. Variation of Max. Displacement in Conv. Slab, Flat Slab and PT Slab Systems.

- From the figure 4.1, Max. storey displacement increases by 102%, and 52% for 4 storey and 8 storey for flat slab building with conv. slab building respectively.
- Max. storey displacement increases by 12% and decreased by 7% for 4 storey and 8 storey for PT slab building with conv. slab building respectively.
- From figure 4.2, Storey shear Decreased by 1% and 22% for 4 storey and 8 storey for flat slab building with conv. slab building respectively.
- Story shear increases by 29% and 43% for 4 storey and 8 storey for PT slab building with conv. slab building respectively.
- From figure 4.3, Story drift increases by 91% and 46% for 4 storey and 8 storey for flat slab building with conv. slab building respectively.
- Story drift increases by 12% and 7% for 4 storey and 8 storey for PT slab building with conv. slab building respectively.
- From figure 4.4, Overturning moment Decreased by 1% and increased by 25% for 4 storey and 8 storey for flat slab building with conv. slab building respectively.
- Overturning moment increases by 29% and 45% for 4 storey and 8 storey for PT slab building with conv. slab building respectively.
- From figure 4.4, Overturning moment increased by 1% and 21% for 4 storey and 8 storey for flat slab building with conv. slab building respectively.
- Auto lateral load increases by 29% and 45% for 4 storey and 8 storey for PT slab building with conv. slab building respectively.

4.2 Discussions of Results

1. The max. storey displacement is found maximum for the flat slab building as compared to conventional slab and PT slab, the maximum displacement of the flat slab building is due to the absence of lateral load resisting system.
2. The storey shear and overturning moment is maximum at the base level for all different types of structures. And storey shear of conventional slab and PT slab structure is maximum in comparison with flat slab. Flat slab with no beams having considerably less base shear than other two slabs (conventional slab and PT slab systems).
3. The drift value of conventional slab and PT slab is less compared to flat slab. Because flat slab has no beams (Due to the absence of lateral load resisting system).

CONCLUSIONS

5.1. Summary

The main cause of damage in building structures during an earthquake is usually their response to ground induced motions. To evaluate the behaviour of the structure for this type of loading condition, the principles of structural dynamics must be applied to determine the stresses and deflections generated in the structure.

The dynamic characteristic of the building is established by its natural frequencies, modes, and damping. The analysis is based on linear-elastic behaviour of materials and the ground input motion is a smoothed design spectrum to calculate the maximum values of the structural response. In the present work, response spectrum analysis to the RC buildings with different slab systems like conventional slab, flat slab and post tensioning slab is studied. The seismic parameters like max. storey displacement, storey shear, storey drift, over turning moment of the multi-storey building with uniform plan dimensions of 20mx15m for different slab systems are evaluated. The variation is studied for various storey levels through dynamic analysis. The performance levels of the multistorey buildings under study are also assessed and compared through non-linear static process.

5.2. Conclusions

The following are the conclusions of the present work:

1. The Flat slab buildings and buildings with Post tensioning slabs even though have many advantages with respect to architectural aspects, it was found they are much vulnerable with respect to seismic behaviour.
2. Maximum Storey Displacement increased up to 102% in buildings with Flat slab whereas it increased up to 12% in buildings with PT slab in comparison with conventional slab system.
3. Storey drift increased up to 91% in buildings with Flat slab whereas it increased up to 12% in buildings with PT slab in comparison with conventional slab system.
4. Auto Lateral load to stories increased up to 21% in buildings with Flat slab whereas it increased up to 45% in buildings with PT slab in comparison with conventional slab system.
5. Storey shear increased up to 22% in buildings with Flat slab whereas it increased up to 43% in buildings with PT slab in comparison with conventional slab system.

6. Overturning moment increased up to 25% in buildings with Flat slab whereas it increased up to 45% in buildings with PT slab in comparison with conventional slab system.

5.3. Scope for Further Study

As the various researchers are getting attracted towards RSA and NSP's, the scope of the studies under a particular topic can be stretched to wide horizons. The application of the method with different slab systems for a better performance of the structure can serve as a good topic for a research program. This method can be tested and applied to different zones of the earthquake. Comparison of a flat slab having a drop with a flat slab without drop can be done for different seismic zones. Comparison between pre-tensioned and post-tensioned for convention slab and Flat slab can be done. Comparison of cost of construction and estimation of cost and loss analysis of various types of structures can be done.

Appendix

Response spectrum Analysis

Table.6.1. Base reactions

		EQ_X	EQ_Y	RSP_X	RSP_Y
Conventional slab	**4**	445.71	445.71	62.22	63.06
	8	622.725	559.261	85.874	77.564
Flat slab	**4**	440.538	420.648	61.489	58.720
	8	488.4911	470.50	68.93	67.080
Post-tensioned slab	**4**	575.32	575.324	79.670	81.1996
	8	892.47	808.51	123.96	112.35

Calculation of Scale factors

$SF_X = 0.85 \frac{Ig}{2R} \times \frac{EQ_X}{RSP_X}$

$SF_Y = 0.85 \frac{Ig}{2R} \times \frac{EQ_Y}{RSP_Y}$

Where,

I = importance factor = 1

R = Response reduction factor = 3

g = Acceleration due to gravity = 9806.65 mm/s^2

Table.6.2. Scale factors

	Conventional slab		**Flat slab**		**Post tensioned slab**	
	4 - Storey	**8 - Storey**	**4 - Storey**	**8 - Storey**	**4 - Storey**	**8 - Storey**
SF_X	9952.008	10074.465	9953.38	9842.61	10032.246	10002.30
SF_Y	9819.22	10017.1126	9952.19	9744.386	9843.434	9997.70