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A Study on Behaviour of Flat Plate under Seismic Effect

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Abstract: Large industrial constructions, parking garages, ramps, warehouses, towering skyscrapers, and hotels all employ flat slabs. They're employed in situations where a beam isn't necessary. These slabs are also employed in situations when minimal formwork is required. Additionally, give improved light dispersion to the simple roof surface. Among the flat slab variants, the flat plate system is favoured nowadays because the floor allows for a wide range of horizontal utilities, such as mechanical ducts, to be located above a suspended ceiling. Simple formwork with no beams, allowing you to use the whole ceiling height for services and lowering the floor-to-floor height. It also excludes the column heads and drop panels. This Study is to understand the behaviour of flat plate under seismic vibrations and to appropriately design them for conventional purpose.
Keywords: Flat Slab, Flat Plate, Seismic Effect, Dynamic Analysis, Response Spectrum, Base Shear.

I. INTRODUCTION

A structure is made up of various interconnected building parts such as walls, beams, columns, foundations, slabs, and so on. The slab is the most important of them. It aids the other components of the structure in withstanding various loads. In building, there are several slab kinds. A slab is a flat, two-dimensional planar structural component of a structure with a thin thickness in comparison to its other two dimensions. It comes in a variety of shapes and sizes, including two-way slabs, one-way slabs, flat slabs, flat plates, ribbed slabs, and precast slabs, among others, depending on the dimensions, area, and circumstances.

The simplest type of two-way slab is the flat plate. A flat plate is a two-way slab of uniform thickness supported by any combination of columns and walls, with or without edge beams, drop panels, column capitals, and brackets. Economical flat-plate spans are limited by shear and deflection to under 30 feet for mild loads and under 20 feet for severe loads. While the use of reinforcing steel or structural-steel shear heads to withstand shear at columns would increase these limitations slightly, its primary purpose is to allow for the use of smaller columns. Other changes, on the other hand, can be employed to increase the load and span restrictions while remaining economically viable.

II. LITERATURE REVIEW

(Navyashree and Sahana 2014) says that the Traditional RC Frame structures are extensively utilized for construction in today's world. Flat slab construction has numerous benefits over traditional RC Frame construction in terms of architectural freedom, space use, ease of formwork, and construction speed. The flat-slab construction's structural efficiency is hampered by its poor performance under seismic loads. In this study, six different conventional RC frame and Flat Slab building models with G+3, G+8, and G+12 storeys are explored. The performance of flat slabs as well as the vulnerability of purely frame and purely flat slab models under various load situations were investigated, and seismic zone IV was used in the research. E-Tabs software is used to do the analysis. It is vital to examine the seismic behaviour of buildings at various heights in order to determine what changes will occur if the height of standard RC Frame and flat slab buildings differs. As a result, the seismic characteristics of flat slab and traditional RC Frame buildings imply that additional steps should be taken to guide the conception and design of these structures in seismic areas. The goal of this study is to compare the behaviour of multi-story commercial buildings with flat slabs and traditional RC frames to those with two-way slabs and beams, as well as to investigate the influence of building height on the performance of these two types of structures under seismic stresses. The current work is an useful source of data on the parameters lateral displacement, storey drift, storey shear, column moments and axial forces, as well as the time period.

(Kaulkhere and Shete 2017) mentions that Flat slabs are becoming increasingly common these days, and they are more cost-effective than beam-column connections. The construction of RC frame structures is very frequent. In terms of architectural tractability, space use, and easier formwork under seismic stresses, flat slab construction has numerous benefits over RC frame construction. In this study, flat slab building models with G+8 storeys are investigated.

We have addressed the findings obtained by doing Non-linear pushover analysis on flat slab buildings of various forms and types, as well as utilising software ETAB2015 on flat slab buildings of various forms and types. To increase building performance, it is vital to examine the seismic behaviour of buildings, as well as the effects of flat slabs with and without drops on the performance of these two types of structures. The current study provides information on the parameters max strip moments, base shear, max storey displacement, and storey drift in accordance with IS 456:2000 code regulations.

(Rha et al. 2014) researched Five half-scale reinforced concrete slab-column frame specimens were subjected to gravity or combined gravity and lateral stresses. Each specimen was a complete storey of a two-bay by two-bay moment frame with a continuous flat plate system and nine columns supposed to be separated at inflection points between floors. The slab reinforcement ratio and loading history were the factors that were put to the test. Consecutive punching failures at the slab column connections caused temporary decreases in the applied load, but the entire system's load-carrying capability was regained and maintained until the system ultimately collapsed, according to the tests. The punching shear capacity, as well as the gravity or lateral load-bearing capacity, stiffness, and ductility, were all impacted by the number of top and bottom slab bars and the loading history. Finally, based on the test findings, the ACI 318-11 punching shear requirements were reviewed and found to be conservative for the continuous flat plate systems tested. The test results are significant because they recreated genuine boundary conditions of inter-story flat plate systems and tracked direct shear and unbalanced moments at each continuous system link.

(More et al. 2013) says 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. Unfortunately, earthquake experience has proved that this form of construction is vulnerable to failure, when not designed and detailed properly, in which the thin concrete slab fractures around the supporting columns and drops downward, leading potentially to a complete progressive collapse of a building as one floor cascades down onto the floors below. The current Indian Standard Codes of Practice only specify design techniques for slabs with consistent geometry and arrangement. However, because to space constraints, height restrictions, and other causes, deviations from a regular geometry and regular arrangement have become increasingly widespread in recent years. In addition, the behaviour and responsiveness of flat slabs during an earthquake is a major concern. Dynamic analysis is used to examine the lateral behaviour of a typical flat slab structure constructed according to I.S. 456-2000.The shortcomings of these structures are explored by contrasting their behaviour with those of traditional beam column framing. This is why the grid slab system was chosen. The influence of drop panels on the behaviour of a flat slab under lateral stresses is also investigated using a flat plate system. The zone factor and soil conditions, two additional essential criteria that determine the structure's behaviour, are also discussed. For this, the software ETABS is employed. The relationship between the number of storeys, zone, and soil condition is explored in this study.

(B.Anjaneyulu1 2016) Flat slabs are a type of construction that eliminates the usage of beams, which are commonly utilised in traditional ways of building. The slab sits directly on the column, transferring the weight from the slab to the columns and subsequently to the foundation. To sustain huge loads, the thickness of the slab at the support with the column is raised, resulting in drops, or columns with expanded heads known as column heads or capitals. The absence of a beam results in a simple ceiling, which has a superior architectural aspect and is less vulnerable to fire than when beams are employed. A plain ceiling diffuses light more effectively, is easier to instal, and requires less form work. Different nations have chosen different methods for designing flat slabs based on local constraints and material availability and have provided guidance in their individual codes. The analysis and design are accomplished utilising the Equivalent Frame Method with staggered column and without staggered column as mandated in different codes such as IS 456-2000 and ACI 318-08. Moments are allocated as column strip moments and middle strip moments in this method.

(Youssef et al. 2015) In reinforced concrete structures, flat plates are commonly employed. The shear forces and bending moments caused by gravity loads are generally used to design them. The lateral building deformations that occur during seismic activity provide extra shear stresses and bending moments that they must bear. An effective slab width must be established in order to estimate the seismic moment capability of a flat plate system. Grillage analysis is used to predict the nonlinear lateral behaviour of flat plate structures in this article. The effective slab width contributing to the lateral strength of residential interior flat plate connections is evaluated using a complete parametric research. The span length, bay width, column diameters, and amount of column axial stress were all investigated. The analysis includes both gravity load designed and moment resistant frames. The impact of material safety factors is determined by running two sets of studies, one with nominal material characteristics and the other with factored material parameters. There are several equations for estimating the effective slab width.

(Karande 2017) Flat slab structures are preferred over traditional structures in the construction sector. Large spans, simple ceilings, minimal shuttering costs, shorter construction time, and increased building height are all advantages of flat slab buildings.

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It's crucial to look at the behaviour of flat slab constructions when they're subjected to seismic loads. Response under seismic loads for different zones is highly significant when building flat slab buildings with thin columns. This work is about a survey of the literature on the behaviour of flat slab structures under seismic loading by various authors in order to gain a better knowledge of flat slab structures and the notion of a slender column. This research gives useful information on variables such as storey shear, lateral displacement, time period, slenderness ratio, and storey drift.

(Desai 2018) says that the flat slabs and flat plate building technology eliminates the usage of beams, which are commonly employed in traditional building methods. The slab sits directly on the column, transferring the weight from the slab to the columns and subsequently to the foundation. To sustain huge loads, the thickness of the slab at the support with the column is raised, resulting in drops, or columns with expanded heads known as column heads or capitals. Traditional RC Frame structures are extensively utilised for construction in today's world. The flat-slab construction's structural efficiency is hampered by its poor performance under seismic loads. Flat Plate and Flat Slab structures of the G+10 storey building typology are explored in this study. The seismic response of systems such as a) flat plate/slab buildings, b) flat plate/slab buildings with steel bracings, and c) flat plate/slab buildings with shear walls is examined and evaluated using ETABS version 9.7.2 in this work. The current research is an excellent source of information on characteristics like maximum displacement, storey drift, storey shear, base shear, and time period performance of shear walls vs steel bracings.

(Giri and Jamle 2019) According to numerous findings, the stresses created in the flat slab analysis should be reduced in intensity in order to guarantee structural stability. On a G+11 multistory residential building located in seismic Zone 4, four cases were studied: simple flat slab providing shear wall at lift area, simple flat slab providing shear wall at lift area and at maximum stress location, flat slab with drop providing shear wall at lift area, and flat slab with drop providing shear wall at lift area and at maximum stress location. To analyse analytic parameters such as nodal displacement, shear forces in column, compressive and tensile stresses, storey drift, von mis stress, and principal stress values, the response spectrum approach was used with the aid of the analysis and design programme STAAD Pro V8i. In terms of stress reduction, the most important instance gained in this work is Building Case B2.

III. FLAT PLATE

A flat plate is a one- or two-way system that is often supported by columns or load bearing walls. It is one of the most prevalent types of building floor construction. The flat plate floor's main characteristic is a uniform or nearly uniform thickness with a level soffit that requires just minimal formwork and is straightforward to instal. Horizontal services can be located above a suspended ceiling or in a bulkhead because to the floor's flexibility. The necessity to regulate long-term deflection limits the economical span of a flat plate for low to medium loads, and it may need to be sensibly pre-cambered (not overdone) or prestressed. A cost-effective span for a reinforced flat plate is 6 to 8 m, whereas a cost-effective span for prestressed flat plates is 8 to 12 m. A reinforced concrete flat-span 'L' plate's is roughly D x 28 for simply supported, D x 30 for an end span of a continuous system, and D x 32 for internal continuous spans. A flat plate's economical span may be extended by prestressing to about D x 30, D x 37, and D x 40, where D is the slab depth.

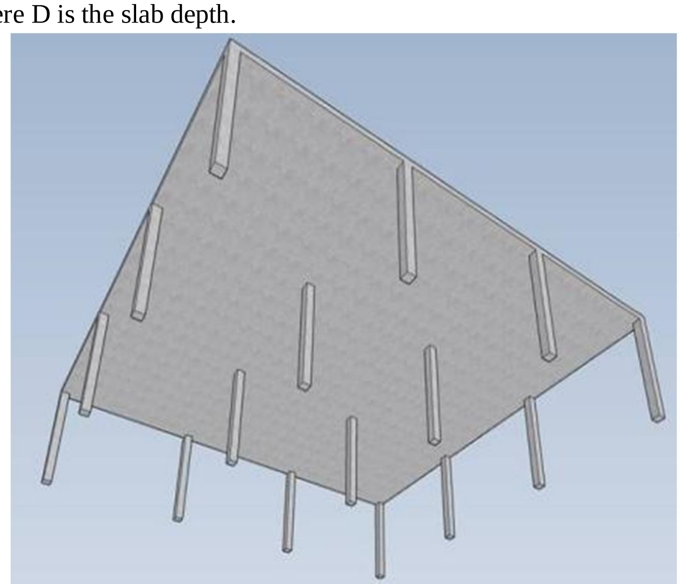

Fig 1. Flat Plate Structure

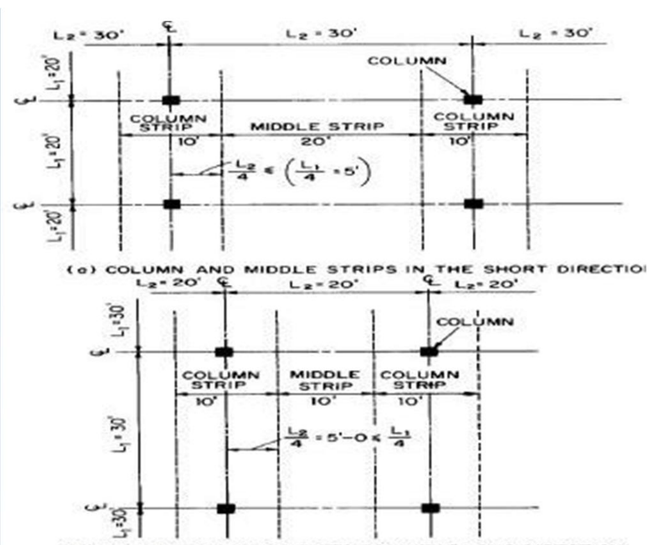

Fig 2. Flat Plate divisions

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IV. ANALYSIS OF FLAT PLATE STRUCTURE

A. A two-storey Structure is Considered for Analysis

The analysis is performed using STAAD.Pro V8i Software. The structure is located considered to be in seismic zone III. To study the behaviour of flat plate under seismic vibration, dynamic analysis is performed using response spectrum method and results are computed. The structure is provided with two-way slab for ground floor roof and RCC Flat Plate for first floor roof and with following parameters

1) *Depth of Foundation – 2.5 m*
2) *Height of Structure – 9 m*
3) *Span b/w each column – 8m*
4) *Thickness of two-way slab – 230 mm*
5) *Thickness of flat plate – 230 mm*
6) *Column width – 450 mm*
7) *Column depth – 750 mm*
8) *Beam width at plinth level – 300 mm*
9) *Beam depth at plinth level – 600 mm*
10) *Beam width at ground floor roof level – 450 mm*
11) *Beam depth at ground floor roof level – 750 mm*
12) *Grade of Concrete –* M30

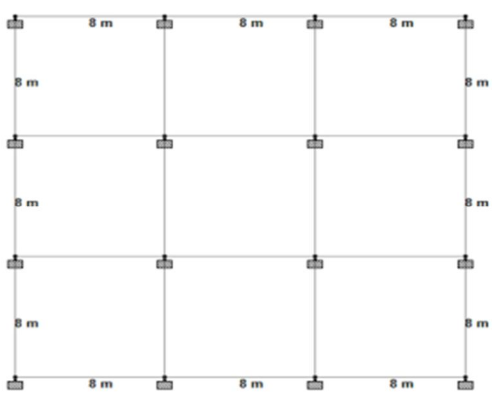

Fig 3. Plan View

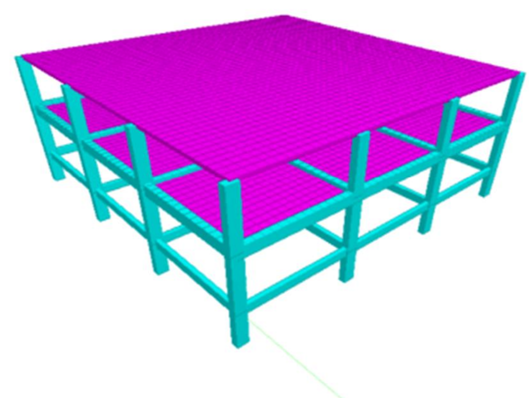

Fig 4. 3D view of the structure with two-way slab and flat plate

B. Loads Given to the Structure

1) Dead Load (DL): Self weight automatically calculated using self-weight factor
2) *Floor Load in the form of Plate Pressure:* Dead Weight – 7.25 KN/m^2
3) *Floor Load in the form of plate Pressure:* Live Load (LL) – 2 KN/m^2
4) *Lateral Loads:* Seismic Load, Seismic Zone - III (Calculations as per IS 1893 – 2002)

Zone Factor (Z) – 0.16
Importance Factor I – 1.5
Response Reduction Factor (R) – 5
Type of Soil – Hard Soil
Damping Ratio – 0.05
Time period along X-direction = 0.193 sec, Time period along Z-direction = 0.193 sec

C. Load Combinations

i)	DL+LL	v)	1.2DL+1.2LL+1.2SX
ii)	1.5DL+1.5LL	vi)	1.2DL+1.2LL+1.2SZ
iii)	1.5DL+1.5SX	vii)	0.9DL+1.2SX
iv)	1.5DL+1.5SZ	viii)	0.9DL+1.2SZ

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D. Dynamic Analysis using Response Spectrum Method

(Ramesh 2020) says that Structural dynamics is particularly useful for analysing dynamic structures under varying loads. It is critical to understand the distinction between structural statics and structural dynamics. Structural engineers in the design area, as well as students pursuing academic subjects, need to know this information. This study will assist you in understanding the basics of structural dynamics. Every structure is loaded in some way. This article discusses the dynamic loads that the structure is subjected to, as well as the significance of performing a dynamic analysis on the structure. Different sorts of degree of freedoms of dynamic structures were also considered. This study is highly useful for students, structural designers, and lecturers who want to learn more about structural dynamics. This paper also discusses the broad relevance of structural dynamics and provides an overview to students and the general public.

The peak response (displacement, stress, etc.) of a structure to a certain base motion or force may be estimated using response spectrum analysis. Although the approach is just approximate, it is frequently an effective and low-cost tool for exploratory design research. The response spectrum approach relies on a subset of the system's modes, which must be retrieved first using the eigenfrequency extraction process. Eigen modes and residual modes will be among the modes, if they were engaged during the eigen frequency extraction process. The number of modes extracted must be sufficient to effectively simulate the system's dynamic response, which is a matter of personal preference.

The Response Spectrum analysis for the structure is performed in both X and Z direction with an design acceleration value 0.024 on both direction (Z/2) * (I/R).

In order to carry out the response spectrum analysis the following load combinations are considered

1) 0.9DL+1.5RSX
2) 1.2DL+1.2LL+1.2RSX
3) 0.9DL+1.5RSZ
4) 1.2DL+1.2LL+1.2RSZ

Where RSX – Response Spectrum Along X axis, RSZ – Response Spectrum Along Z axis

V. RESULTS

Thus, we have analysed a building with Flat Plate and following results were computed. Further optimisation will be performed based on the requirement. The Post analysis result includes mode shape, deflection, bending stress, Base Shear. Since Seismic effect is the governing force, the dynamic analysis plays major role here and it is found that the worst load combination is 0.9DL+1.5RSZ and the structure will be designed for this.

A. Mode Shapes

Understanding structural vibrations from the modal domain is one view. When structures are aroused at their native frequencies, they vibrate or deform in certain forms termed mode forms. A structure will vibrate in a complicated mixture of all mode forms under normal operating circumstances. Under seismic stimulation, these are the mode forms formed for the flat plate.

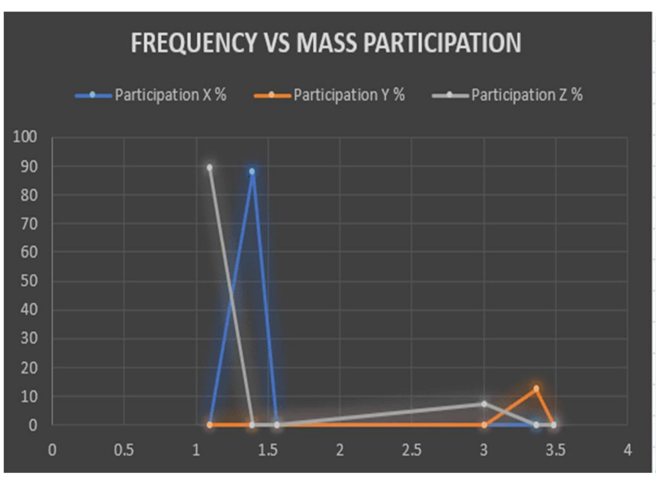

Fig 5 Frequencies Vs Mass Participation along X,Y,Z direction

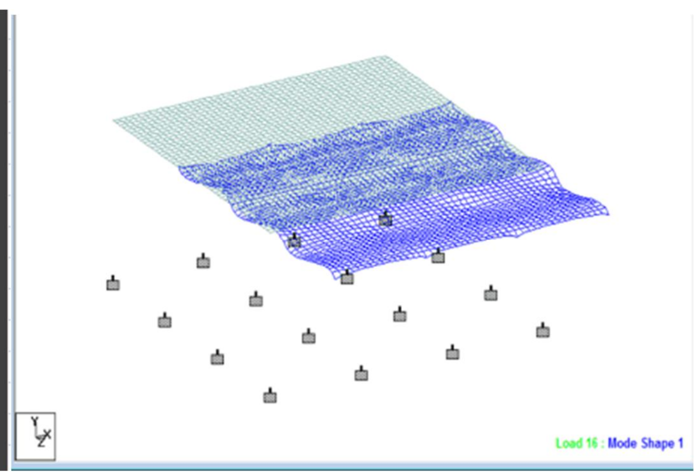

Fig 6 Mode Shape Along Z direction at 1.094 Hz

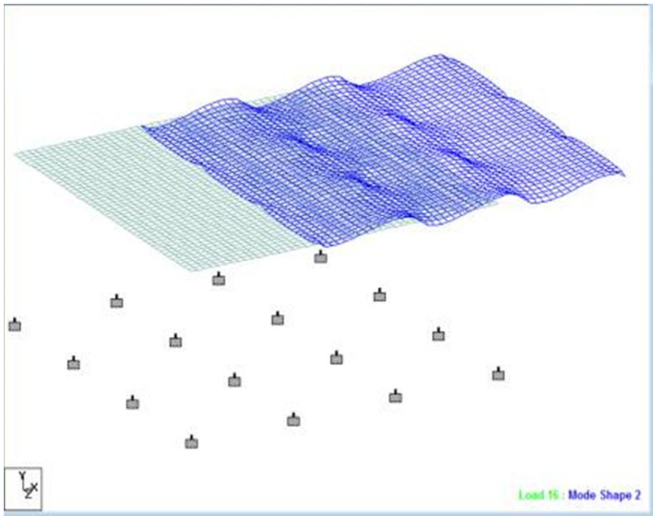

Fig 7 Mode Shape Along X direction at 1.393 Hz

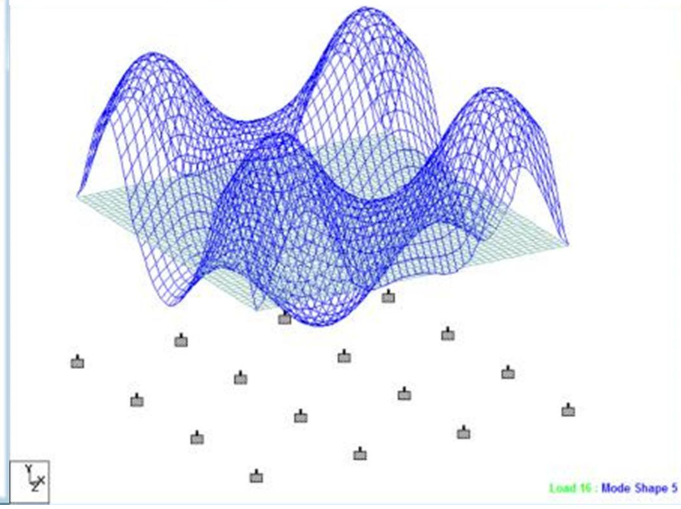

Fig 8 Mode Shape Along Y direction at 3.365 Hz

B. Stress Pattern

The Stress Pattern is used to determine the Maximum in plane stresses i.e Max Absolute stress, Base Pressure, Major Principal Stress, Minor Principal Stress etc.

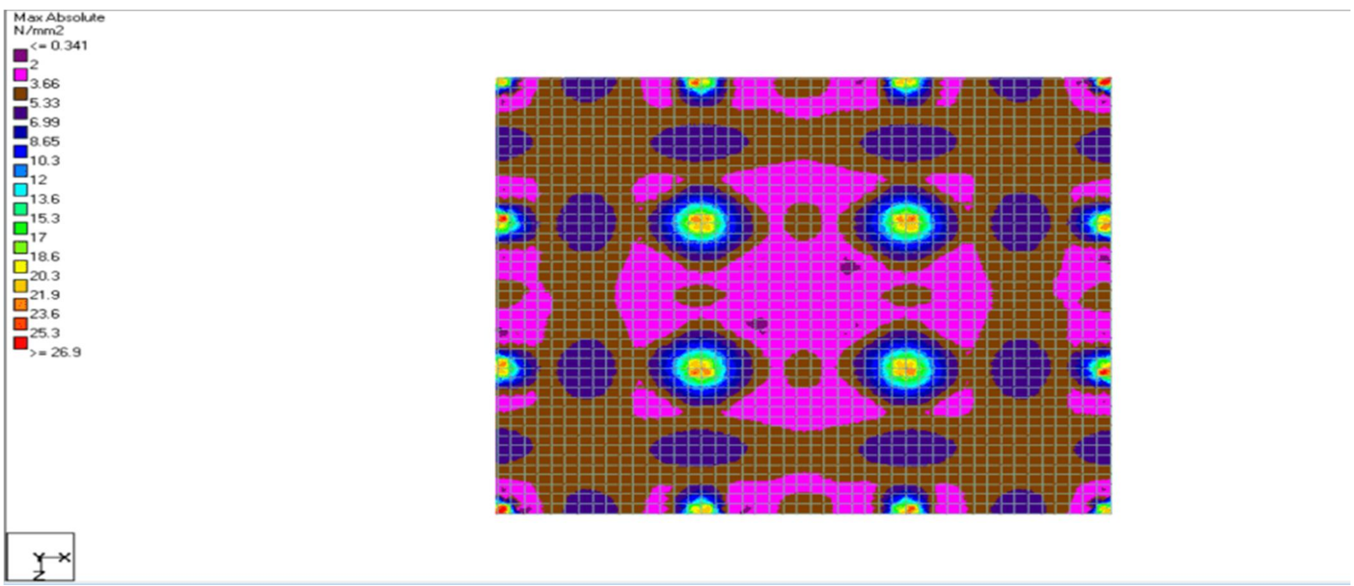

Fig 9 Maximum Absolute Stress at Various Regions

C. Base Shear

The static or analogous lateral force approach can be used to determine the lateral forces produced on the structure by ground vibrations. The greatest predicted lateral stress on the base of the structure owing to seismic activity is called base shear. It's estimated using the seismic zone, soil material, and lateral force formulae from the building code.

1) *For X-Direction:* (Obtained from Staad)

NOTE: The Base Shear (VB) From Response Spectrum is less than the Base Shear (Vb) calculated using Empirical Formula for fundamental time period with multiplying factor (Vb/VB) of **1.875**

2) *For Z-Direction:* (Obtained from Staad)

NOTE: The Base Shear (VB) From Response Spectrum is less than the Base Shear (Vb) calculated using Empirical Formula for fundamental time period with multiplying factor (Vb/VB) of **2.316**

VI. CONCLUSION

Thus, The Flat Plate Structure is analysed, and the following conclusions are derived.

A. These Mode shapes indicate how the structure deforms at different natural frequencies. This is helpful since we don't want the weld regions to be high-stress areas because this might shorten the structure's fatigue life. Furthermore, the mode participation parameters reveal which modes will elicit the most excitement. The effective masses inform us about which modes must be included in the dynamic simulations. As a result, the Eigen Value solution of modal analysis must be thoroughly investigated in order to establish the wave pattern and peak response it produces, and stiffeners must be provided correspondingly.
B. The Maximum Absolute Stress (Fig.9) for the entire region in flat plate is obtained and it is found that it is maximum with magnitude of 26.9 N/mm^2 at Plate Column Connection.
C. Base Shear Vb obtained from dynamic analysis is scaled to the base shear using empirical formula and design acceleration value in direction X is given as 0.045 and design acceleration value in Y is given as 0.0556. Base shear scaling is a way of ensuring that the minimum strength of a structure developed using the Modal Response Spectrum technique (MRS) is comparable to the strength necessary if the building were built using the Equivalent Static Method (ESM).

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