International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 9 Sep 2023, pp: 110-121 www.ijaem.net ISSN: 2395-5252

Seismic performance of Magnetically levitated RC Building

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Date of Submission: 05-09-2023 Date of Acceptance: 15-09-2023

ABSTRACT: Reinforced concrete structures are the fastest growing structures in the world. Design of tall structures has definite features that must be well-thought-out by designers and engineers for earthquake vibrations. Since the Earth's recent conditions (frequent occurrences of earthquakes as in Turkey and Syria) and requirement of new technologies, the trends are going toward new generation of towers with consideration of cost, sustainability, performance, resistance and flexibility. Therefore, magnet as potential material can be used as design and engineering element in towers. Manipulating magnetic fields and controlling their forces can levitate an object. Magnetic levitation is the practice of magnetic fields to levitate a metallic object. The present work deals with the analysis of a building modelled with magnetic base, magnetic floor slabs, with the help of light concrete can make floating building that not only partakes strong flexibility against earthquake but its double skin provides sustainability potentials.
KEYWORDS: Magnetic levitation, Earthquake, RC Building, Magnet, floating building

I. INTRODUCTION

The earthquakes occurred everywhere on the earth caused extensive building damage. As an outcome, seismic isolation and response control buildings were rapidly developed and adopted in many parts of the earth as the main technological means for reducing the seismic response of buildings. The effectiveness of these seismic isolation and response control buildings in reducing damage has been demonstrated to a certain extent in the major earthquake-shaking that have happened since then. However, since the magnitude of ground motion predicted for a Nankai Trough mega-quake or for Tokyo inland earthquake exceeds the magnitude currently considered in designs, the limitations of seismic isolation and response control structures have been indicated. Therefore, further advancement of response-reducing technology during earthquake is required.

The ground motion occurring at a site, is input into a building, under the effect of the dynamic behaviour between the ground and structure. The seismic Response of a building can be significantly reduced if the foundation base is isolated from the ground and the transmission pathway of the ground motion is artificially excised. There are quite a lot of methods for separating the base of a foundation from the ground, such as using compressed air or the repulsive force of magnets to levitate a structure. The building model is magnetically levitated using permanent magnets and the base sides are supported by soft, high damping artificial geo-material to control horizontal displacement.

Magnetic Levitation means levitating any object with the help of magnetism i.e. it is a process of suspension of a body by magnetic forces in order to overcome Earth’s gravitational forces and to hover in air (happens to be known as ‘Levitation’), thus Magnetic Levitation. A technique of supporting and transporting items/vehicles which is based on the physical- property, that the force between two magnetized-bodies is inversely proportional to their remoteness, with this magnetic force to counter-balance the gravitational force, a steady and contactless suspension between a magnet (attractive body) and a fixed guideway (charged body) is obtained.

Structure supported on a single-column, provides better architectural view, as related to construction supported on numerous columns. These single-column constructions save ground room, as requires less area for providing foundation and provides more space for parking. They are also incomparable. Single column structure can be made either by using Reinforced cement concrete or Steel

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as a construction material. Reinforced cement concrete structures are more common now a day in the world. Reinforced cement concrete as a construction material is widely used in many types of constructions. It is competitive with steel if economically designed and executed. It has a comparatively high compressive strength and better firefighting characteristics than steel material. Reinforced cement concrete has better assurance with low-maintenance price. Reinforced cement concrete molded into a desired shape.

II. LITERATURE

Mr. Jayant S. Ramteke, Mr. M.R. Nikhar, (2019) describes comparisons of a one- column RCC structure and a multi-column RCC structure. They edit and analyze multiple columns and single-column structure G+4 in software. The design is grounded on the requirements and standards recommended by IS codes and national building codes. Editing is done using 3D modeling software with the help of AutoCAD 2014. The purpose is to develop, edit and analyze a high-level model in STAAD-Pro and study the seismic load used in the building by IS 1893-2002.

Also, confirm the reduction of one Column and multi-column structures and learn the lateral function of lateral migration in area II. Authors has concluded that a single-column structure is 20% more expensive than a multi-column structure. They also determined that the RCC column provides satisfactory results under normal loading conditions. The rise of the news in the system of a high ascent denotes to the extreme deviation.

Ankur Pandey, Vaibhav Singh, and Gaurav Awasthi, (2018) analyzed single- column storey structure using the software. Various steps are geometric exhibiting, provision of visual aids and phase structures, adjustment of foundations and edge conditions, requirement of loads and loading integration, analysis description and design instruction comparison of composite materials and reinforced cement. From the survey, it was finalized that the RCC column provided satisfactory results under the constant loading conditions. The composite structure with less dead weight compared to the reinforced-cement concrete structure and with increasing migration of co-deliver floor node displacement is also growing.

Yuji Miyaoto, Takaharunakano et. al (2022): The present work deals with the study on the seismic response of a house supporting base sides with a polymeric displacement control material by magnetically levitating the foundation base. In this paper, they explored the possibility and efficacy of a seismic-isolated detached house from both a shaking table experiment of model and three-dimensional finite element analysis. Study concluded that the seismic-isolated model showed stable response and its acceleration response was meaningfully lowered as compared to the base-fixed model in the shaking table -test and they found that the seismic response analysis of a full-scale detached house, the seismic-isolated model showed response reduction and its residual displacement was lesser, than that of the sliding-base isolation model.

Anshul Singh Chauhan (2020): The report submitted by him on Magnetic Levitation in Architecture aims at the discussion of relevance, applications, principles and basics of magnetic levitation further objectifies into a physics whilst making this process of levitating architecture feasible and to analyze the different techniques and the functioning of different larger scale and more conventional studies carrying out the possibilities for the research. The scope of his study enlists and discusses the techniques and possibilities of magnetic levitation in architecture while discussing the feasibility of maglev in architecture by discussing the principles and functioning.

S. Jeya Anusuya, G. Pavithra Devi et.al (2019): The paper Magnetic Levitation Building Preventing from Earthquake, have the object of saving the building at the times of earthquakes by smearing the consequence of magnetic levitation. This paper designs a wireless sensor- network-system using microcontroller as a base station, sensor node as combination of sensors. In this project they built a building in between the two-repulsion magnetic base levitating building.

Here LCD is utilized to show user how the crack and earthquake level propagates. They determined that comparing with collection and forwarding information or data of traditional base station (gateway), this system has low-cost, low power consumption, and easy to maintain.

To understand how mono-column structure behaves under seismic and gravity loads many experimental, analytical and numerical investigations and possible study on application of magnetic levitation to RC building have been conducted.

III. MODEL DESCRIPTION

G+2, 3 story building, Slab thickness 125mm, 1.5m diameter central column, 3.75m radius of floor, Height of all the stories is 3.0m. The following loads were considered while analyzing the building model in ANSYS Software.

DL of light weight concrete slab= 0.125 x 25 =3.125 KN/m^2,

DL of central column = Π x $1.5^2/4$ x 6 x 25 =265.025 KN,

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DL of steel plate = Π x $7.5^2/4$ x 0.10 x 7850 x 10 = 350KN,
LL = 2.5 KN/m² (As per IS: 875 -1987 part III),
EQ = 25% of LL (As per IS 1893:2002) = 0.25x2.5 = 0.625KN/m^2.

Choosing the materials from material data available from the selected ANSYS module and assigning the required properties to the selected materials. Material like concrete, steel and magnetic materials are selected from the various material library. Concrete slab of thickness 150mm is provided in between two steel plates of 50mm thickness as shown in figure 1.

Table 1
Properties of materials

Properties of Concrete		**Properties of steel**	
Density kg/m3	2500	Density kg/m^3	7850
Dilatancy Angle Degrees	15	Young's Modulus MPa	200000
Young's Modulus MPa	25000	Poisson's Ratio	0.3
Poisson's Ratio	0.18	Bulk Modulus MPa	166670
Bulk Modulus MPa	13021	Shear Modulus MPa	76923
Shear Modulus MPa	10593	Yield Strength MPa	250
Uniaxial Compressive Strength MPa	25	Tangent Modulus MPa	1450
Uniaxial Tensile Strength MPa	3.5	**Properties of Air**	
Biaxial Compressive Strength MPa	28.75	Isotropic Relative Permeability	1.0
Magneticmaterials – NdFeB (Nickel Ferrous Boron)			
Coercive Force mA mm^-1	8.12e+6	Residual Induction mT	1050

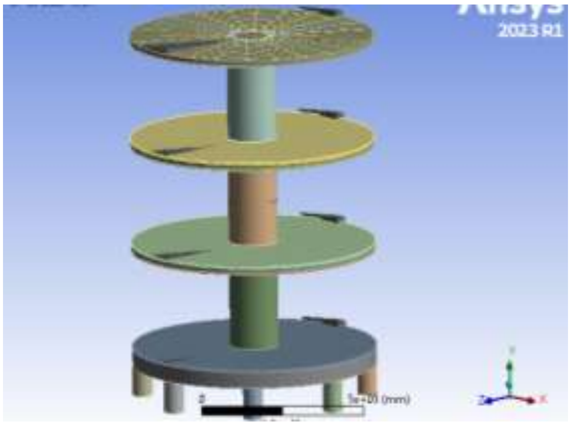

Figure 1 Soild model view

IV. OBESERVATIONS FROM THE TESTS CONDUCTED

Analysis systems

Select the suitable analysis systems for the selected problem. For the current work static structural system is selected and results are then feed to the modal analysis and then solution of those are coupled to find the response spectrum of the chosen RC building model. Then the magnetostatics analysis system is used to do the magnetic analysis.

After selecting the static structural analysis using the space claim area model generation is followed. These are shown in the following figure 1 and figure 2. Size of reinforcement in Slab, Radial bars – 20mm diameter and Circular bars – 16mm diameter. Column reinforcement, Vertical bars – 38mm diameter and Stirrups 8mm diameter.

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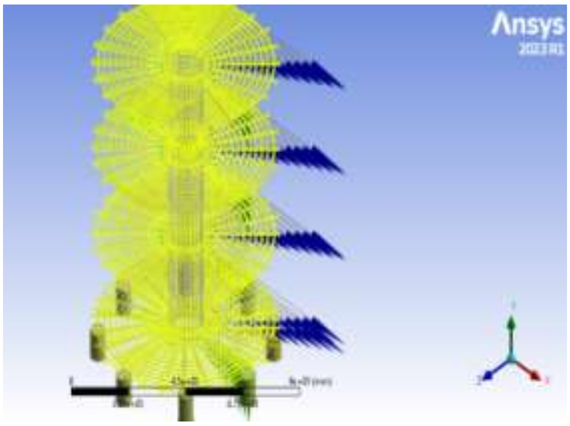

Figure 2 Reinforcement provided in the building

After model creation in geometry, it is updated in ANSYS model where choosen material is specified to the particular member by right-click on the geometry. Connection to various members are checked. ANSYS divides the model into small, interconnected elements (finite elements) to create, a desired size mesh. The mesh density affects the accuracy and time process of the analysis, so it is essential to choose an appropriate mesh size. After genrating the sketch in the space claim select the model or member and enter the generate mesh command. Mesh sizing may be provided initially or it is refined later as per the accuracy requried in the outpt. Generally coarse, medium and fine mesh options available. For this model mesh size of 150mm is provided. Generated mesh is shown in the figure 3.

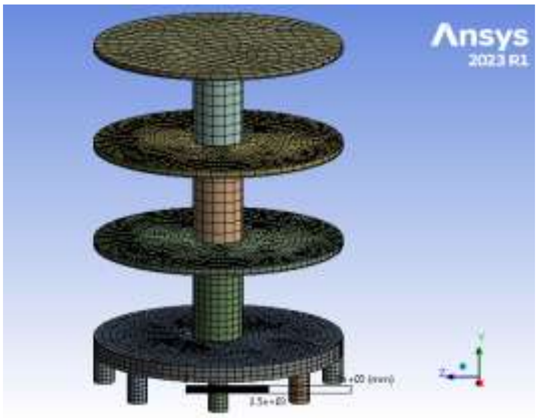

Figure 3 Meshing of the model

Static-structural analysis

Static-structural analysis in ANSYS is a type of simulation that evaluates the behavior of a structure or component under applied loads or constraints in a static (non-changing) environment. It is a fundamental analysis type used in engineering to understand how a structure will respond to various loading conditions without considering dynamic effects or time-dependent behavior. Load applied on the building model is shown in figure 4.

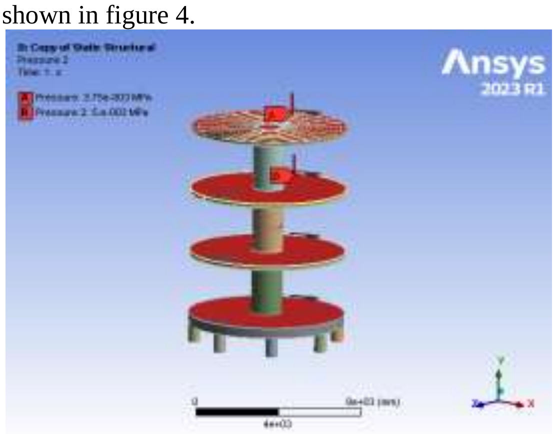

Figure 4 Applying Gravity loads on slab Roof and Ground floor

Solution is obtained by solution command on the left side of workbench tree. Insert the solution required such as deformation, directional deformation, stress (Principal or von-mises stress) and strains if required. The number of steps given for the static analysis is 5. Following figures 5 and figure 6 shows the deformation and stress generated for the given loading conditions.

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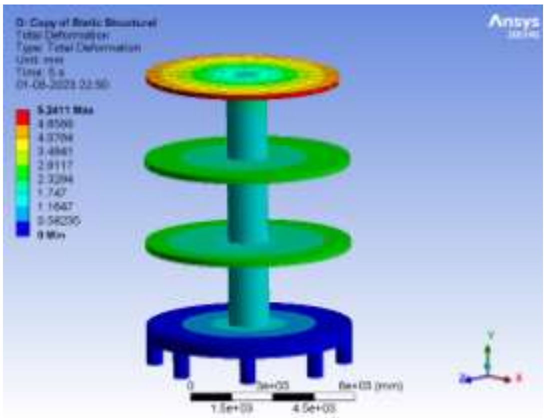

The figure 5 shows that the maximum deformation caused at the end of the cantilever slab is 5.2411mm.

The figure 6 shows that for the given gravity loading conditions the maximum stress developed in the RC building is 34.319MPa or 34.3190N/mm^2 (rounded of to 34.20MPa).

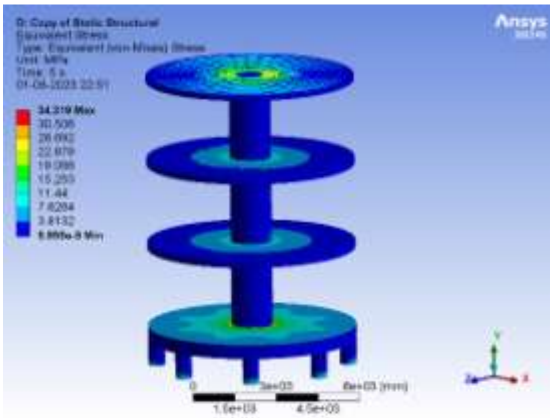

Figure 6 Equivalent stresses

Figure 7 represents the Force in N and time for 0.05 seconds sub steps. In the graph it shows that force results for time steps 2 to 5 are remains constant for these time periods.

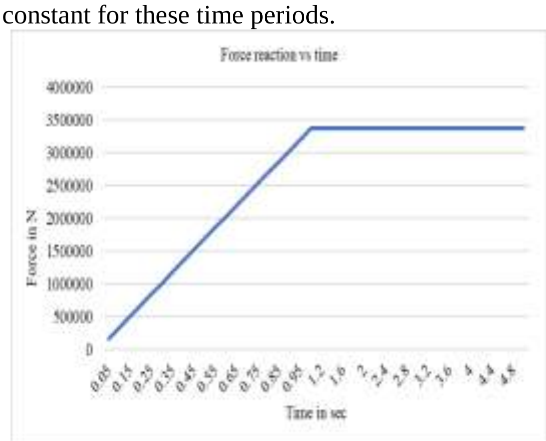

Figure 7 represents the Force reaction vs time

Figure 8 represents the displacement in mm and time for 0.05 seconds sub steps. In the graph it shows that deformation results for time steps 2 to 5 are remains constant for these time periods.

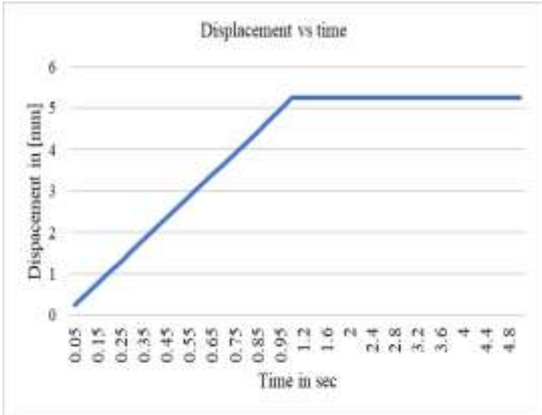

Figure 8 Force vs Displacement

Modal analysis

Modal analysis in ANSYS is a reproduction strategy used to decide the regular frequencies, mode shapes, and relating modular damping proportions of a design/structure. It is an essential move towards the plan and examination of mechanical frameworks, as it assists engineers with grasping the powerful way of behaving of a construction and recognize potential vibration issues.

Modular examination in ANSYS is a recreation method used to decide the regular frequencies, mode shapes, and relating modular damping proportions of a design. It is an essential move toward the plan and examination of mechanical frameworks, as it assists engineers with grasping the powerful way of behaving of a construction and distinguish potential vibration issues.

Modal analysis conducted on the planned model is presented below. For 30 modes frequency is found out and maximum deformation for each mode is shown in the figure 9.

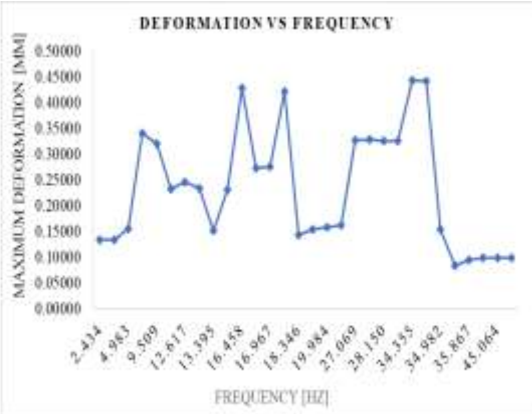

Figure 9 Frequency vs deformation for 30modes

The Mass Participation Factor (MPF) is an idea utilized in modal analysis to evaluate the commitment of mass at various areas in a design to a particular mode of vibration. It helps in grasping the circulation of mass and its effect on the powerful way of behaving of the framework.

In a vibrational mode, the structure undergoes motion at specific frequencies and patterns known as mode shapes. The MPF is defined as the ratio of the mass of a particular degree of freedom (DOF) to the total mass participating in a specific mode shape. It is also known as the Modal Mass Percentage or Modal Mass Participation. Resulatant of ratio of effective mass to total mass for various frequency and direction is given in the table 2

Table 2
Summary of ratio of effective mass to total mass

Mode	Frequency (Hz)	Direction X	Direction Y	Direction Z	Rotation X	Rotation Y	Rotation Z
1	2.4341	0.45096	2.81E-08	1.29E-02	2.62E-02	6.87E-10	0.91656
2	2.4417	1.29E-02	1.34E-06	0.45024	0.91614	2.32E-10	2.62E-02
3	4.9825	8.29E-10	1.09E-11	6.64E-10	4.92E-10	0.58677	1.05E-09
4	9.2705	4.48E-03	5.35E-04	7.08E-02	1.25E-02	3.82E-09	7.75E-04
5	9.5088	7.65E-02	5.41E-05	4.82E-03	8.31E-04	8.97E-09	1.30E-02
6	11.172	9.20E-05	0.52304	3.19E-04	3.70E-05	1.26E-10	1.32E-05
7	12.617	2.36E-03	1.58E-03	4.81E-02	6.11E-03	1.48E-08	2.94E-04
8	12.964	4.49E-02	1.01E-04	2.10E-03	2.63E-04	1.45E-08	5.51E-03
9	13.395	6.02E-09	2.55E-07	2.71E-08	3.84E-09	5.22E-02	1.96E-10
10	15.065	8.98E-06	0.24076	1.06E-06	8.36E-09	1.71E-08	1.10E-06
11	16.458	2.33E-06	1.77E-03	4.10E-06	3.51E-08	1.11E-10	6.16E-10
12	16.893	3.52E-05	1.26E-04	3.20E-02	7.02E-04	5.58E-09	2.08E-06
13	16.967	4.09E-02	8.12E-05	4.37E-07	5.18E-07	3.69E-09	1.08E-03
14	17.042	1.13E-03	4.10E-04	3.70E-04	1.07E-05	5.53E-09	3.41E-05
15	18.346	1.17E-11	1.51E-09	1.02E-07	5.75E-09	6.81E-03	1.66E-11
16	19.649	4.25E-03	1.08E-04	0.10301	5.74E-03	2.58E-09	2.33E-04
17	19.984	9.07E-02	2.50E-05	3.93E-03	2.20E-04	7.83E-09	5.00E-03
18	21.271	1.22E-04	3.67E-03	2.76E-04	1.14E-05	9.70E-10	6.02E-06
19	27.069	3.26E-08	4.57E-05	1.62E-08	1.35E-09	5.44E-12	1.36E-09
20	27.295	1.50E-06	3.21E-05	1.60E-06	4.01E-08	1.07E-11	5.23E-08
21	28.15	7.24E-06	1.27E-06	1.33E-07	7.63E-10	3.76E-10	1.03E-07
22	28.261	1.64E-06	2.36E-06	3.89E-06	4.06E-08	3.71E-09	2.07E-08
23	34.355	2.83E-04	1.18E-06	1.97E-04	1.53E-06	5.20E-11	2.19E-06
24	34.736	6.71E-04	2.49E-03	6.86E-04	4.54E-06	6.78E-10	4.55E-06

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25	34.982	9.51E-09	6.35E-02	3.71E-04	3.41E-06	3.18E-08	2.28E-08
26	35.81	1.31E-03	4.44E-05	0.16077	8.00E-04	5.11E-09	6.20E-06
27	35.867	0.16137	1.19E-05	1.46E-03	8.06E-06	6.84E-08	7.81E-04
28	45.027	8.08E-02	7.17E-07	1.61E-02	6.44E-05	1.06E-07	3.07E-04
29	45.064	1.62E-02	9.37E-07	8.13E-02	3.14E-04	8.41E-08	6.29E-05
30	54.892	4.57E-08	2.05E-10	5.10E-09	4.44E-10	7.65E-12	3.59E-09
SUM	-	**0.98986**	**0.83844**	**0.98987**	**0.96988**	**0.64575**	**0.96985**

The tabular column represents that the ratio of effective mass to total mass in X, Y and Z axis is more than 90% average hence missing mass effect need not to be considered.

Response spectrum analysis

The reaction range assists engineers with figuring out the structure's conduct under various quake situations. It shows which recurrence ranges energize the construction the most and can be utilized for plan and retrofitting purposes. Designers can contrast the reaction range with configuration codes or acknowledgment models to guarantee that the structure fulfils the expected security guidelines.

Reaction range examination, a broadly involved technique in earthquake designing since it permits specialists to productively assess a construction's reaction to a scope of potential ground movements without playing out various time-space investigations for every individual tremor situation. Following frequency, acceleration presented in the figure 10 are used for the Response spectrum analysis.

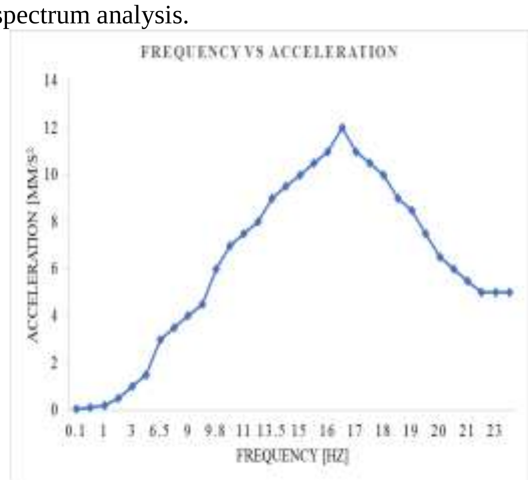

Figure 10 Acceleration vs frequency

Magnetostatic analysis

Magnetostatic solvers module assume steady-state currents and permanent magnets as excitations. From an application perspective, the steady currents in a winding create steady fields and static flux linkages for each winding.

Advancement in electromagnetic analysis is the Ansys Maxwell. This is an electromagnetic simulation tool that is integrated into the Ansys Electronics Desktop. Maxwell is used for analyzing low-frequency electronic devices and machines or when simulating with materials that have a nonlinear BH curve or material anisotropy. It uses various types of solvers to evaluate magnetic and electric fields. Electromagnetic analysis also involves the selection of magnetic material from engineering data

Magnetostatics summation force

In magnetostatics, the summation force refers to the total magnetic force acting on a magnetic body or collection of magnetic elements due to the occurrence of an external magnetic field. The force arises from the magnetic interaction between the external magnetic field and the magnetic moments of the individual elements or the magnetic-properties of the body. Magnetostatics summation force in presence of the magnetic plates provided is shown in figure 11

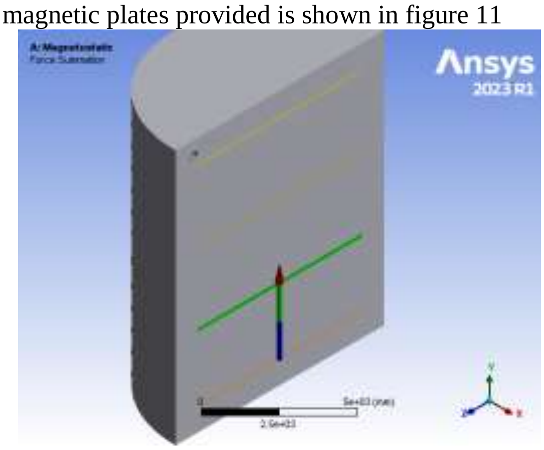

Figure 11 Magnetostatics force summation

Magnetic-flux density

Magnetic-Flux Density, often denoted as as "B," is an essential idea in magnetism and is utilized to portray the strength and direction of a magnetic field in a given restricted room. It measures how much magnetic transition going

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through a unit region opposite to the path of the magnetic field. The SI-unit of attractive motion thickness is the Tesla (T),

The magnetic flux density is connected with the magnetic-field strength and the magnetic properties of the material. In a vacuum or free space, where no magnetic materials present, the magnetic transition thickness (B) is equivalent to the magnetic field-strength (H). Notwithstanding, within the sight of magnetic-materials examples are, ferromagnetic or paramagnetic materials, the charge M adds to the absolute attractive transition thickness (B).

Magnetic flux density developed in the presence of the magnetic plates of 50mm thick and 3000mm vertical distance is shown in figure 12.

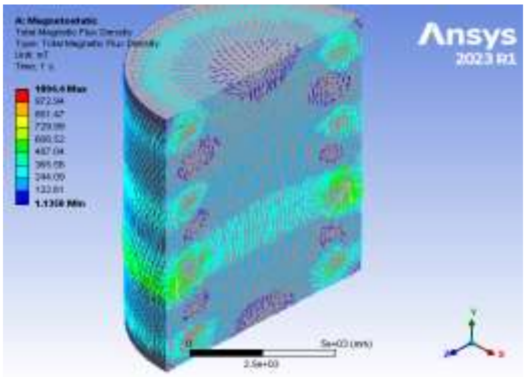

Figure 12 Magnetic flux density

V. RESULTS AND DISCUSSIONS

Summary of Static analysis

Static analysis is conducted to discover response of the structure to the gravity loads. This analysis is considered as the pre-requisite for finding natural frequency in modal analysis. Summary of the result are presented in the figure 13 it shows Total deformation vs thickness of plate.

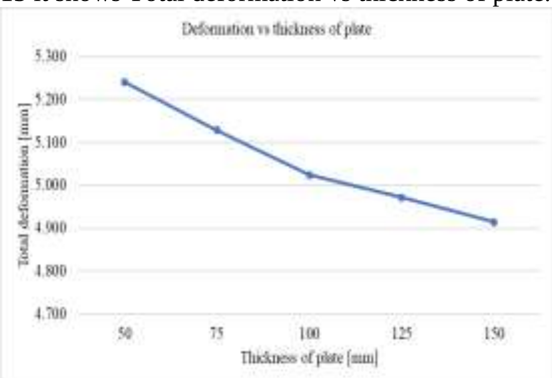

Figure 13 Total deformation vs thickness of plate

Figure 14 shows the force reaction versus thickness of the plate; the curve shows that as the thickness of the plate increases the reaction force also increases.

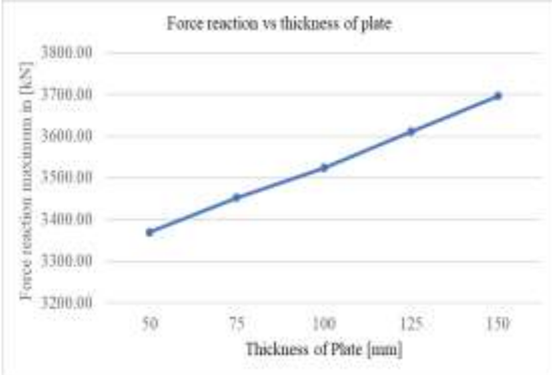

Figure 14 Force reaction vs thickness of plate

Figure 15 shows the stress vs strain developed for the various thickness of the plates. The curve shows that stress vs strain reduce as the thickness of the plate increases.

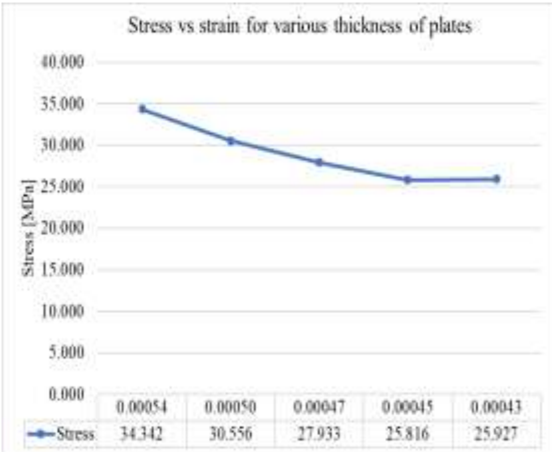

Figure 15 Stress vs Strain for various thickness of plate

Summary of Modal Analysis

Modal analysis is a process of solving for the natural frequencies and mode shapes of a structure or component.

By understanding the natural frequencies and mode shapes, we can better understand how the system will respond to vibrations or accelerations. The following Figure 5.4 indicates the frequency at each calculated mode. It shows maximum frequency of 54.892 Hz at 30th mode.

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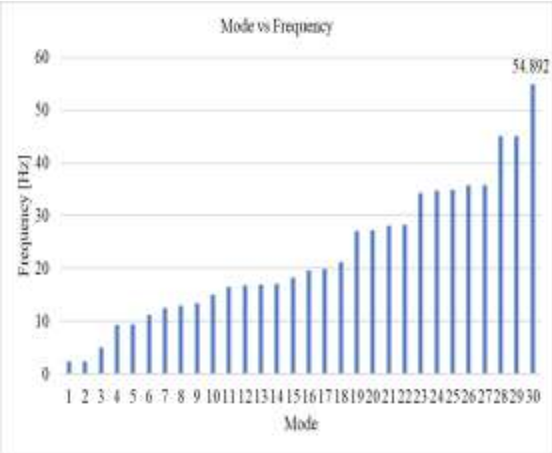

Figure 16 Mode vs frequency

Summary of Response spectrum analysis

Figure 17 shows the Normal stress developed for the applied load obtained from the response spectrum analysis. Figure shows Normal stress is maximum at the foundation level along Y-axis. Figure 18 shows Normal stress is maximum at the roof slab reinforcement along X-axis.

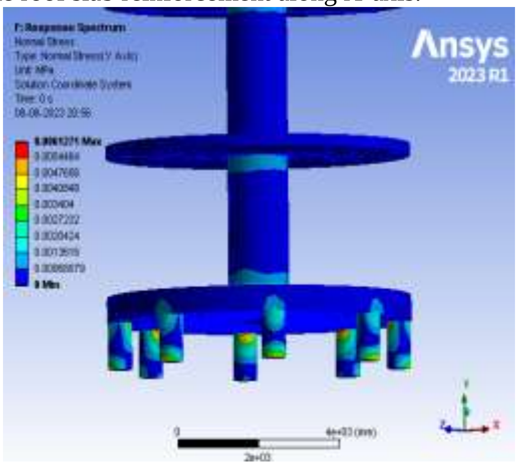

Figure 17 Normal stress distribution along Y-axis

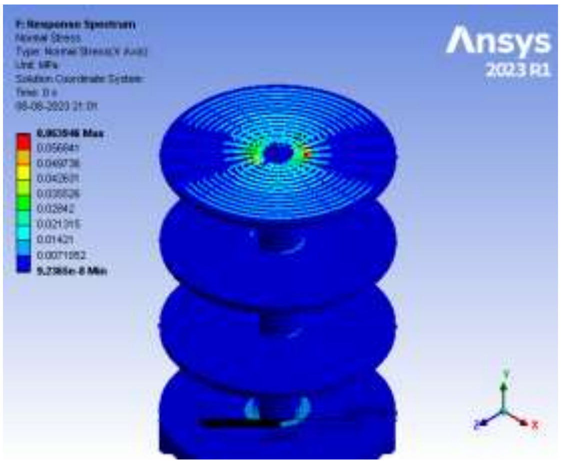

Figure 18 Normal stress distribution along X-axis

Summary of Magnetostatics analysis

The figure 19 shows summary of the magnetic summation force versus various thickness of plates. From the figure it can be finalized that as the thickness of the plate increases magnetic summation force also increases. Magnetic-flux density also decreases as the thickness of the plate increases. As the vertical distance between the two plate increases magnetic summation force also decreases.

Table 3
Magnetic force for different thickness of plates and for various vertical distances

Name	Radius of Magnetic plate [mm]	Vertical distance between the two plates [mm]	Thickness of plate [mm]	Force Summation Maximum Y Axis [N]	Total Magnetic Flux Density Maximum [mT]
DP 0	3750	3000	150	6615259.193	1094.42058
DP 1	3750	2900	150	6531751.808	1087.30395
DP 2	3750	2800	150	6558926.452	1096.468762
DP 3	3750	2700	150	6483143.527	1065.93118

DP 4	3750	3000	100	3994146.23	979.1460437
DP 5	3750	2900	100	3900236.072	868.1251138
DP 6	3750	2800	100	3885677.61	861.3363852
DP 7	3750	2700	100	3886035.847	882.1544359
DP 8	3750	3000	50	1461479.776	531.0344674
DP 9	3750	2900	50	1447980.879	508.3669057
DP 10	3750	2800	50	1430951.249	475.5181875
DP 11	3750	2700	50	1435757.123	470.6951778
DP 12	3750	3000	25	478646.2444	279.7665533
DP 13	3750	2900	25	467131.4112	256.571174
DP 14	3750	2800	25	466014.5296	282.2550389
DP 15	3750	2700	25	469564.8049	263.1351853

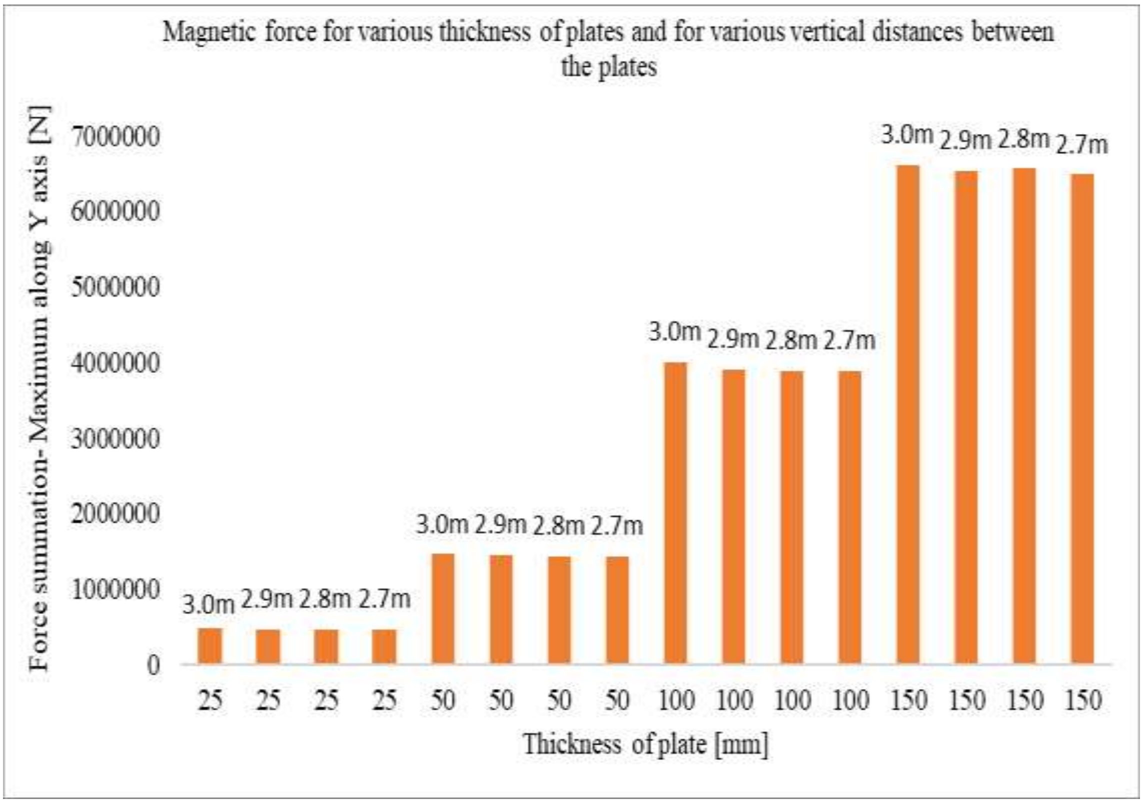

Figure 19 Magnetic summation force for various thickness of plates and for various vertical distances

From the table 3 it can be finalized that as 50mm plate is sufficient to carry the gravity from the floor and steel plate. For the 50mm plate minimum magnetic summation force is 1462kN which is equal to 33.12kN/m^2 and corresponding Magnetic flux density is 531mT. Hence this force 33.12 kN/m^2 is higher than 9.05 kN/m^2 (gravity load). Hence this is sufficient to keep the plate and slab from collapse.

CONCLUSION

To understand the behavior of mono-column Reinforced concrete building under the effect of gravity loads and lateral loads, a well-planned analytical study was conducted. For the examination of mono-column building the efficiency of Finite-Element-Analysis using ANSYS application is used. The major conclusions from the study conducted have been presented below.

The study conducted to analyze the behavior of Mono-column structure under gravity loading and lateral loading using ANSYS application has been successfully and effectively adopted. All the slabs supported on mono-column are subjected to maximum deformation at the free end. The magnetic summation force developed for the 50mm thick magnetic plate have enough force to keep the slab from falling/collapsing on the bottom slab. Minimum stress 0.0071052 occurs at the bottom slab or foundation level along the X axis.

ACKNOWLEDGEMENT

The authors wish to thank the authorities of VTU, Belgaum and University BDT college of engineering for giving us an opportunity to conduct the analytical/software work in the computer laboratory in Civil Engineering department Davanagere.

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