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COMPARATIVE STUDY OF A TALL BUILDING WITH CONVENTIONAL AND FLAT SLAB SITUATED ON SLOPING GROUND UNDER SEISMIC FORCES.

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Keyword
Sloping ground, tall building, conventional slab, flat slab, equivalent static analysis, response spectrum method.

Abstract
The structures are generally constructed on plain surface, but due to scarcity of plain ground in hilly regions leads to construction of building on a sloping ground. One of the biggest challenges of structural engineer is to design an earthquake resistant building on sloping ground. In present study conventional slab & flat slabs with RC building situated on sloping ground without any change of natural terrain have been considered for the analysis. The modeling & analysis of RC building has been done by using structure analysis tool ETABS 2019, to study the behavior of building for earthquake force. The equivalent static analysis and response spectrum analysis apply on building results were obtained in the form of maximum displacement, story drift, story shear, base shear, time period, axial force, shear force, bending moment.

Introduction

The scarcity of plain ground in hilly areas compels construction activity on the sloping ground resulting in various important buildings such as reinforced concrete framed hospitals, colleges, hotels, and offices resting on hilly slopes. Since, the behavior of buildings during earthquakes depends upon the distribution of mass and stiffness in both horizontal and vertical planes of the buildings, both of which vary in the case of hilly buildings with irregularity and asymmetry due to step back and step backset back configuration.
The presence of such constructions in seismically prone areas makes them exposed to greater shears and torsion as compared to conventional construction. In order to highlight the differences in behavior, this may further be influenced by the characteristics of the locally available foundation material.
The height and gradient of hill slopes depend on the strength and deformation characteristics of soil/rock mass. Improper selection and development of sites, drainage, and variation of bearing capacity are some of the important factors which should be considered in the planning and design of hill buildings.
The RCC framed buildings having different configurations can be constructed on flat and sloping grounds. The buildings on flat ground may have regular or setback configurations. The buildings on a sloping ground may have setback or combination of step back and setback configurations.

Buildings on hill differ from those in plains. The floors of such buildings step back towards the hill slope and at the same time building may also have setbacks. A setback is a sudden change in plan dimension or a sudden change in stiffness along the height of a building. Stepping back of building towards hill slope may result into unequal column heights at the same floor.

Buildings on sloping ground are constructed with minimum possible cutting and fitting of the hill slope. The earth on one side of the building may be in contact with the building at various levels which will be supported by retaining walls, or by separating the earth from the building by providing retaining walls at different levels. Both the superstructure and the sub-structure of such buildings need to be analyzed completely.

As most of hill areas fall in active seismic belts, the buildings constructed in hill areas are much more vulnerable to seismic hazards. Landslides and unstable slopes can create problems to building on hill slopes. Sufficient information is available for construction of earthquake resistant wooden, stone, brick & concrete buildings in plains.

1. METHODOLOGY: -

2.1 SOFTWARE CAPABILITY: -

The software used for the analysis in present study is ETABS 2019. It is product of Computer and Structures, Berkeley, USA. ETABS is used for analyzing general structures, buildings, etc. fully integrated program that allows model creation, modification, execution of analysis, and design optimization and result review from within a single interface. ETABS is a standalone finite element based structural program for the analysis and design of civil structures. It offers an intuitive, yet powerful user interface with many tools to aid in quick and accurate construction of models, along with sophisticated technique needed to do most complex projects.
ETABS is object based, meaning that the models are created with members that represent physical reality. Results for analysis and design are reported for the overall object, providing information that is both easier to interpret and consistent with physical nature.
The ETABS structural analysis program offers following features:

1. Static & dynamic analysis
2. Linear & Non-linear analysis
3. Dynamic & static non-linear pushover analysis.
4. Dynamic response spectrum & time history analysis.
5. Frame & shell structural elements.
6. Different types of slab design etc.

2.2 GEOMETRY DATA: -

In this project, we have selected the G+25 floor building on sloping ground, and the ground condition is medium soil. For this project, we are selecting the conventional slab and the flat slab for designing the building and will also check the behavior of the building.

Table 2.1: - Geometry Data

DATA	CONVENTIONAL SLAB	FLAT SLAB
Plan	30.5m x 36.6m	
Typical story Hight	3.35m	
Sloping angle	20 degrees	
Thickness of slab	150mm	200mm
Thickness of drop	-	345mm
Beam size	Base to S-10= 300mm x 600mm S-11 to S-26=300mm x 450mm	Base to S-2= 345mm x 750mm S-3 to S-26=345mm x 600mm
Column size	Base to S-3=750mm x 750mm S-4 to S-14=600mm x 600mm S-15 to S-26=450mm x 450mm	Base to S-15=750mm x 750mm S-15 to S-26=600mm x 600mm
External wall thickness	150mm	150mm
Floor finish	1.25KN/m^2	1.25KN/m^2
Live load	4KN/m^2	4KN/m^2

Earthquake zone	Zone-III (Type of Medium Soil) Importance Factor=1 Response Reduction Factor=5 Damping Ratio=0.05
Grade of concrete	M-50
Grade of steel	Fe 550

2.3 LOAD CALCULATION: -

Unit weight of A.C.C. block concrete = 8.0 KN/m^3

Unit weight of concrete = 25 KN/m

- Wall load: -

External Wall Load Thickness of Wall = 150m
All floor Unit Weight of Brick X Thickness of Wall X (Floor Height – Beam Depth)
= 8.0 X 0.150 X (3.35-0.6)
= 3.35 KN/m
Terrace floor Unit Weight of Brick X Thickness of Wall X (Floor Height – Beam Depth)
= 8.0 X 0.150 X 0.90
= 1.20 KN/m

- Dead Load: -

Floor Finish = 1.25 KN/m (As Per 875 Part I)
Total Floor Load = 1.25kN/m

- Live Load: -

Total Floor Load = 4kN/m

2.4 EARTHQUAKE CALCULATION: -

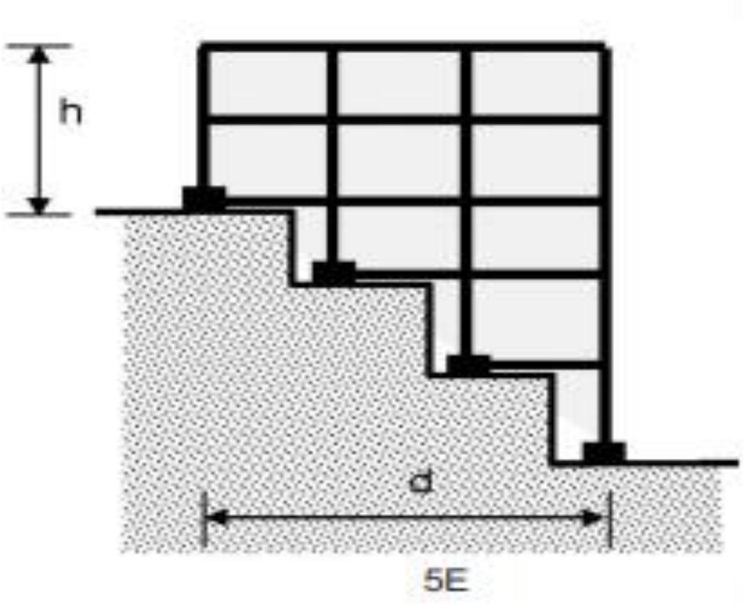

Fig.2.1: - Hight Consider for Time Period as per IS 1893-2016(part-I) pg.22

- IN X- DIRECTION: -

Time Period (IS 1893-2016 Part-I, Pg. No. -21)

$$T_a = \frac{0.09h}{\sqrt{d}}$$

T_a = 0.09 X 87.1/√36.5
= 1.29

- IN Y- DIRECTION: -

Time Period (IS 1893-2016 Part-I, Pg. No. -21)

$$T_a = \frac{0.09h}{\sqrt{d}}$$

T_a = 0.09 X 87.1/√30.5
= 1.41

2.5 LOAD COMBINATION: -

Design Of the Structures Would Have Become Highly Expensive in Order to Maintain Either Serviceability and Safety If All Types of Forces Would Have Acted on All Structures at All Times. Accordingly, The Concept of Characteristics Loads Has Been Accepted to Ensure At Least 95 Percent of The Cases, The Characteristic Loads Are to Be Calculated on The Basis of Average/Mean Load Of Some Logical Combinations of All Loads Mentioned Above.

Is 456:2000, Is 875:1987 (Part-V) And IS 1893(Part-I):2016 Stipulates the Combination of The Loads to Be Considered in The Design of The Structures. The Different Combinations Used Are:

All These Combinations Are Built in The ETABS 2019.Analysis Results from The Critical Combinations Are Used for The Design of Structural Member.

DL – dead load

LL – live load

EQ-X – earthquake load in x direction

EQ-Y – earthquake load in y direction

3. RESULTS & CONCLUSION: -

In This Section Results Obtained from Analysis of Building with Conventional Slab & Flat Slab Situated on Sloping Ground Using ETABS Software Have Been Formatted.

In equivalent lateral analysis and response spectrum analysis modals to check the Performance and Behavior of Both Structures on Different Criteria Like Story Displacement, Story Drift, Story Shear, Base Shear, Time Period, axial force, shear force and bending moment Has Been Analyzed and Discussed as Follows.

Where represent,

M1: - equivalent lateral analysis for conventional slab building in x- direction

M2: - equivalent lateral analysis for conventional slab building in y- direction

M3: - equivalent lateral analysis for flat slab building in x- direction

M4: - equivalent lateral analysis for flat slab building in y- direction

M5: - response spectrum analysis for conventional slab building in x- direction

M6: - response spectrum analysis for conventional slab building in y- direction

M7: - response spectrum analysis for flat slab building in x- direction

M8: - response spectrum analysis for flat slab building in y- direction

3.1 STORY DISPLACEMENT OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

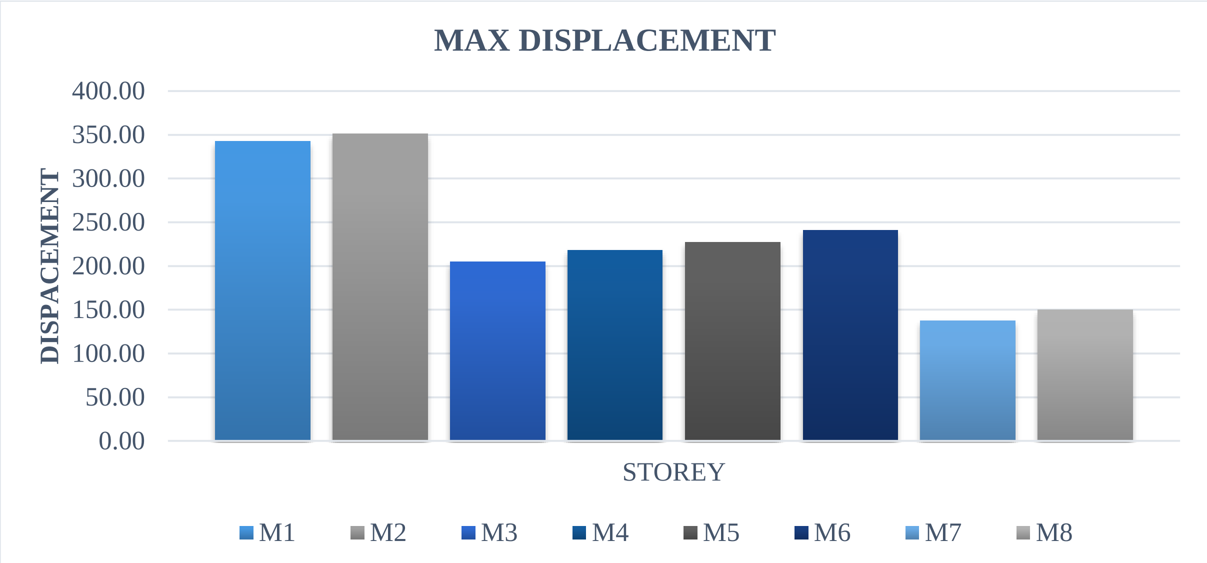

Fig.3.1 Max. Displacement

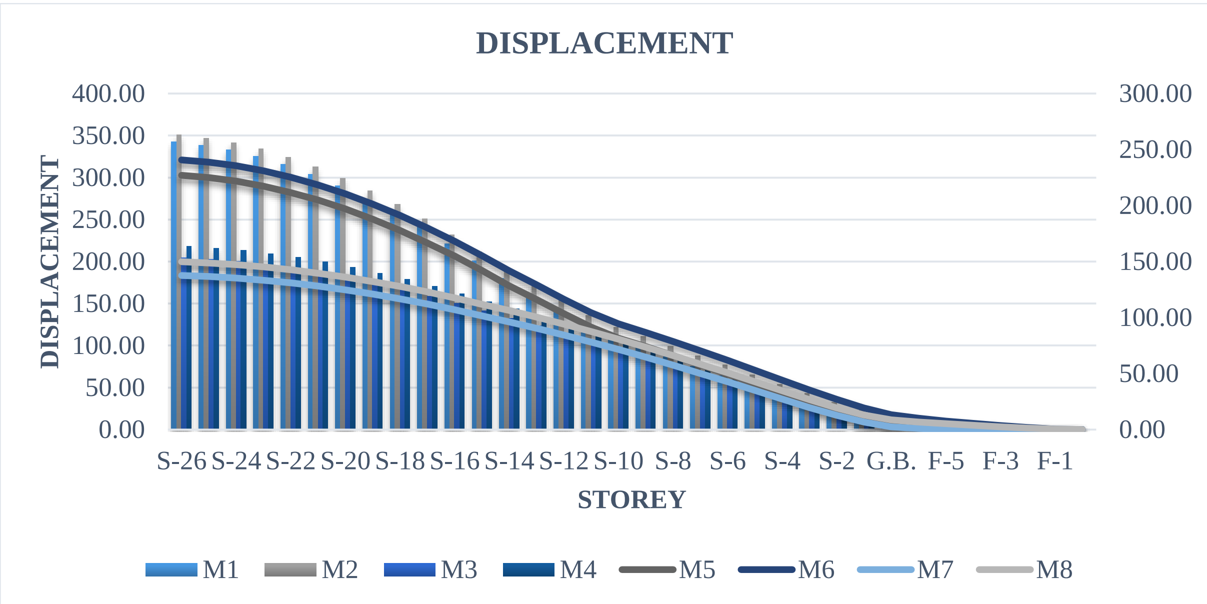

Fig.3.2 Displacement of all storey

1. The equivalent static analysis in x- direction is observed that maximum displacement in conventional slab building is 40.24% more than flat slab building.
2. The response spectrum analysis in x- direction is observed that maximum displacement in conventional slab building is 39.34% more than flat slab building.

3. The conventional slab building in x- direction is observed that maximum displacement in equivalent static analysis is 33.71% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum displacement in equivalent static analysis is 32.71% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum displacement in conventional slab building is 37.83% more than flat slab building.
6. The response spectrum analysis in y- direction is observed that maximum displacement in conventional slab building is 37.79% more than flat slab building.
7. The conventional slab building in y- direction is observed that maximum displacement in equivalent static analysis is 31.36% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum displacement in equivalent static analysis is 31.31% more than response spectrum analysis method.

3.2 STORY DRIFT OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

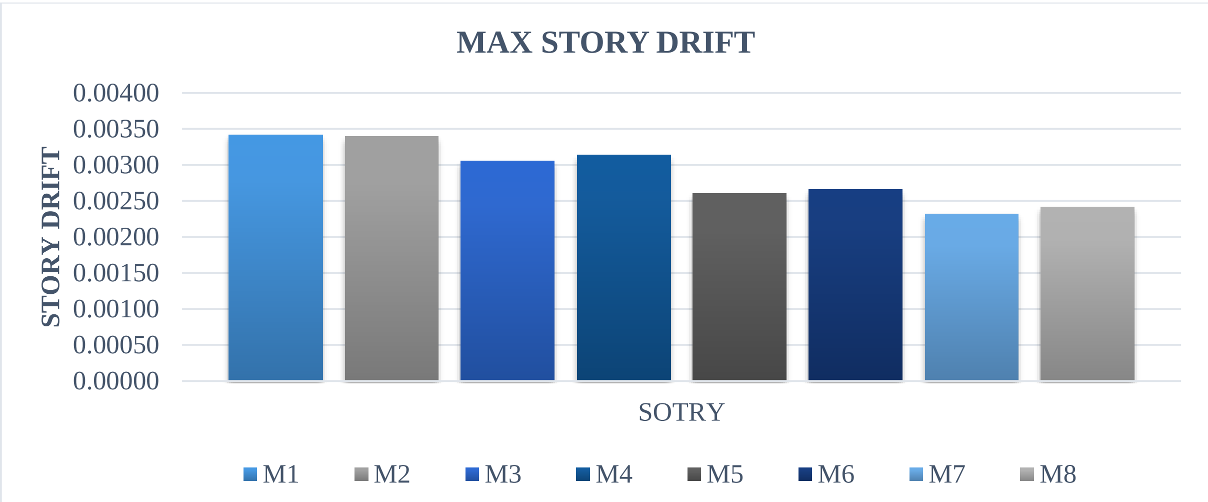

Fig.3.3 Max. Story Drift

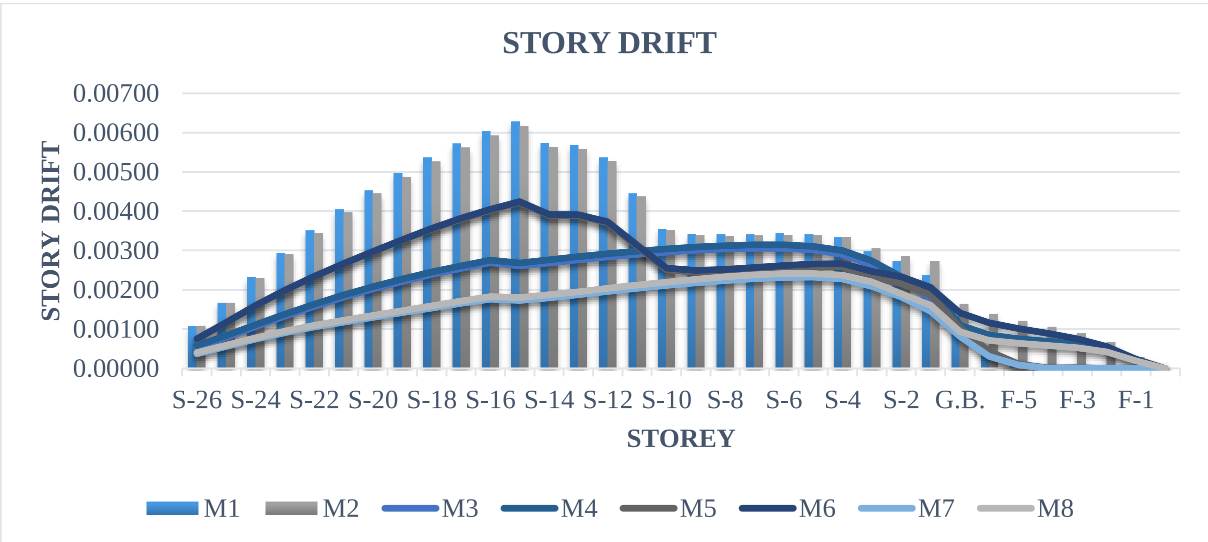

Fig.3.4 Story Drift in all storey

1. The equivalent static analysis in x- direction is observed that maximum story drift in conventional slab building is 10.53% more than flat slab building.
2. The response spectrum analysis in x- direction is observed that maximum story drift in conventional slab building is 10.77% more than flat slab building.
3. The conventional slab building in x- direction is observed that maximum story drift in equivalent static analysis is 23.98% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum story drift in equivalent static analysis is 24.18% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum story drift in conventional slab building is 7.37% more than flat slab building.
6. The response spectrum analysis in y- direction is observed that maximum story drift in conventional slab building is 12.78% more than flat slab building.
7. The conventional slab building in y- direction is observed that maximum story drift in equivalent static analysis is 21.53% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum story drift in equivalent static analysis is 22.53% more than response spectrum analysis method.

3.3 STORY SHEAR OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

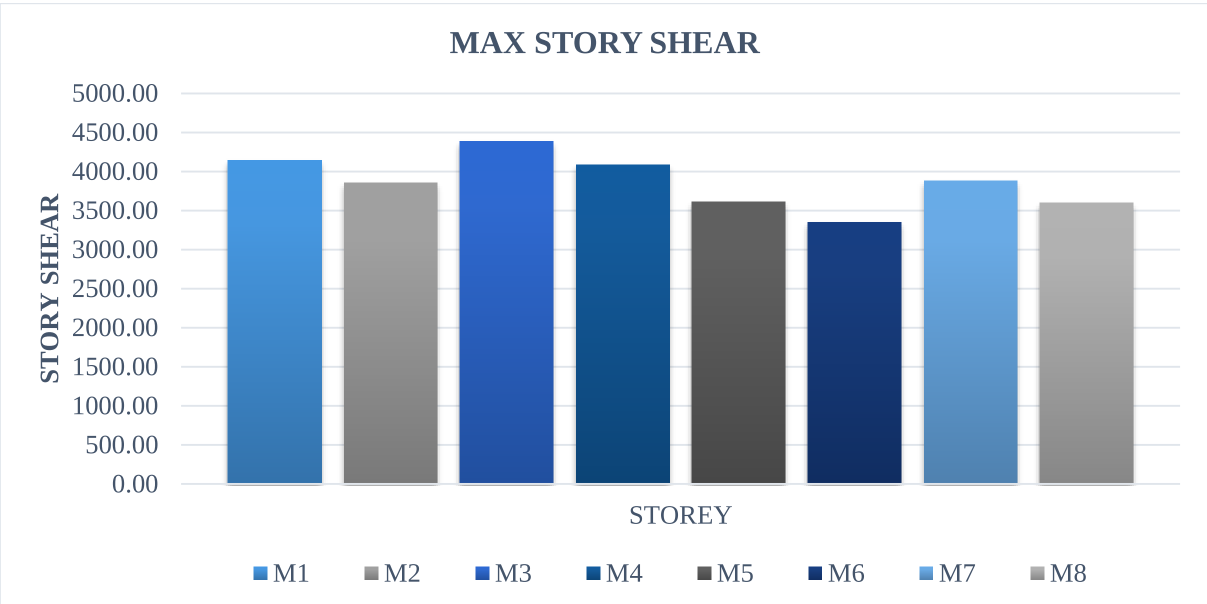

Fig.3.5 Max. Story Shear

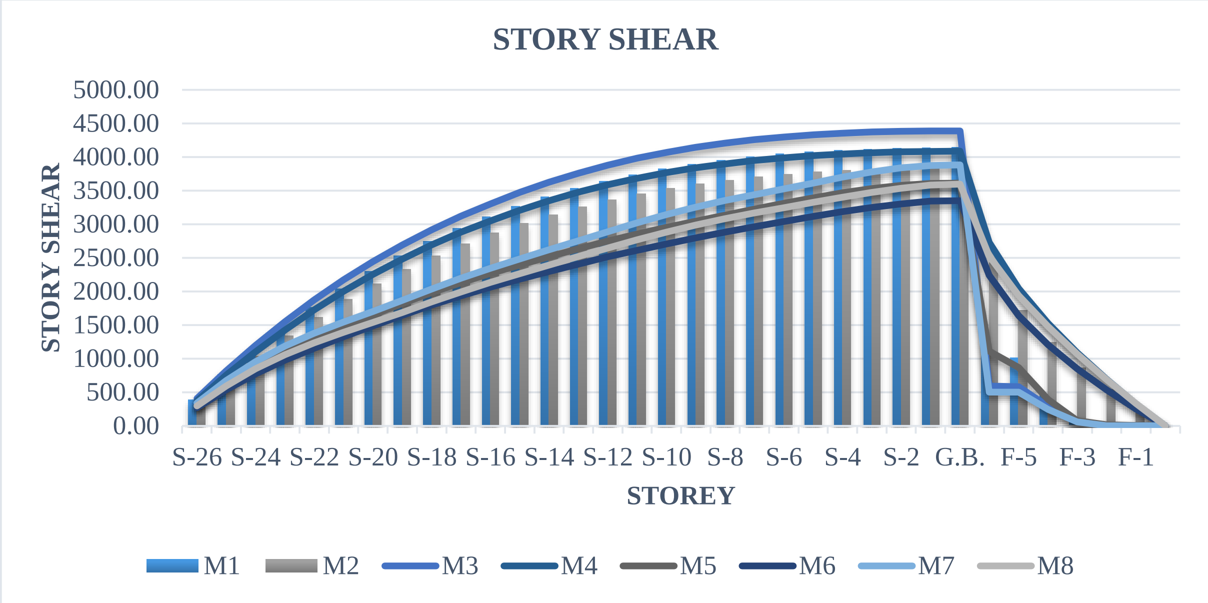

Fig.3.6 Story Shear in all storey

1. The equivalent static analysis in x- direction is observed that maximum story shear in flat slab building is 5.67% more than conventional slab building.
2. The response spectrum analysis in x- direction is observed that maximum story shear in flat slab building is 6.99% more than conventional slab building.
3. The conventional slab building in x- direction is observed that maximum story shear in equivalent static analysis is 12.83% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum story shear in equivalent static analysis is 11.59% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum story shear in flat slab building is 5.71% more than conventional slab building.
6. The response spectrum analysis in y- direction is observed that maximum story shear in flat slab building is 6.77% more than conventional slab building.
7. The conventional slab building in y- direction is observed that maximum story shear in equivalent static analysis is 13.03% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum story shear in equivalent static analysis is 12.03% more than response spectrum analysis method.

3.4 BASE SHEAR OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

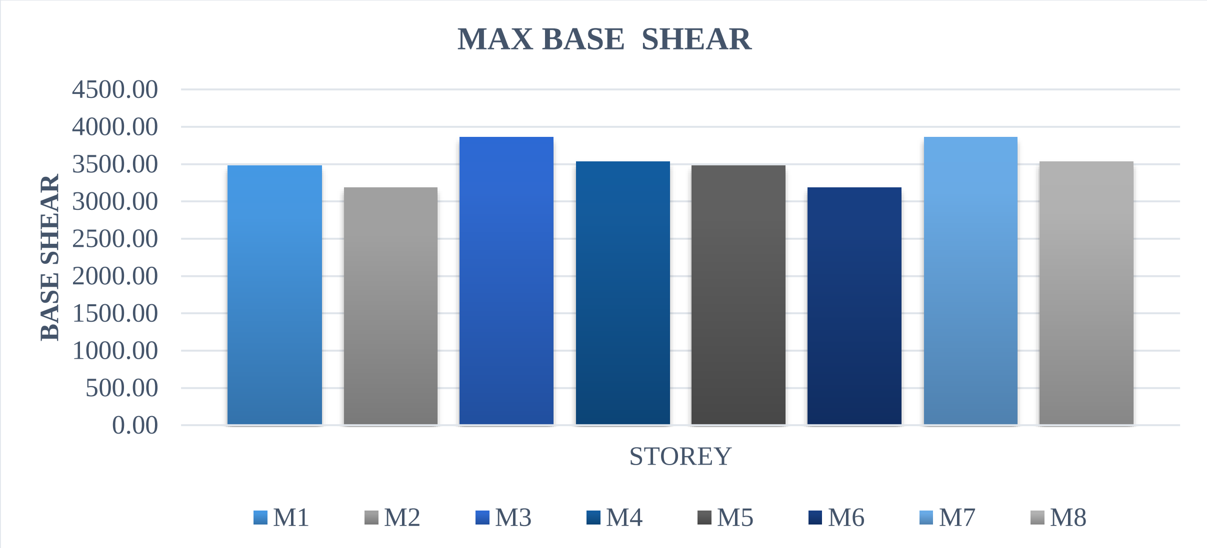

Fig.3.7 base Shear

1. The equivalent static analysis & response spectrum analysis in x- direction are observed that maximum base shear in flat slab building is 9.86% more than conventional slab building.
2. The conventional slab & flat slab buildings in x- direction is observed that base shear is same in equivalent static analysis & response spectrum analysis method.
3. The equivalent static analysis & response spectrum analysis in y- direction are observed that maximum base shear in flat slab building is 9.86% more than conventional slab building.
4. The conventional slab & flat slab buildings in x- direction is observed that base shear is same in equivalent static analysis & response spectrum analysis method.

3.5 TIME PERIOD OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN DYNAMIC RESULTS:

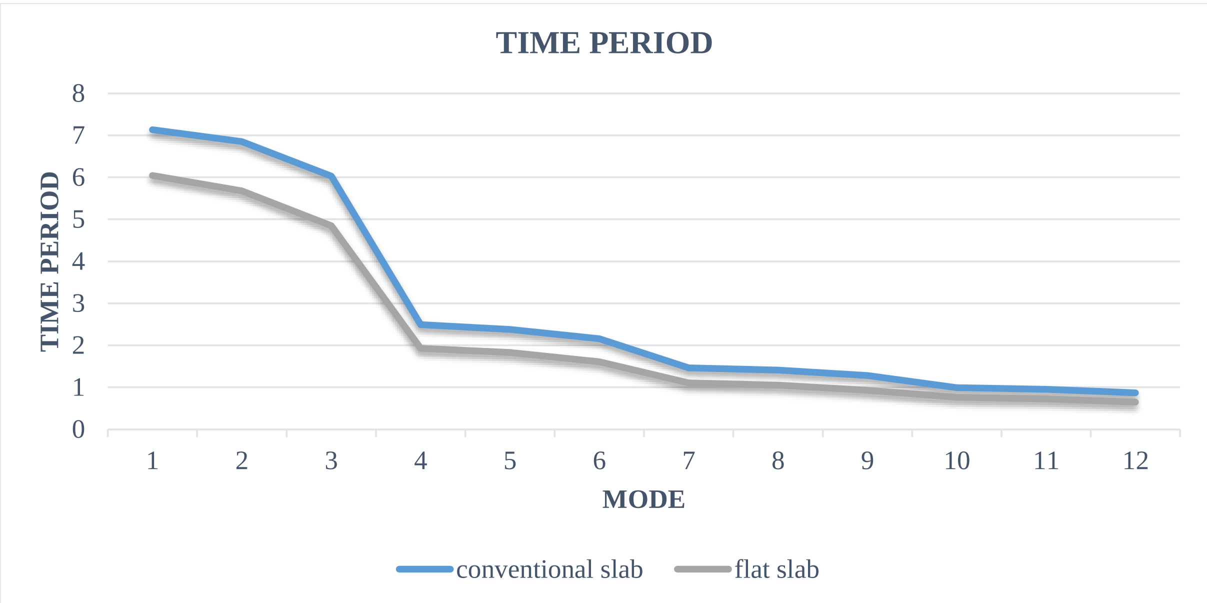

Fig.3.8 time period

Time required for undamped system to complete one cycle of free vibration is the natural time period of vibration of system in unit of second. The response spectrum analysis is observed that maximum time period in conventional slab building.

3.6 AXIAL FORCE OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

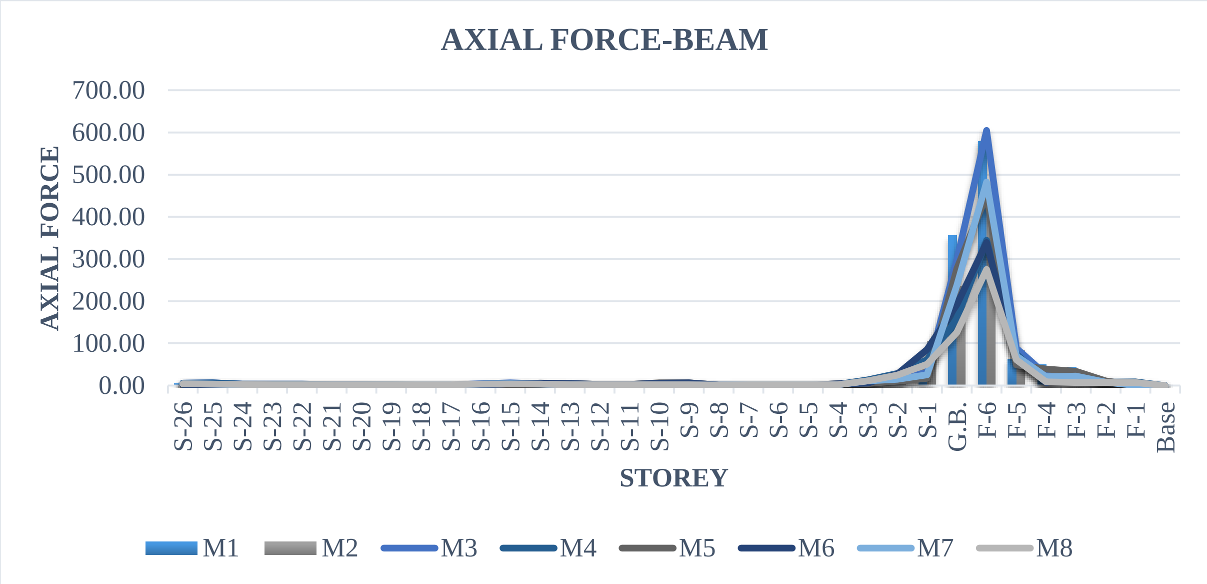

Fig.3.9 axial force in beam

1. The equivalent static analysis in x- direction is observed that maximum axial force in flat slab building is 4.18% more than conventional slab building.
2. The response spectrum analysis in x- direction is observed that maximum axial force in flat slab building is 6.45% more than conventional slab building.
3. The conventional slab building in x- direction is observed that maximum axial force in equivalent static analysis is 22.03% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum axial force in equivalent static analysis is 20.14% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum axial force in conventional slab building is 17.16% more than flat slab building.
6. The response spectrum analysis in y- direction is observed that maximum axial force in conventional slab building is 18.84% more than flat slab building.
7. The conventional slab building in y- direction is observed that maximum axial force in equivalent static analysis is 18.46% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum axial force in equivalent static analysis is 20.11% more than response spectrum analysis method.

3.7 SHEAR FORCE OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

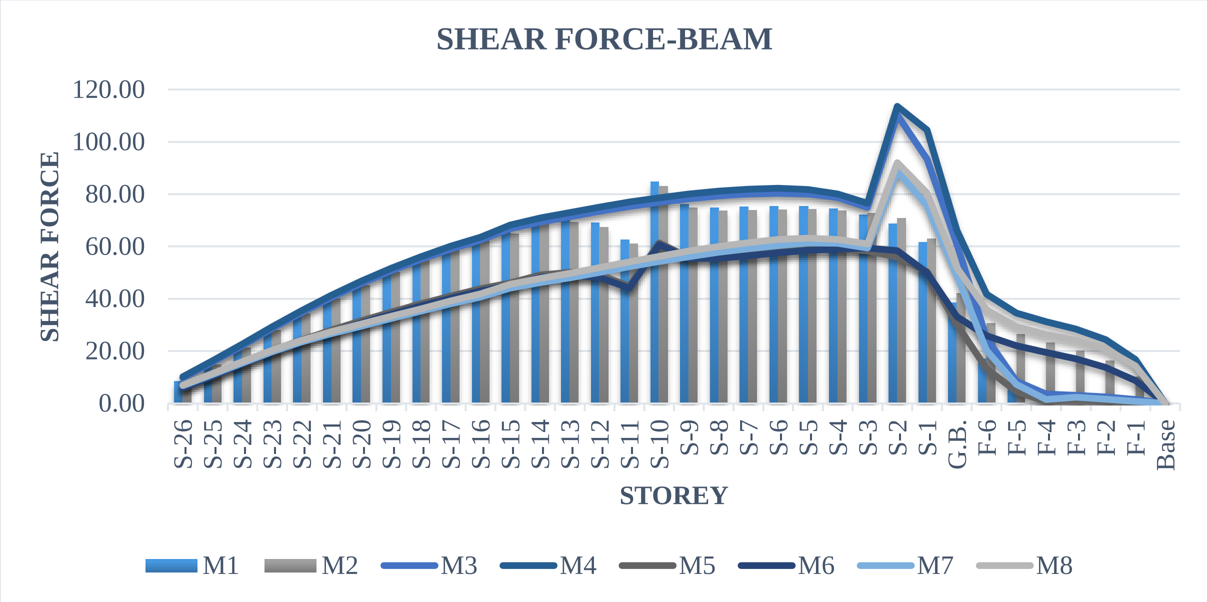

Fig.3.10 shear force in beam

1. The equivalent static analysis in x- direction is observed that maximum shear force in flat slab building is 23.34% more than conventional slab building.
2. The response spectrum analysis in x- direction is observed that maximum shear force in flat slab building is 31.08% more than conventional slab building.
3. The conventional slab building in x- direction is observed that maximum shear force in equivalent static analysis is 27.56% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum shear force in equivalent static analysis is 19.42% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum shear force in flat slab building is 26.90% more than conventional slab building.
6. The response spectrum analysis in y- direction is observed that maximum shear force in flat slab building is 34.08% more than conventional slab building.
7. The conventional slab building in y- direction is observed that maximum shear force in equivalent static analysis is 26.91% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum shear force in equivalent static analysis is 18.94% more than response spectrum analysis method.

3.8 BENDING MOMENT OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

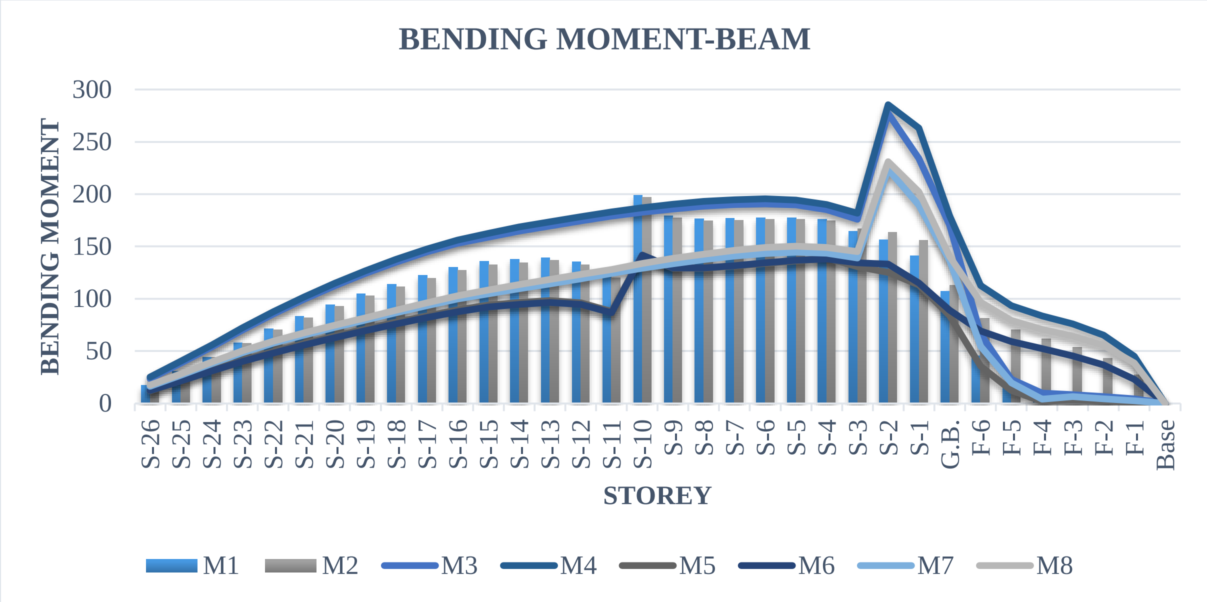

Fig.3.11 bending moment in beam

1. The equivalent static analysis in x- direction is observed that maximum bending moment in flat slab building is 28.25% more than conventional slab building.
2. The response spectrum analysis in x- direction is observed that maximum bending moment in flat slab building is 36.57% more than conventional slab building.
3. The conventional slab building in x- direction is observed that maximum bending moment in equivalent static analysis is 28.73% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum bending moment in equivalent static analysis is 1.66% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum bending moment in flat slab building is 31.04% more than conventional slab building.
6. The response spectrum analysis in y- direction is observed that maximum bending moment in flat slab building is 38.74% more than conventional slab building.
7. The conventional slab building in y- direction is observed that maximum bending moment in equivalent static analysis is 28.08% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum bending moment in equivalent static analysis is 19.08% more than response spectrum analysis method.

3.9 AXIAL FORCE OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

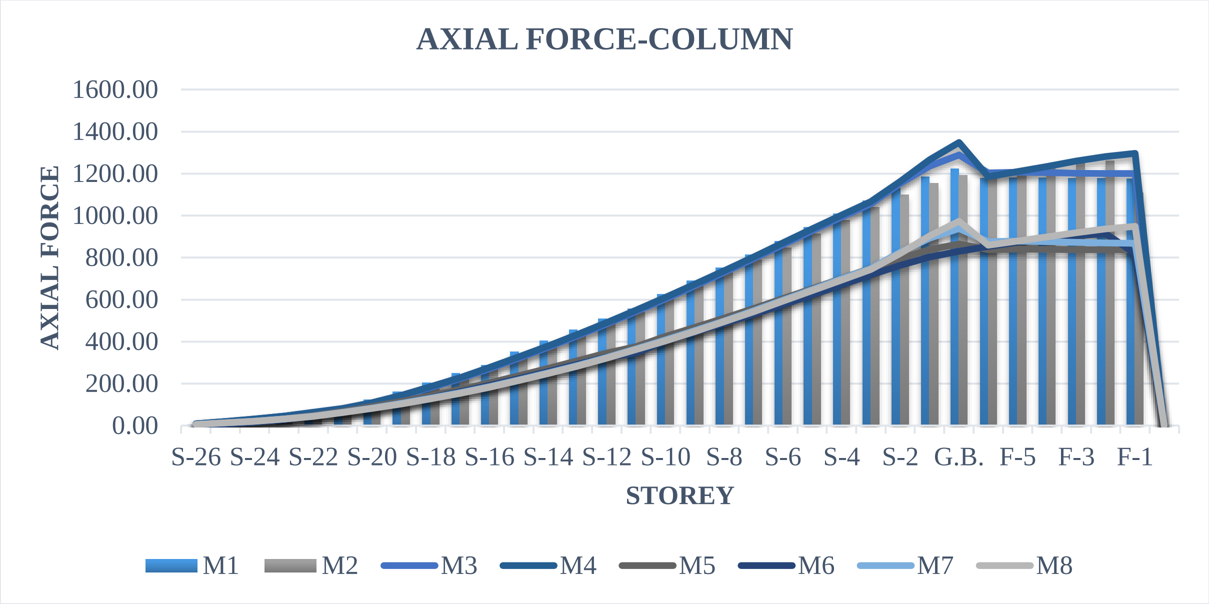

Fig.3.12 axial force in column

1. The equivalent static analysis in x- direction is observed that maximum axial force in flat slab building is 5.10% more than conventional slab building.
2. The response spectrum analysis in x- direction is observed that maximum axial force in flat slab building is 7.77% more than conventional slab building.
3. The conventional slab building in x- direction is observed that maximum axial force in equivalent static analysis is 29.24% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum axial force in equivalent static analysis is 27.18% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum axial force in flat slab building is 6.38% more than conventional slab building.
6. The response spectrum analysis in y- direction is observed that maximum axial force in flat slab building is 6.11% more than conventional slab building.
7. The conventional slab building in y- direction is observed that maximum axial force in equivalent static analysis is 27.62% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum axial force in equivalent static analysis is 27.83% more than response spectrum analysis method.

3.10 SHEAR FORCE OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

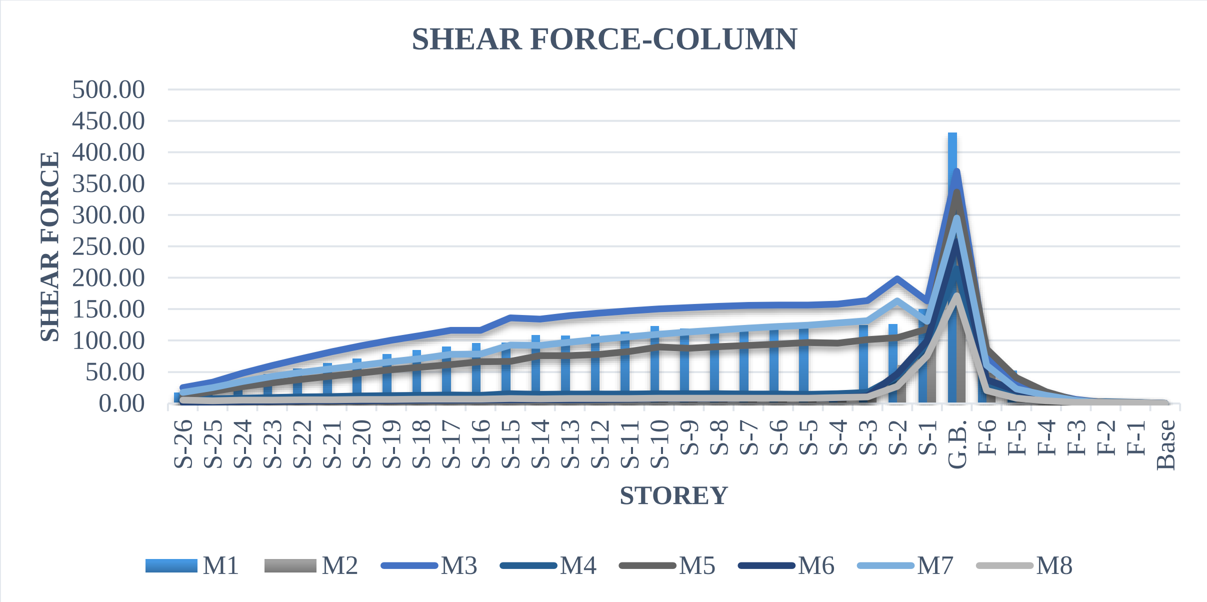

Fig.3.13 shear force in column

1. The equivalent static analysis in x- direction is observed that maximum shear force in conventional slab building is 14.27% more than flat slab building.
2. The response spectrum analysis in x- direction is observed that maximum shear force in conventional slab building is 12.28% more than flat slab building.
3. The conventional slab building in x- direction is observed that maximum shear force in equivalent static analysis is 21.94% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum shear force in equivalent static analysis is 20.13% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum shear force in conventional slab building is 32.10% more than flat slab building.
6. The response spectrum analysis in y- direction is observed that maximum shear force in conventional slab building is 33.43% more than flat slab building.
7. The conventional slab building in y- direction is observed that maximum shear force in equivalent static analysis is 18.39% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum shear force in equivalent static analysis is 19.98% more than response spectrum analysis method.

3.11 BENDING MOMENT OF CONVENTIONAL AND FLAT SLAB BUILDINGS IN STATIC AND DYNAMIC RESULTS: -

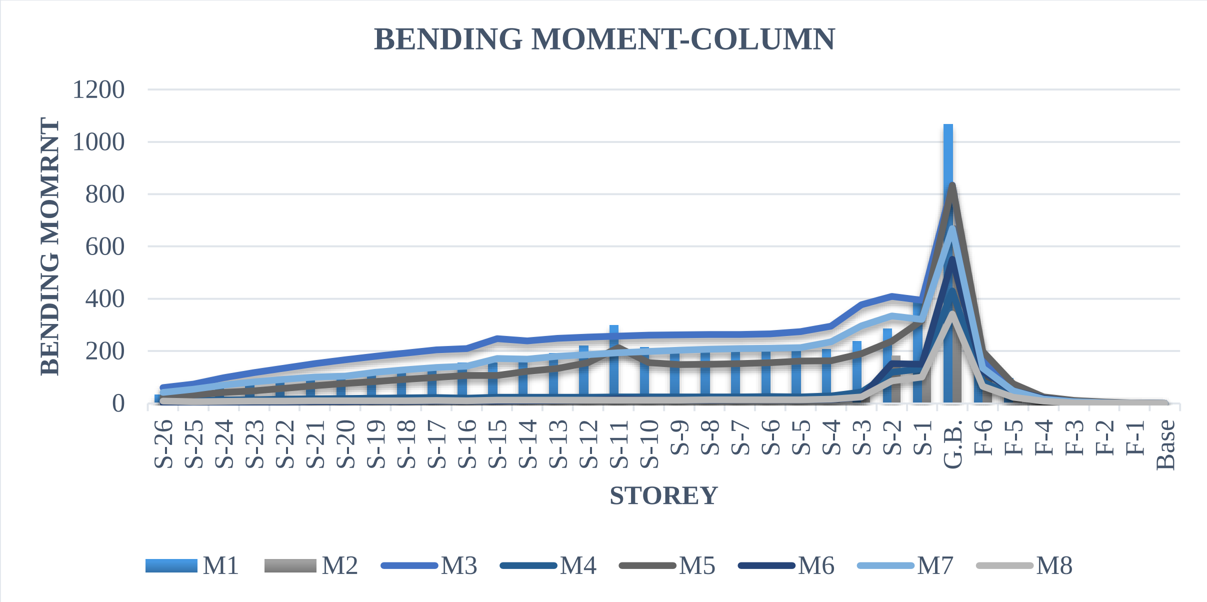

Fig.3.14 bending moment in column

1. The equivalent static analysis in x- direction is observed that maximum bending moment in conventional slab building is 21.66% more than flat slab building.
2. The response spectrum analysis in x- direction is observed that maximum bending moment in conventional slab building is 24.35% more than flat slab building.
3. The conventional slab building in x- direction is observed that maximum bending moment in equivalent static analysis is 21.82% more than response spectrum analysis method.
4. The flat slab building in x- direction is observed that maximum bending moment in equivalent static analysis is 19.98% more than response spectrum analysis method.
5. The equivalent static analysis in y- direction is observed that maximum bending moment in conventional slab building is 18.86% more than flat slab building.
6. The response spectrum analysis in y- direction is observed that maximum bending moment in conventional slab building is 38.05% more than flat slab building.
7. The conventional slab building in y- direction is observed that maximum bending moment in equivalent static analysis is 18.86% more than response spectrum analysis method.
8. The flat slab building in y- direction is observed that maximum bending moment in equivalent static analysis is 20.60% more than response spectrum analysis method.

4. FUTURE SCOPE OF STUDY: -

- The structure can be analyzed in different seismic zone and soil conditions.
- The structure can be analyzed with shear wall or bracing or damper.
- The structure can be analyzed in different sloping ground conditions.
- Comparison of conventional slab & flat slab with using post-tension cable.
- The structure can be analyzed in different types of slabs.
- The structure can be analyzed with using FRP steel bars.

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