OPTIMIZATION OF THE EFFECTIVE LOCATION OF REINFORCED SHEAR WALL FOR HIGH RISE RCC STRUCTURE (G+19)

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Abstract: Diagrid structures have been prevalently used for tall buildings worldwide due to their structural efficiency and aesthetic potential. The key concern of tall building design is controlling deflections under lateral loads. There are many structural forms to resist lateral loads; the diagrid structural system is one of the effective solutions in mitigating seismic responses of core-tube-type tall buildings. Since the diagonal angle of the diagrid structure enormously influences the adequacy of the diagrid as far as the lateral strength at the highest point of the tall structure, the present research is focused on the determination of optimal angle of the diagrid structures and the behaviour of diagrids on various seismic responses with different aspect ratios by fixing the plan of the building in all zones and medium soil type in India.

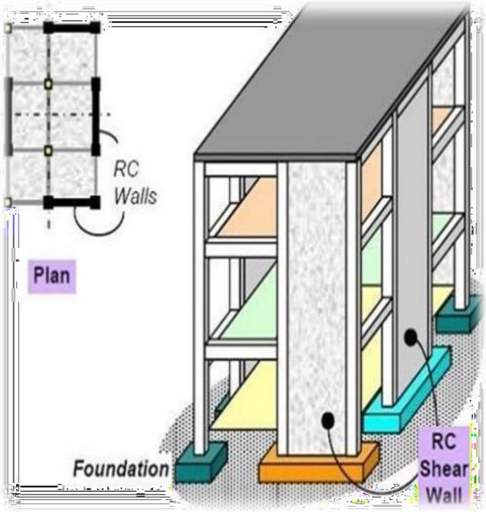
This study focuses on the determination of optimum diagonal angle of the steel diagrid structure for greater resistance to lateral loads depending upon the aspect ratio of the buildings. The results have shown that the diagrid structures with the uniform diagonal angle between 50° to 70° seemed to be the most efficient in resisting lateral loads as well as gravity loads for aspect ratio of building models between 1.6-0.55 and diagrid structures showed effective results than regular conventional type building in all zones in India. Finally, the research is concluded with the optimum angle of complete module diagrid structures with uniform diagonal angle of different aspect ratios. Further research is needed for the behaviour of incomplete module diagrid structural system in tall buildings as the number of storeys directly depend upon the primary module height.

Keywords: Dia Grid, Building, Aesthetic, Seismic Response, Diagonal Angle.

I. INTRODUCTION

In structural engineering, a shear wall is a vertical element of a seismic force resisting system that is designed to resist in-plane lateral forces, typically wind and seismic loads. In many jurisdictions, the International Building Code and International Residential Code govern the design of shear walls.

A shear wall resists loads parallel to the plane of the wall. Collectors, also known as drag members, transfer the diaphragm shear to shear walls and other vertical elements of the seismic force resisting system. Shear walls are typically light-framed or braced wooden walls with shear panels, reinforced concrete walls, reinforced masonry walls, or steel plates.



In reinforced concrete framed structure, the effects of wind forces increase in significance as the structure increases in height. Codes of practice impose limits on horizontal movement or sway.

Limits must be imposed on lateral deflection to prevent:

- Limitations on the use of building,
- Adverse effects on the behaviour of non-load bearing elements,
- Degradation in the appearance of the building,
- Discomfort for the occupants.

Generally, the relative lateral deflection in any one Storey should not exceed the Storey height divided by 500. The figure below shows the deflected profiles for a shear wall and a rigid frame

Figure 1.1 Maximum Storey slope of a building

One way to limit the sway of buildings and provide stability is to increase the section sizes of the members to create a rigid, moment-resisting frame. However, this method increases Storey heights, thus increasing the building cost. It is rarely used for more than 7 or 8 Storey. Another way is to provide stiff, shear resisting walls linked to a flexible frame. These can be external walls or internal walls around lift shafts and stairwells (a core) or sometimes both are provided.

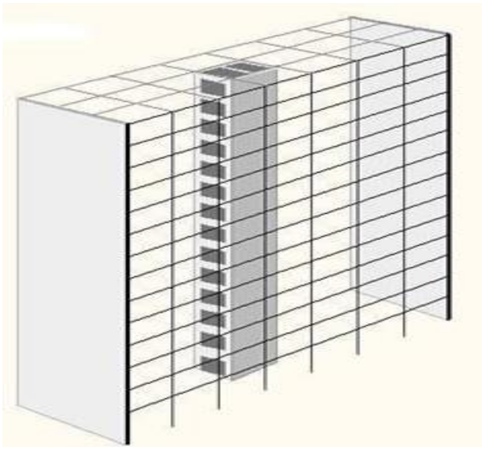


Fig 1.2 2D wireframe of a building along with shear walls on the ends

1.2 Structural Design Considerations.

1.2.1 Loading And Failure Mechanisms.

A shear wall is stiffer in its principal axis than it is in the other axis. It is considered as a primary structure which provides relatively stiff resistance to vertical and horizontal forces acting in its plane. Under this combined loading condition, a shear wall develops compatible axial, shear, torsional and flexural strains, resulting in a complicated internal stress distribution. In this way, loads are transferred vertically to the building's foundation. Therefore, there are four critical failure mechanisms; as shown in Figure 1.3. The factors determining the failure mechanism include geometry, loading, material properties, restraint, and construction.

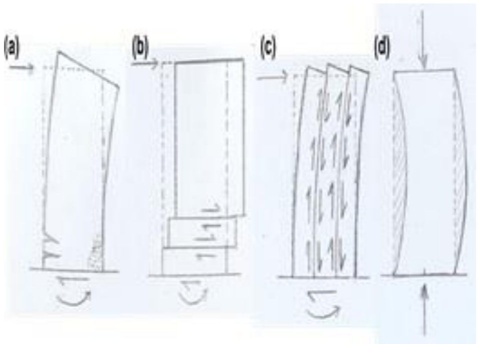


Fig 1.3 Failure mechanisms of shear walls. (a) Flexural failure,(b)Horizontal shear, (c) Vertical shear, (d) Buckling.

1.2.2. Slenderness Ratio

The slenderness ratio of a wall is defined as a function of the effective height divided by either the effective thickness or the radius of the gyration of the wall section. It is highly related to the slenderness limit that is the cut-off between elements being classed "slender" or "stocky". Slender walls are vulnerable to buckling failure modes, including Euler in-plane buckling due to axial compression, Euler out-of-plane buckling due to axial compression and lateral torsional buckling due to bending moment. In the design process, structural engineers need to consider all these failure modes to ensure that the wall design is safe under various kinds of possible loading conditions.

1.2.3. Coupling Effect of Shear Walls

In actual structural systems, the shear walls may function as a coupled system instead of isolated walls depending on their arrangements and connections. Two neighboring wall panels can be considered coupled when the interface transfers longitudinal shear to resist the deformation mode. This stress arises whenever a section experiences a flexural or restrained warping stress and its magnitude is dependent on the stiffness of the coupling element. Depending on this stiffness, the performance of a coupled section will fall between that of an ideal uniform element of similar gross plan cross-section and the combined performance of the independent component parts. Another advantage of coupling is that it enhances the overall flexural stiffness dis-proportionally to shear stiffness, resulting in smaller shear deformation.

1.2.4. Modelling Techniques

Modelling techniques have been progressively updated during the last two decades, moving from linear static to nonlinear dynamic, enabling more realistic representation of global behaviour, and different failure modes. Different modelling techniques shear walls span from macro models such as modified beam-column elements, to micro models such as 3D finite element models. An appropriate modelling technique should:

- Be capable of predicting the inelastic response

- Incorporating important materials characteristics
- Simulate behavioural feature: Lap splice and Bar Slip
- Represent the migration of the neutral axis
- Tension stiffening
- Interaction of flexure and shear actions

Different models have been developed over time, including macro-models, vertical line element models, finite-element models, and multi-layer models. More recently, fiber-section beam-columns elements have become popular, as they can model most of the global response and failure modes properly, while avoiding sophistications associated with finite element models.

II. LITERATURE REVIEW

Arturo Tena et al. (2009) Simplified Method for the Seismic Analysis of Masonry Shear-Wall Buildings [1]. In this investigation, it is found that the impact of shear deformations in the 3D distribution of the forces absorbed by these walls was assessed for different wall aspect ratios H/L. Based on extensive parametric studies, effective shear area factors _FAE_ originally proposed in the SMSA were evaluate and modified to improve the estimates of shear forces using this simple method. To use SMSA the walls must carry up to 75% gravity load. The storey was monitored to access the difference in the storey shear force attracted by walls with respect to those computed 3D static analyses. Then again effective shear factor was modified to improve the estimate of shear force using this simple technique. They proposed improvements for the SMSA were done to have a better correlation with a conventional 3D static analysis advocated by Mexican seismic codes. These results have not been yet compared with solutions obtained from pushover analyses or nonlinear time-history analyses for such structures, studies that are planned to do in the future.

HalukSucuogluetal.(2003) Performance-Based Seismic Rehabilitation of Damaged Reinforced Concrete Buildings[2]. In this investigation, it is found that buildings were rehabilitated by using simple, cost-effective methods where the newly added shear walls. different seismic performance evaluation procedures are tested such as linear spectral procedure, non-linear static procedure capacity spectrum method first on the samples of damaged buildings for predicting their observed performances. It has been found that the nonlinear static procedure is equally successful as the nonlinear dynamic procedure in predicting the observed performances of damaged buildings.4-storey and 8-storey buildings in dinar and Ceyhan were weaker which is added by shear walls and observed performance was well. Life safety performance can be easily achieved by added shear walls. The rehabilitation cost of the two sample buildings with respect to their replacement cost was 23 and 25%. so effective rehabilitation method presented here can be suggested as a realistic solution for the vulnerable medium rise concrete buildings in seismic region.

Hamed Layssiet al. (2012) Seismic Response and CFRP Retrofit of Poorly Detailed Shear Walls [3] This research work focuses experimental research on the behaviour of existing poorly designed and detailed shear walls before and after retrofit. Before retrofit it is poor confinement of the boundary elements, insufficient shear strength to develop flexural hinging, and poor anchorage. To evaluate the effectiveness of a retrofit with minimum intervention by using one layer of CFRP to avoid premature failure of the lap splices in the location of potential plastic hinging. Four walls were selected and reverse cyclic load test was done. The applied retrofit technique satisfied the performance objectives to delay failure of the lap splices and avoid shear failure. The CFRP retrofit was effective in increasing the cumulative dissipated energy and increasing the bond strength of the lap splices.

Saeid Mojiriet al. (2014) Seismic Fragility Evaluation of Lightly Reinforced Concrete-Block Shear Walls for Probabilistic Risk Assessment [4] This paper investigates on the development of analytical fragility curve based on performance under base excitation. nonlinear response history analyses using the analytical model developed in the first phase. Fragility curves are derived based on the experimental capacity data and four different intensity levels, L0, L1, L2, and L3, covering a wide range of seismic hazard levels specified for high seismic zones across Canada. This record was selected due to its high frequency content, which was compatible with the high fundamental frequency of the scaled walls. The peak ground accelerations (PGA) of L0, L1, L2, and L3 intensity levels were 0.19 g, 0.24 g, 0.61 g, and 0.84 g, respectively. Peak response of walls and flexural response was done then fragility curve was developed. development of seismic fragility curves for various SFRS based on different performance and damage levels facilitates generating PRA and loss estimation tools, the fact remains. This study is part of ongoing research program.

III. MODELING AND ANALYSIS

The present work is based on linear analysis of Structural Shear walls structures with different shapes and thickness on the exterior periphery of the building. This chapter presents a summary of various parameters defining the computational models, the basic assumptions and the geometry considered for this study. The modelling and assemblage of its various load carrying elements. Modelling of the material properties and structural elements used in the present study is discussed below.

The analysis is carried out on the 4 different types of models with different shape types of shear wall varying thickness with 150mm and 230mm with comparision of basic model without any shear walls structures was also prepared for the comparison in zone-4 and zone-5 with medium soil type. The results obtained from the analysis are taken into consideration based on the aim of the research. After getting the results, these are compared to draw the conclusion from it. In the chapter 3 the Response Spectrum Analysis is arried out, from that the effectiveness of the results on these models is given.

3.2 Design Data

3.2.1 Material Properties:

M30 grade of concrete and Fe 415 grade of Steel are used for all slabs and vertical columns of the diagrid structure. Elastic material properties of these materials are taken as per IS 456-2000[20]. The short-term modulus of elasticity (Ec) of concrete is taken as:

$Ec = 5000\sqrt{fck}$ Mpa

Where *fck*= Characteristic compressive strength of concrete cube

For the Steel rebar with stress and modulus of elasticity is taken as per IS 456-2000.

3.2.2 Structural Elements:

The different structural Shear walls with L-shaped, U-shaped and Rectangular shaped elements considered are placed at effective locations such as at the edges of building, at core section of the building and at the corner of building with 150 mm and 230 mm on exterior periphery of the building, with variable sections are mentioned below

Slab sizes:

1) Panel Area = 6m x 6m = 36 m^2
2) Slab thickness = 150 mm
3) Modelling type = Shell thin
4) Diaphragm = Rigid
5) Shear wall type-1 = 150 mm
6) Shear wall type-2 = 230 mm

Table - 1: Details of Modelled Building

Plan dimension	42m X 42m
Story height	3.6m
No. of bays in X-direction	7
No. of bays in Y-direction	7
Bay width in X and Y-direction	6m and 6m resp.
Shear walls	Shear wall 1,Shear wall 2.

3.2.3 Loads:

While applying the loads to the structure we consider only the external loads which are actually acting on the members neglecting its self-weight because ETABS [16] automatically takes the members self-weight.

3.2.3.1 Applied Loads:

The Shell loads (on Slabs) acting in the Gravity direction are Dead=1.5 kN/m^2 and Live = 3 kN/m^2.

The Seismic loads EQ-x and EQ-y are given in Load patterns directly using Code IS1893:2016[17].

Table- 2:Load Patterns

Name	Type	Self weight Multiplier	Code
DL	Dead	1	IS 875-(Part-I)
LL	Live	0	IS 875-(Part-II)
ELx	Seismic	0	IS1893 2016
ELy	Seismic	0	IS1893 2016

Table - 3: Seismic Details of Building

Zone	Zone Factor (Z)	Soil Type	Importance Factor (I)	Response Reduction Factor (R)
IV	0.24	II (Medium)	1.5	5
V	0.36	II (Medium)	1.5	5

Table- 4: Load Cases

Name	Type
DL	Linear Static
LL	Linear Static
ELx	Linear Static
ELy	Linear Static
RSA-X	Response Spectrum
RSA-Y	Response Spectrum

3.2.3.2 Applied Load combinations:

The load combinations which are considered for design as per IS code provision i.e., IS 1893:2016[17], clauses 6.3.2.1 are as follows:

- 1.5(DL + LL)
- 1.2(DL + LL ± ELx)
- 1.2(DL + LL ± ELy)
- 1.5(DL ± ELx)
- 1.5(DL ± ELy)
- 0.9(DL) ± 1.5(ELx)
- 0.9(DL) ± 1.5(ELy)

3.3 Building Models

The geometric properties of the sections are defined here. Beams and columns are given the basic properties like length, width and depth. Slab is given its thickness and the slab type is defined as membrane element which is used to represent only the plane stiffness of members.

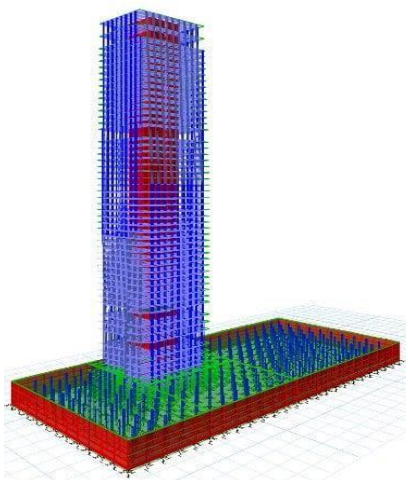


Fig 3.1 High Rise Multi Story Building Base Model

Geometry Of Model 1:

The below figure shows the 2D base model elevation view and plan view of the building without shear walls. The Model – 1 is elevated for twenty floors with height of 61 m shear walls throughout the height of the building. The walls are provided at 6 m spacing along the periphery of the building as shown in Figure 3.2 (a) & (b). The 3D view with all connecting structural members is also shown in Figure 3.3 (a), (b) & (c) along with live and no loads.

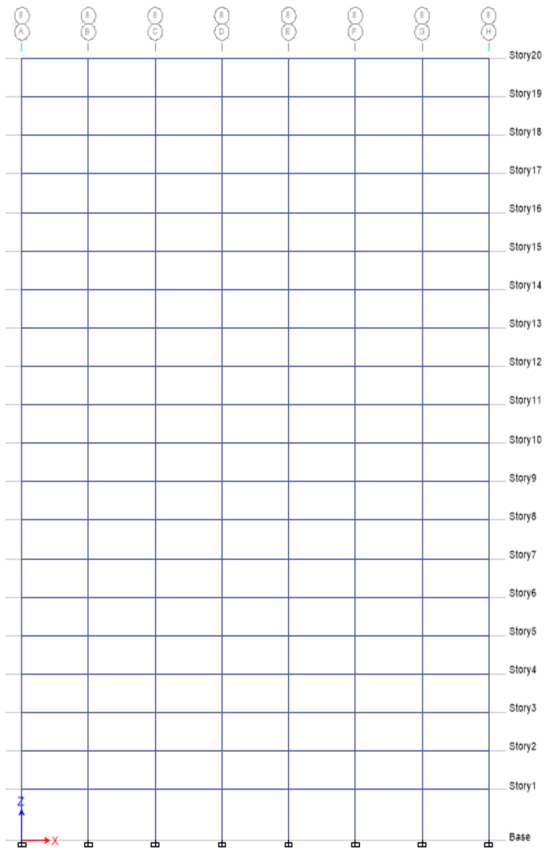


Fig 3.2 (a) MODEL – 1 Base Model Elevation View

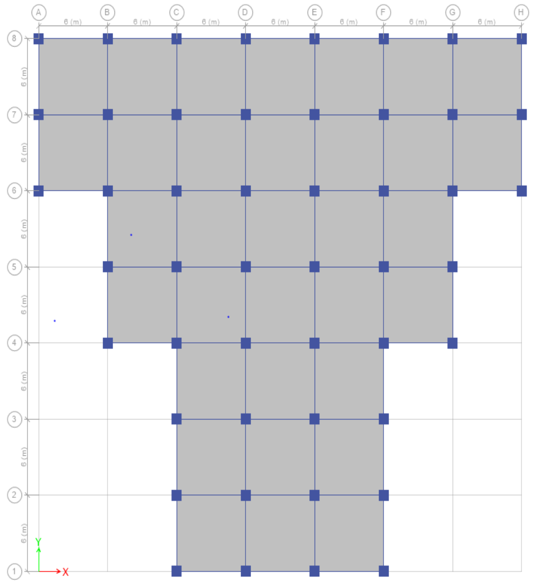


Fig 3.3 (b) MODEL – 1 Base Model Plan View

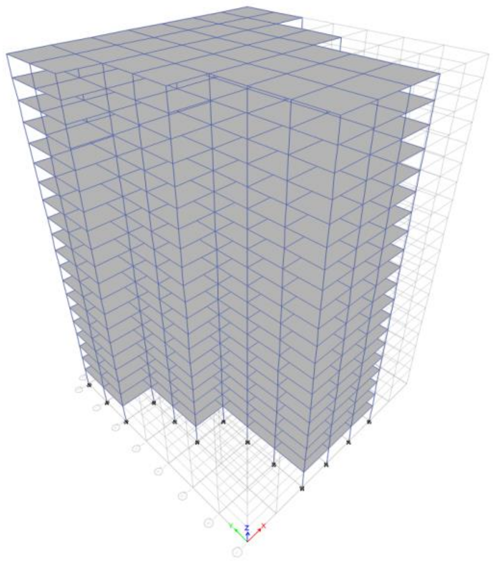


Fig 3.4 (a) MODEL – 1 Base Model 3D View

3.5 Response Spectrum Analysis:

In order to perform the seismic analysis and design of a structure to be built at a specific location, the particular time history record is required. However, it's impossible to possess such records at each and each location. Further, the seismic analysis of structures can't be administered simply supported the higher value of the bottom acceleration because the response of the structure depend on the frequency content of ground motion and its own dynamic properties. To beat the above difficulties, earthquake response spectrum is that the hottest tool within the seismic analysis of structures. There are computational advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The tactic involves the calculation of only the utmost values of the displacements and member forces in each mode of vibration using smooth design spectra that are the typical of several earthquake motions.

Response spectrum analysis of the building models is performed in on ETABS 17. In Analysis only one invariant lateral load pattern was utilized to represent the likely distribution of inertia forces imposed on the frames during an earthquake and the utilized lateral load pattern.

3.5.1 Response Spectrum Function

The lateral load distribution generated by ETABS respond to the selected seismic zones and selected soil types and the 5% damped response spectrum function is given in IS: 1893-2002. The plot of response spectrum function is shown in Figures.

3.5.2 Response Spectrum Analysis procedure in Software

Response Spectrum Analysis (RSA) may be implemented within ETABS 17 using the process outlined as follows:

1. **Model**. Create the analytical model using conventional techniques.

2. **Mass**. Define the mass source through Define > Mass Source. Mass must be present within joint locations to enable formulation.

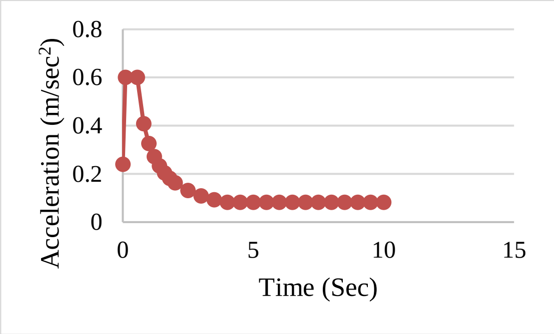


Figure 3.23: Response Spectrum Function used for RSA zone IV and soil type II

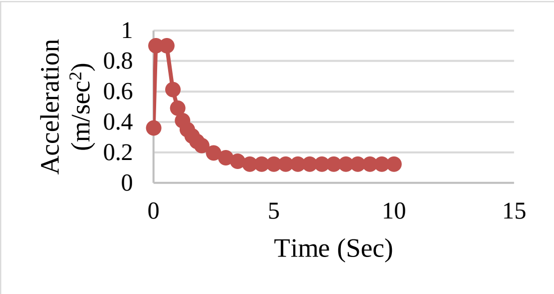


Figure 3.24: Response Spectrum Function used for RSA zone V and soil type II

3. **Modal load case**. Modify the existing modal load case to use Eigen Vectors, by selecting Define > Load Cases > Modal > Modify/Show Load Case > Eigen.

4. On the same form, under Loads Applied, select a Load Type and orientation which is suitable for the given model and investigation. For example, Accel and UX would be suitable for the lateral analysis of a 2D portal frame. Maximum Cycles and Participation Ratios may remain on default settings. During analysis, data from the modal load case will then coordinate with the RSA load case.

5. Response Spectrum function. Define the response spectrum function through Define > Functions > Response Spectrum. The existing ramp and uniform functions may be modified, or a function may be added from the various types available, based on seismic zone (Z), soil type and importance factor (I).

6. **Response Spectrum load case**. Add a new load case for the response spectrum analysis by selecting Define > Load Cases > Add New Load Case.

- Name the time-history load case.
- Select Load Case Type > Response Spectrum, Analysis Type > Linear.
- Under Loads Applied, select Load Type > Acceleration, Load Name > U1, then select the response spectrum function previously defined. If conversion from gravity units to distance units is necessary, enter the appropriate scale factor.
- In other parameters, select the modal combination method > CQC, then select the directional combination type > SRSS.
- Select appropriate modal damping and Diaphragm Eccentricity from Modify/show button.
- Perform the above mentioned steps for both RSA – X and RSA – Y load cases.

7. Analysis. Run analysis with both the modal and response spectrum load cases.

8. Output. Various options are available for reviewing output, including:

- Graphically display member forces per time step by selecting Display > Story Response plots > in case/combo > RSA – X. Next, specify the Display type > Max story displacements.
- In Display type data lateral loads to diaphragms, max story drifts, story stiffness and base shear.

IV. RESULTS AND DISCUSSIONS

4.1 General

This chapter provides the report of the results of linear dynamic response spectrum analysis carried out in the present study. Importance is given mainly to understand the behaviour of L, U and rectangular type grids in structural system and their comparison with the conventional type buildings of the same kind.

4.2 Response Spectrum Analysis

4.2.1. Story Displacements

ETABS provides a simple table in the summary output with "Story Maximum Lateral Displacements". This provides indication of maximum deflections for shear wall structures at different zones with conventional type models. Due to the un-symmetry of the building plan the Maximum Displacements due to RSA-X in X-direction and RSA-Y in Y-direction are different and are mentioned below for different building models in zone4 and zone 5 with medium soil types in India considered for this research.

4.2.1.1. Story Displacements For Model – 1

The Story displacements of Model - 1 i.e., 20 – Story structure without shear walls in zone4 and zone5 with medium soil type was observed and the mini displacement was observed among all models. The conventional type model shown a minimum displacement of 56.9 mm and a maximum displacement of 57.9 mm at zone 4 and minimum displacement of 80.5 mm and a maximum displacement of 81.4 mm at zone 5 is obtained. This is shown in the below graphs. The storey height of the building is G + 19 where the distance between the two columns is 6m. Here this graph is shown for which no shear wall is used.

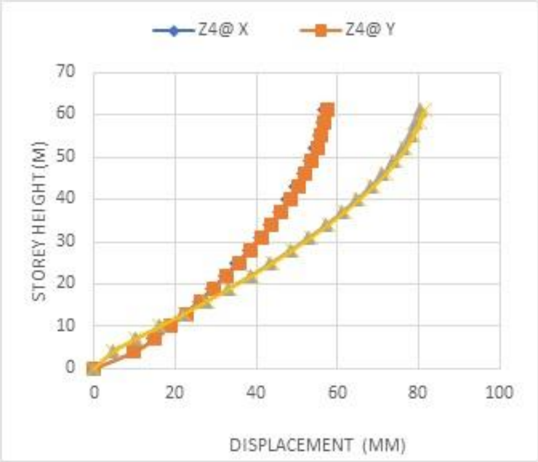


Fig 4.1 Storey Vs Displacements with no shear walls at Zone 4 and zone 5

4.2.1.2. Story Displacements For Model – 2

The Story displacements of Model - 2 i.e., 20 – Story structure with L - Type shear walls with medium soil type was observed and the minimum displacement was observed among all models. Here two types of shear walls are used. One is Shear Wall Type 1 which has 150 mm thickness of wall and the second one is Shear Wall Type 2 which has 230 mm of thickness. Here the graphs are extracted in such a way that they represent the type 1 zone 4 and type 1 zone 5 as well as type 2 zone 4 and type 2 zone 5. The storey height of the building is G + 19 where the bay width is 6m. The L- Type shear wall has shown a minimum displacement of 44.2 mm and a maximum displacement of 47 mm at type 1 zone 4 and minimum displacement of 68.3 mm and a maximum displacement of 72.3 mm at type 1 zone 5 is obtained. Similarly a minimum displacement of 43.4 mm and a maximum displacement of 46.2 mm at type 2 zone 4 and a minimum displacement of 66.8 mm and a maximum displacement of 71.1 mm is obtained.

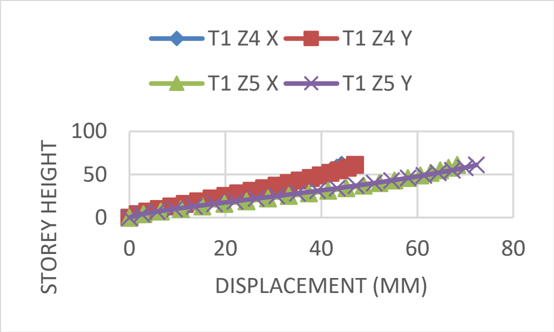


Fig 4.2 Storey Vs Displacements of L – Type Shear Wall Type 1 at Zone 4 & Zone 5

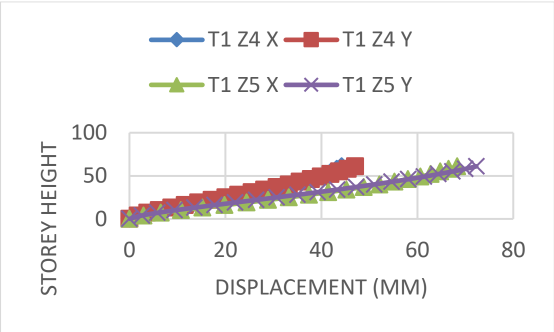


Fig 4.3 Storey Vs Displacements of L – Type Shear Wall Type 2 at Zone 4 & Zone 5

4.2.1.3.STORY DISPLACEMENTS FOR MODEL – 3

The Story displacements of Model - 3 i.e., 20 – Story structure with U - Type shear walls with medium soil type was observed and the minimum displacement was observed among all models. Here two types of shear walls are used. One is Shear Wall Type 1 which has 150 mm thickness of wall and the second one is Shear Wall Type 2 which has 230 mm of thickness. Here the graphs are extracted in such a way that they represent the type 1 zone 4 and type 1 zone 5 as well as type 2 zone 4 and type 2 zone 5. The storey height of the building is G + 19 where the bay width is 6m. The U- Type shear wall has shown a minimum displacement of 33.1 mm and a maximum displacement of 43.1 mm at type 1 zone 4 and minimum displacement of 50.9 mm and a maximum displacement of 67.4 mm at type 1 zone 5 is obtained. Similarly, a minimum displacement of 32.5 mm and a maximum displacement of 42.2 mm at type 2 zone 4 and a minimum displacement of 49.9 mm and a maximum displacement of 64.9 mm is obtained.

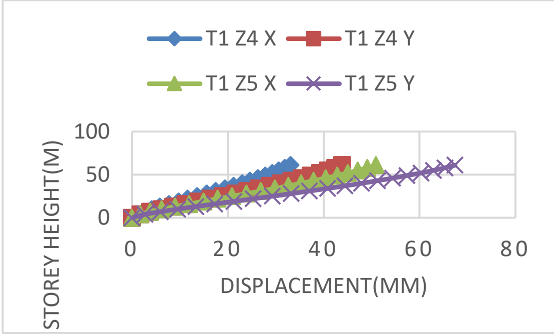


Fig 4.4 Storey Vs Displacements of U – Type Shear Wall Type 1 at Zone 4 & Zone 5

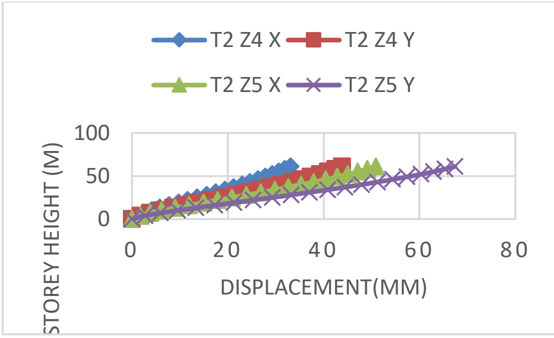


Fig 4.5 Storey Vs Displacements of U – Type Shear Wall Type 2 at Zone 4 & Zone 5

V.CONCLUSIONS

This study proposed four building models to evaluate the seismic response for buildings of different Model-1, Model-2, Model-3 and Model-4 i.e., G+19-story structure without Shear wall, L-type shear wall, U-type shear wall and rectangular shear wall in zone-4 and zone-5 with medium soil type throughout India. Linear dynamic response spectrum analysis was performed using response spectrum function as per IS 1893(part 1):2016. The relationships between the story displacements, story drift ratio, story stiffness and base shear in order to reduce seismic response of the building model with Shear wall structural system by two types of thickness were investigated. The results were compared with Basic model. Based on the analytical results, the following conclusions may be drawn:

1. The Shear wall with different shapes and thickness with effective locations has decreased maximum displacement and is most efficient to reduce maximum lateral displacements. U-shaped model has given maximum decrease in displacement.
2. Maximum decrease in the displacements when compared with the same dimensioned regular conventional type buildings in zone-4 and zone -5.
3. The minimum displacement and minimum IDR was observed at zone II when the diagonal angle of the diagrid is 50.2° i.e., 1-storey module diagrid structure.
4. The maximum increase in stiffness percentage for diagrid structures in comparision with regular conventional type building observed is 86% to 90%.
5. It is observed that change in the structural system has less effect on maximum base shear. Among all models Maximum Base Shear was observed at models with 1-story diagrid module or 50.2° diagonal angle in all zones and soil types.

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