"The Impact of Floor Shape and Wall Modelling on the Seismic Response of Multi-Storey Buildings" A Comparative Discourse

Samir H. Helou Ph. D., P.E.
Civil Engineering Department
An-Najah National University
Nablus, Palestine

Abstract **- With the burgeoning housing industry in Palestine, investors justifiably scrutinize efficient structural topologies that address economy and structural reliability in resisting laterally applied forces, namely seismic loadings. Thorough seismic analysis is a technical requirement imposed by the local Association of Engineers and since Palestine lies on an active earthquake prone zone, this discourse is quite legitimate. In the following narration, a broad repertoire of different structural models are examined. The models represent symmetric and asymmetric architectural floor plans that are common in the local vernacular construction practice; they all share the same floor area. The investigated models have a T, L, X and Z floor shapes in addition to the basic form of a square. Moreover, the effect of masonry wall vertical distribution is investigated; equivalent compression only diagonal struts represent masonry walls. A group of models with shear walls in lieu of struts is likewise scrutinized. The comparison between all structural numerical models includes, inter alias, the standard dynamic parameters in addition to deflection, base shear and force distribution. Standard Seismic Analysis, following the Response Spectrum Method forms the prime component of the present discourse. The present study explores the adequacy of the various floor schemes and offers prudent design recommendations.**

Keywords - Response Spectrum Analysis; Base Shear; Masonry Wall Modelling; Wall Masonry Struts; Floor Shapes.

I. INTRODUCTION

It is a perpetual debate among architects and planners as to what floor plan shape would produce the optimum effect for resisting lateral forces particularly the seismic ones. This discourse is valid in earthquake prone zones particularly in regions where lower building cost advances sales. Various floor plans are usually suggested; this includes but is not limited to T, L, X and Z in addition to the standard rectangular shape. Such structures may also be vertically regular or irregular. In the following study exercise, five different yet vertically regular structures are investigated. The study models enjoy the following general topologies together with their respective model labels:

Bare Frame Structural Models

- Model 1: A Square Type Floor Shape. ` S0
  This configuration forms the basis for comparison.
- Model 2: A T Type Floor Shape T0
- Model 3: An L Type Floor Shape L0
- Model 4: An X Type Floor Shape X0
- Model 5: A Z Type Floor Shape Z0

All frames are comprised of G+10 storeys and have a five-meter module spacing in the x and in the y directions. This is a popular form for a residential building topology. Thorough comparison of the analysis results is conducted against the structure of the square floor plan. The comparison includes, inter alias, the fundamental frequencies, story displacements and the maximum bending moment magnitudes at the base
Furthermore, the above numerical models were regenerated to include masonry walls, albeit with no window openings. The masonry walls are judiciously distributed around the corners up to the fifth floor level as well as the upper six storey levels. All structural models with masonry walls in the lower five floors, modelled as diagonal struts, are labelled S1, T1, L1, X1 and Z1, while structures with masonry walls in the upper floor levels are labelled S2, T2, L2, X2 and Z2. The same models yet with shear walls in lieu of diagonal struts are investigated. When shear walls are in the lower levels, the models are labelled S3, T3, L3, X3, Z3. When shear walls are at the upper levels the models are labeled S4, T4, L4, X4 and Z4.
All of the investigated models exhibit regular mass distribution along their height. The present narration includes seismic analysis by the standard linear elastic methods, namely the Response Spectrum Method. Pauley and Priestly macro method for modelling infill walls with no window openings is invoked in the present exercise. Table 1 shows pertinent data.

Model Description	
Storey Height	3.20 m
Beam Size	50 x 30
Column Size (first 3 levels)	60 x 60
Column Size (next 4 levels)	50 x 50
Column Size	40 x 40
Thickness of Slab	15 cm
Infill Wall Thickness	15 cm

Earthquake Data	
Seismic zone	III
Zone Factor PGA	0.3g
Damping	5%
Importance Factor	1
Soil Type	Hard
Type of Structure	OMRF
Response Modification factor	3

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 09, September-2020

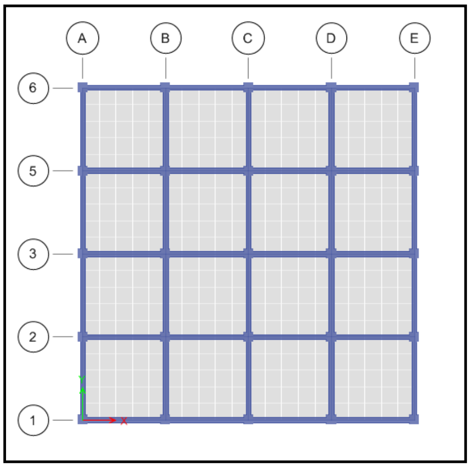
Material Details	
Concrete f'_c	30 MPa
Steel Grade F_y	420 MPa
Modulus of Elasticity of Concrete	$30x10^6$ MPa
Modulus of Elasticity of Masonry	$1.24x10^6$ MPa
Poisson Ratio of Concrete	0.20
Poisson ratio of Masonry	0.19

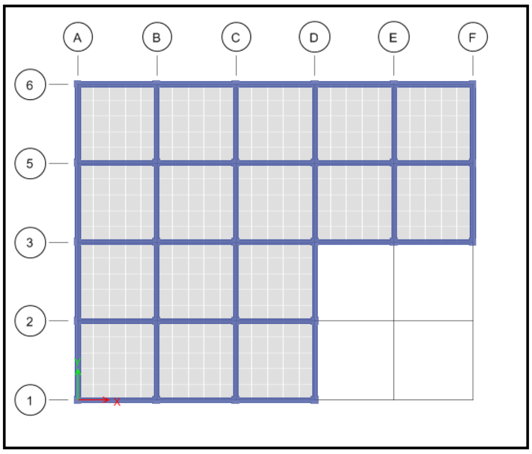
Table 1: Model Description, Material and Earthquake Data

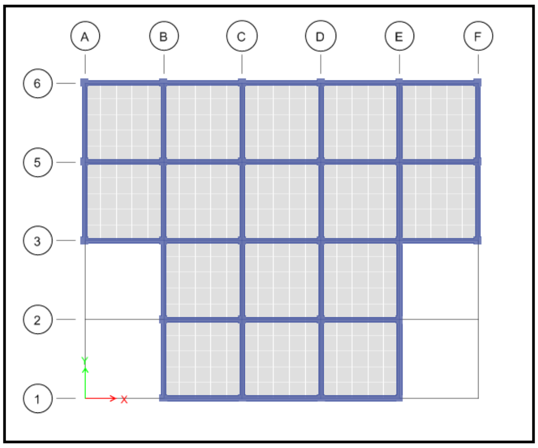
II. THE NUMERİCAL MODELS

Five different structural models of distinctly different floor shapes are investigated; they are comprised of a G+10 storeys having a uniform grid of 5-meter spacing in both directions. The Storey height at all levels is 3.2 meters while the flooring system is comprised of 15-centimeter thick slabs resting on drop beams. Columns and beams are modeled in ETABS 18.1.1 using two node linear frame elements. A rigid diaphragm action is assigned to all slabs to ensure integral lateral inclusion of all beams of each floor. The Response Spectrum selected is a smooth one with soil profile C and a damping ratio of 5%. The loads and the architectural modules are in accordance with standard vernacular building predilection. Four of the structural systems selected are slightly irregular in the vertical direction while one model is strictly regular and forms the basis for comparison. All structural models share similar topology, comprised of identical structural elements. A total fixity is assigned for all ground supports.
The structures investigated have floor plans of the same yet have the same number of columns and beams. The numerical analysis is carried out under the assumption that the primary construction material, reinforced concrete, is homogeneous, isotropic and elastic. P-Delta analysis is included and deemed compulsory for accurate analysis predictions; each nodal point has six degrees of freedom, three translational and three rotational. The strut widths, according to the macro approach, are based on the suggestions presented by Pauley and Priestly i.e. $d_{if}/4$ =150 cm. [one fourth of the diagonal length]. The struts are assigned as frame compression only masonry elements with moment releases at both ends.
The following are the assumed applied loads together with the relevant seismic analysis parameters:

- Live Load: 3 KN/m^2
- Superimposed Dead Load: 4 KN/m^2
- Importance Factor = 1 [ASCE Table 1.5-2]
- Peak Ground Acceleration, Z = 0.3g [Amendment n° 3 to SI 413 (2009)]
- S_s, Spectral Response Acceleration at short periods; $S_s = 2.5$ Z
- S_1, Spectral Response Acceleration at a period of 1 second; $S_1 = 1.25$ Z
- Modifiers per ACI Table 6.6.3.1.1 [for Beams: 0.35; for Columns: 0.7; for Slabs: 0.25].
- Risk Category II; Soil Profile C; Seismic Design category D
- Ordinary Moment Resisting Frame, R = 3.0
- Over Strength Factor, $\Omega_o = 3$
- Deflection Amplification Factor, Cd = 2.5
- Structural Damping: 5%







International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 09, September-2020

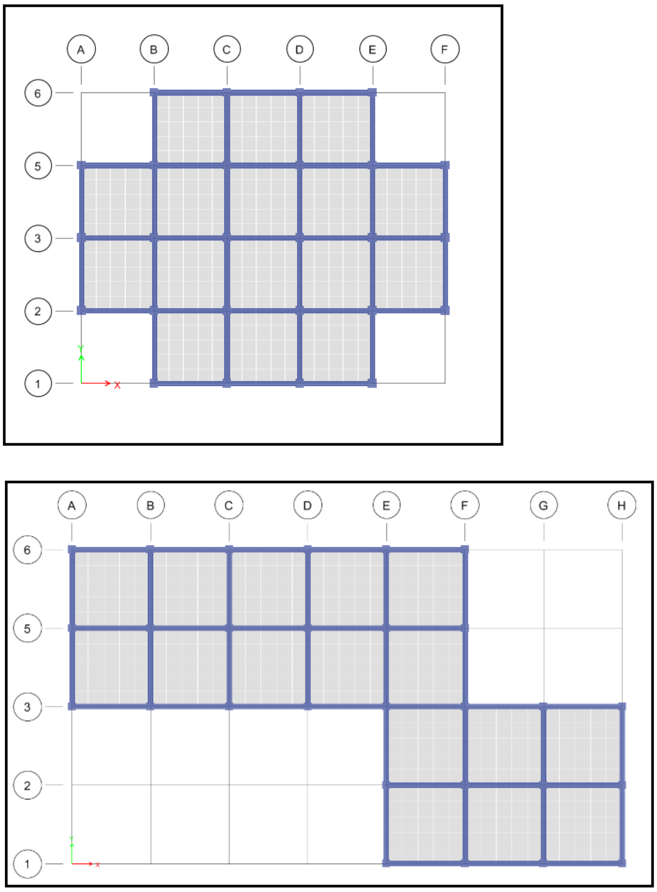


Figure 1: The Investigated Floor Plans

III. ANALYSİS PROCEDURE

The present study proceeds by the Standard Response Spectrum procedure; this includes extracting the proper number of mode shapes, setting a mass source, defining a Response Spectrum function, selecting a suitable scaling factor and finally carrying out modal superposition. Twelve mode shapes are selected and the CQC method is set for modal combination while a SRSS is set for directional combination. The seismic mass source is defined as 30% of the applied live loads added to the entire self-weight of the structure. The twelve modes of vibration included in the analysis guarantee better than 90% contribution of the total mass. Analysis is initially performed by the Equivalent Lateral Load Method. This is mandatory for better quatifying the scaling factors in the two principal directions. Following ASCE 16.3.4 a 5% accidental eccentricity is called for.

IV. RESULTS OF THE LİNEAR ANALYSİS

In Table 2 and in Figure 2, the fundamental period for all models is presented. Within each group of models, there is essentially no change in the magnitude of the fundamental period. For bare frame models with the same topology yet with the same area, no appreciable change in the fundamental period is observed. The same conclusion is drawn for models having masonry walls in the lower five storeys or with the models having the masonry walls in the upper floors. However, the values observed indicate that masonry walls in the lower five storeys decrease the period of their corresponding bare frame periods by about 38%. With shear walls instead of masonry walls however, the periods decrease by about 40%. Furthermore, with masonry or shear walls in the upper storeys the fundamental periods decrease by 11% and 8% respectively. The models that show distinctive change in values are the ones of a T, L or a Z shape. Figure 3 shows the maximum lateral displacements of all structural models. Each group of models manifests different values yet within each group, the displacements are within the same order of magnitude. Furthermore, generally the models of T, L and Z shapes present higher values of lateral displacement. The X shape being symmetrical and regular exhibits lower lateral deflections.

Figure 14, exhibits that the base shear values in all models are generally comparable. However, the difference of base shear values in models with masonry walls or shear walls in lower storeys is evident. A similar trend is visible for the variation of the maximum bending moment at the base. The models with shear walls at the lower storeys present maximum values; with the shapes of T, L and Z clearly creating larger bending moment values.

Figures 4 through Figure 13 the displacements due to the Response Spectrum Method of analysis of each group type of Models are presented for both the lateral and the transverse directions. For bare frames, Figures 4 and 5, the L floor shape model seems to be the most vulnerable in the x direction while in the transverse direction the Z shape is. In both directions, the X shape presents the least deflection.

No substantial difference in behavior and in deflection pattern is observed between the masonry modelled walls, Figures 6 and 7, and the shear wall models, Figures 10 and 11, provided they are present at the same levels. Finally, Figures 8 and 9 illustrate the behavior of the structural models with masonry walls modelled as strut elements versus the models with shear wall at the same location; shown in Figures 12 and 13. The deflection values are comparable. However, the L shape is the most vulnerable in the x direction of the masonry model while the T is the most vulnerable in the transverse direction. The X shape appears to be the sturdiest in both directions.

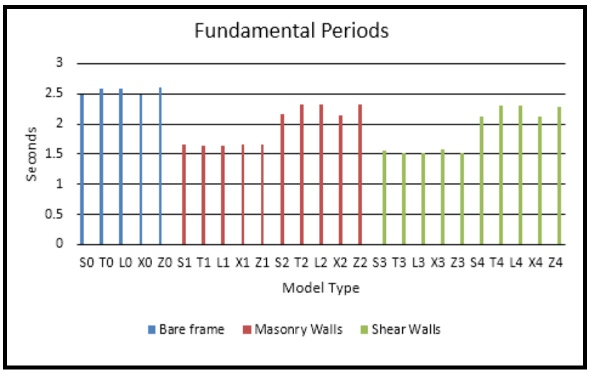


Figure 2: The Fundamental Period of the Models

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 09, September-2020

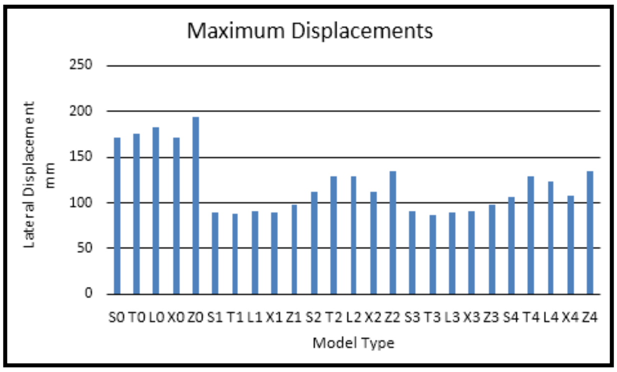


Figure 3: Maximum Storey Displacements Of Various Models

	Bare frame	Masonry Walls	Shear Walls
S0	2.48	-	-
S1	-	1.66	-
S2	-	2.155	-
S3	-	-	1.564
S4	-	-	2.12
T0	2.59	-	-
T1	-	1.64	-
T2	-	2.324	-
T3	-	-	1.515
T4	-	-	2.294
L0	2.59	-	-
L1	-	1.64	-
L2	-	2.324	-
L3	-	-	1.516
L4	-	-	2.294
X0	2.495	-	-
X1	-	1.65	-
X2	-	2.146	-
X3	-	-	1.574
X4	-	-	2.115
Z0	2.60	-	-
Z1	-	1.649	-
Z2	-	2.322	-
Z3	-	-	1.526
Z4	-	-	2.292

Table 2: Fundamental Periods in seconds

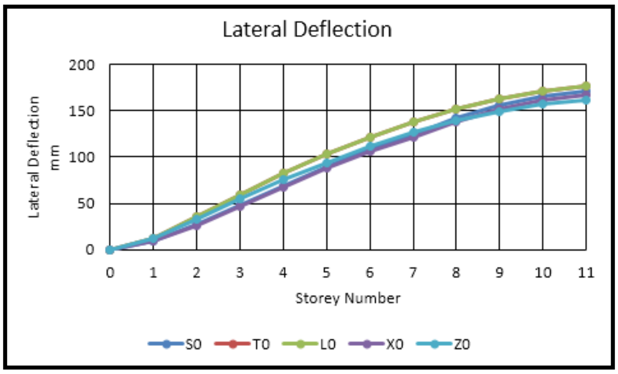


Figure 4: Lateral Displacements of the Bare Frame Model in the x-direction

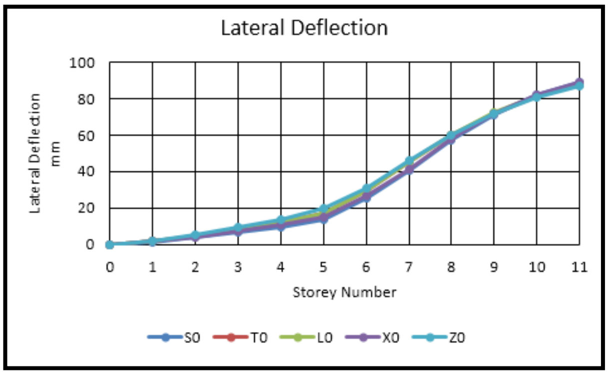


Figure 5: Lateral Displacements of the Bare Frame Model in the y-direction

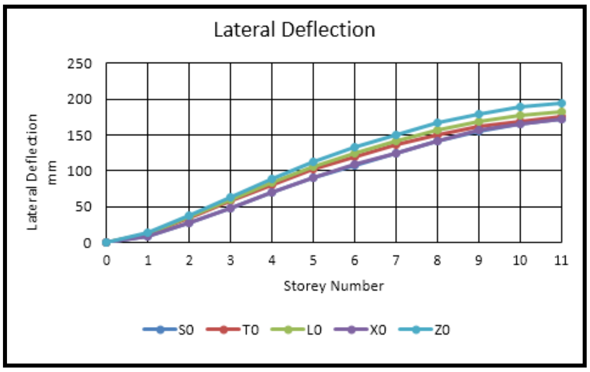


Figure 6: Lateral Displacements of Frames with Masonry at Lower levels - x-direction

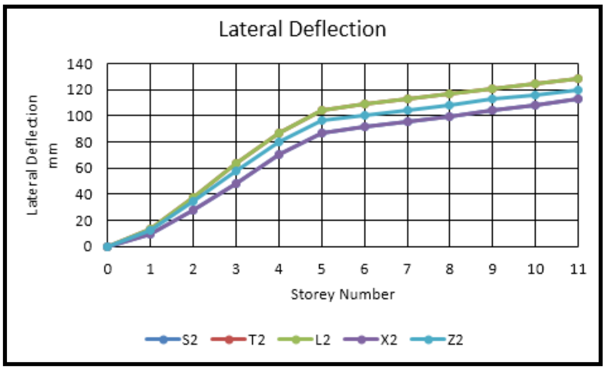


Figure 7: Lateral Displacements of Frames with Masonry at Lower levels - y-direction

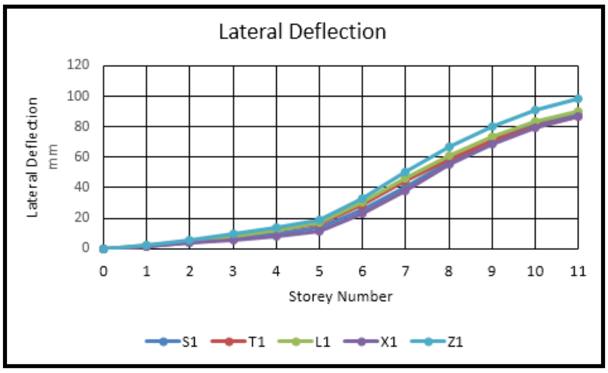


Figure 8: Lateral Displacements of Frames with Masonry Walls at Upper levels - x direction

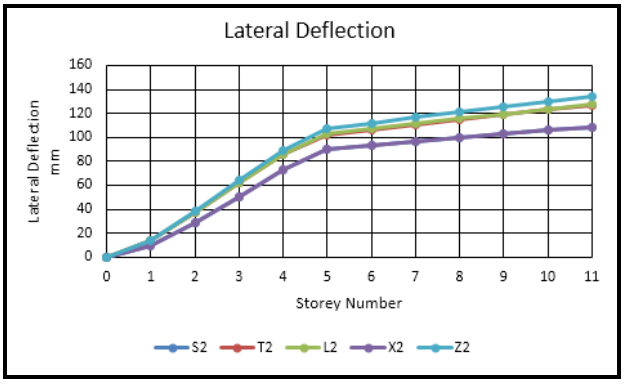


Figure 9: Lateral Displacements of Frames with Masonry Walls at Upper levels - y direction

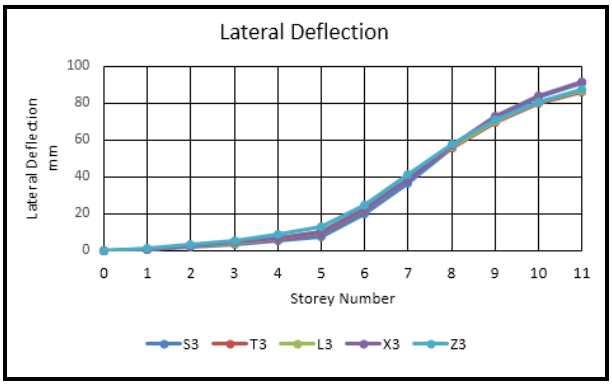


Figure 10: Lateral Displacements of Frames with Shear Walls at Lower levels - x direction

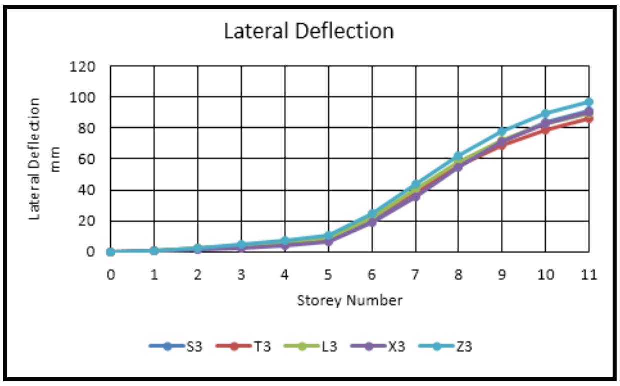


Figure 11: Lateral Displacements of Frames with Shear Walls at Lower levels - y direction

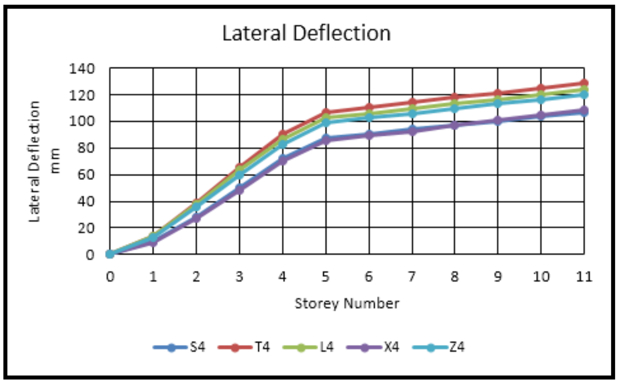


Figure 12: Lateral Displacements of Frames with Shear Walls at Upper levels - x direction

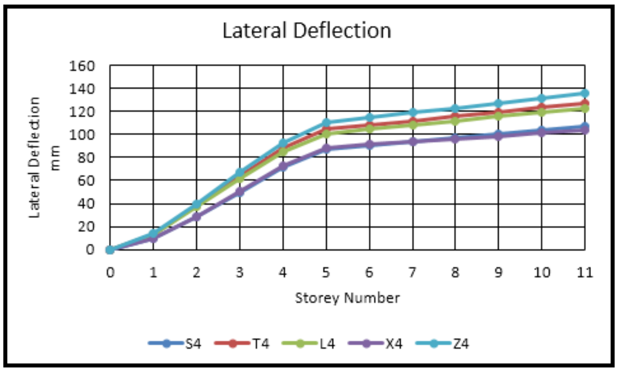


Figure 13: Lateral Displacements of Frames with Shear Walls at Upper levels - y direction

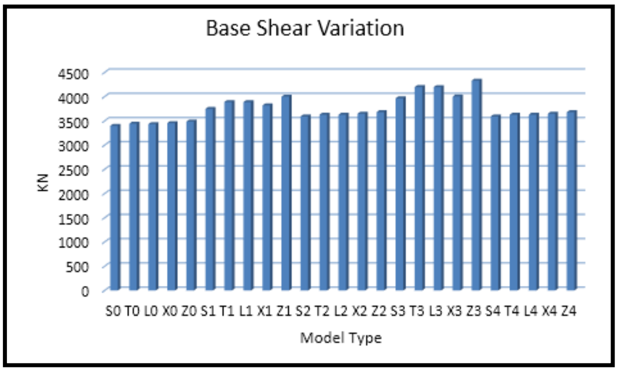


Figure 14: Base Shear for the Various Models

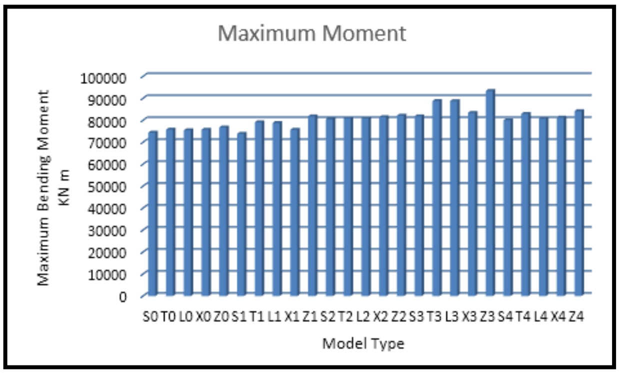


Figure 15: Maximum Base Moment

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 09, September-2020

V. CONCLUSİON AND RECOMMENDATİONS

1. The five different type groups of structures enjoy distinctly different behavior due to seismic action. An efficient behavior is exhibited in the structural models with masonry walls or with shear walls at the bottom while the maximum displacement is observed in bare frame structures.
2. For bare frame structures and all other forms, the structural models having an X shape floor plan are the sturdiest while the T, L and Z are vulnerable.
3. For structures with masonry walls, whether the walls are at the lower levels or at the upper levels, the X shape structure seems to have the edge while the T, L and Z shapes manifest relatively poor behavior.
4. The rather weak masonry struts, which are essentially brittle, alter the structural response considerably by attracting forces that are not initially called for.
5. For structures with the shear walls at lower levels, the resulting displacements are negligible in lower storeys. Similar models exhibit almost identical behavior. However, when shear walls are present in the upper storeys the X floor shape shows less deflection in both directions while the T floor shape presents the maximum deflection. Furthermore, larger deflections are observed, by about 20%, when shear walls are at upper levels.
6. When shear walls or masonry walls are at lower storeys, the deflection is almost negligible in the lower levels.
7. Masonry walls or shear walls are more effective when they are placed in lower storeys. Conversely upper level inclusion is detrimental.
8. The symmetric X-floor plan has the edge among all others in resisting seismic induced forces. The Z shape is poor in the x direction
9. The maximum base shear occurs in the models with shear walls at the bottom. Hence, they are more effective in resisting seismic induced forces.

VI. REFERENCES

[1] Anushri C. and Swamy B. S. “Study on Performance of Regular and L-Shape Irregular Building with Dampers, Shear wall and infill walls”, International Journal of Engineering and Technology VOL. 03, Issue 10, Oct 2016 J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[2] A. Touqan and S. H. Helou, “Scrutiny of the Equivalent Lateral Load Method of design for Multistory Masonry Structures” AIP Conference Vol. 1020, pp1151-1158, 2008 Proceedings K. Elissa, “Title of paper if known,” unpublished.

[3] Building Code Requirements for Structural Concrete, ACI 318-08 and Commentary, American Concrete Institute, Farmington Hills, MI, 2008.

[4] Grover A. , Verma S. K., “Effect of Infill Walls on RC Framed Structure”, IJIRSET, Vol. 5, Issue 7, July 2016

[5] Habibullah, A. et al, (2005) SAP 2000 "Static and Dynamic Finite Element Analysis of Structures", Computers and Structures Inc. Berkeley, California.

[6] International Building Code, International Code Council, Washington, D.C. 2009.

[7] Minimum Design Loads for Buildings and Other Structures, ASCE/SEI 7-10, American Society of Civil Engineers, Reston, VA, 2010.

[8] S. H. Helou and Ibrahim Muhammad, “Equivalent Lateral Load Method vs. Response Spectrum Analysis; Which Way is Forward”; Asian Journal of Engineering and Technology (ISSN: 2321-2462) Volume 02 – Issue 05, October 2014.

[9] S. Chandana, B. K. Raghu Prasad, K. Amarnath, “Elastic and Inelastic Responses of Multi-Storey Buildings Symmetric and Asymmetric in Plan”, IRJET VOL. 04 Issue 07, July 2017 Singh B et al., “Comparison of Reinforced Concrete Frames Modelled with and without Infill Walls”, International Journal of Civil Engineering and Technology Volume 8, Issue 8 August 2017pp 1636-1644

[10] Paulay, T. and Priestley, M. J. N., Seismic Design of Reinforced Concrete and Masonry Buildings, John Wiley & Sons, 1992

[11] Wilson Edward L., 2002. "Three dimensional Static and Dynamic Analysis of Structures", Computers and structures, Inc., Berkeley, California