Effect Of Shape Of Shear Wall On Performance Of Mid-Rise Buildings Under Seismic Loading

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Abstract-In multi-storey reinforced concrete (RC) buildings, one of most common practices to increase their lateral stiffness against earthquakes is to introduce shear walls at the critical location of the RC building. Various shapes including (e.g. Rectangular, T-Shape, L-Shape, C-Shape) are most commonly adopted for shear walls. The present study is to investigate the effectiveness of the shear walls regarding efficiency and economy to provide lateral stiffness to multi-storey buildings in a better way and hence resist seismic loads. In this study, different shapes of shear walls are selected for comparison i.e. Rectangular, C-Shape, L-Shape, T-Shape etc. A typical twenty (20) storey RC building with regular plan is selected for analysis purpose. The building is first modeled and analyzed by introducing columns only. No shear wall is provided in the first model which will be used as reference. Then all shapes of shear walls, selected for comparison, are introduced one by one in each separate models and analyzed. The results for various analysis outputs i.e. storey drifts, storey displacements, and storey shears are obtained, plotted and compared. It is seen that Rectangular and L-Shaped walls are most effective in resisting seismic forces while H & T-Shaped walls show the least resistance towards earthquake impacts.

Keywords-Shear Walls, Base Shear, Storey Drifts, Storey Displacements, Storey Shears, ACI.

I. Introduction

The use of shear wall begins with the start of 20th century. The problem for the structural engineers was to find the optimize design farming for tall RC building and location of shear wall, against earthquake disasters[i]. The solution is the strengthen and more stiffness of the critical structural member to reduce the damage effect against the lateral loads. This idea led to the usage of shear walls in tall RC buildings.

This research is conducted to find the most optimize shape of the shear wall that is able to resist lateral loads in a much better and economical way. Hence, the output of this research will provide a guideline to solve the problem of selection of a suitable and safe shape of shear wall.

The methodology involves modeling and analysis of a typical twenty (20) storey building with regular plan, for which a suitable architectural plan of the building is selected, as shown in fig.1. For this investigation well known building analysis and design software, ETABS (Extended Three Dimensional Analysis of Building Systems) is used.

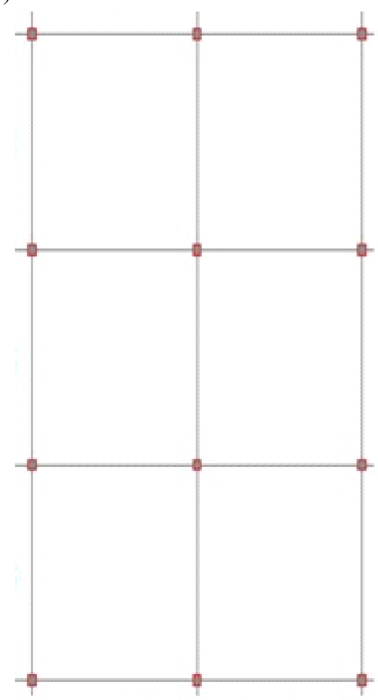

Fig. 1. Typical Building Plan

The seismic zone assumed is Zone-III which is the seismic zone for most of the developed areas of Pakistan, as per BCP-07 [ii]. Fig.2 shows the all possible shapes of the shear wall i.e. L-shape, T-shape, C-shape, H-shape and Rectangular shape, which used in the design procedure. Then these wall are added in the typical tall RC building plan one by one. For the reference ,first the RC building has been analyzed without using any shear wall. The results of this reference building then used for the comparison. Then, different shapes of shear walls are used in the same plan and different results are then compared. The area of shear wall is kept constant for all the shapes in order to compare them in terms of economy and effectiveness. The results of various building parameters i.e. storey shears, storey displacements and storey drifts. have been compared and checked for all types of shear walls.

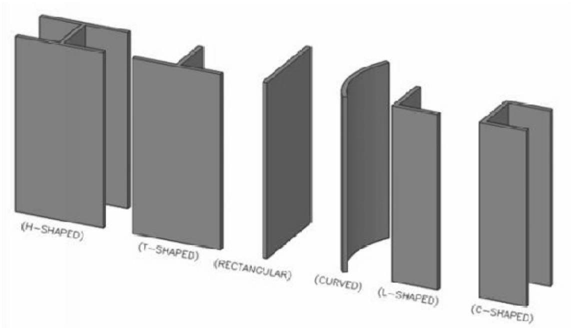

Fig. 2. Typical Shapes of Shear Walls

II. Literature Review

Burak investigated the shear wall area against the floor area under the seismic loading [iii]. Wallace presented research on seismic design of RC structural walls as per US codes and introduced various criteria to design different shapes of shear walls [iv]. Designers worked on strengthening of existing buildings for seismic forces by introducing shear walls into the old structure [v]. They suggested that external shear wall application will be a practical and economical solution for the detached buildings. There will be no changes made to the interior architecture of these buildings. Moreover, it was also observed by them that the strengthening and system improvement performed through adding external reinforced concrete shear wall to the reinforced concrete buildings will enhance behavior, strength and rigidity to the system with its low cost besides ease of construction and application. This methodology was developed for the existing reinforced concrete primary school buildings constructed as typical projects in Turkey, and was applied in most of the primary school buildings without any problems [v]. Paknahad along with his researchers worked to analyze Shear Wall Structures using optimal membrane triangle element [vi]. Wallace and Kutay Orakcal made a critical study for the provisions for seismic design of shear walls used by ACI 318-99 and prior codes and concluded that Major changes to the provisions for proportioning and detailing of structural walls were incorporated into ACI 318-99 to take advantage of displacement-based design, as well as to address shortcomings associated with prior ACI 318-99 codes [vii]. Kazimi performed analysis of Shear-Wall buildings and concluded that the shear wall buildings were evidently the most economical structural form for tall buildings. He also included a few methods to facilitate stress calculations as well as other analysis parameters through simple methods [viii]. Oztorun et al, worked on "Three-Dimensional Finite Element Analysis of Shear Wall Buildings" and concluded that "An improved simplified method for the analysis seems to be inappropriate. Three dimensional finite element analysis as presented in his study is the proper method of solution. The increasingly high speed of computers together with the use of appropriate software will make the finite element approach as a convenient design tool" [ix]. Computers and Structures Inc. provides several useful software manuals for Etabs, Sap2000, Safe etc. to aid the computerized analysis of shear walls as well as various civil structures [x,xi]. McCormac provided useful literature on design of shear walls for seismic forces [xii]. Kyaw and Thiha conducted a useful research on performance of existing buildings using ordinary moment resisting frames and concluded that most critical force for columns is bending moment which should properly be dealt with. Hence, shear walls satisfy the criteria for resisting the bending moments to a large extent [xiii].

III. Structural Analysis Parameters

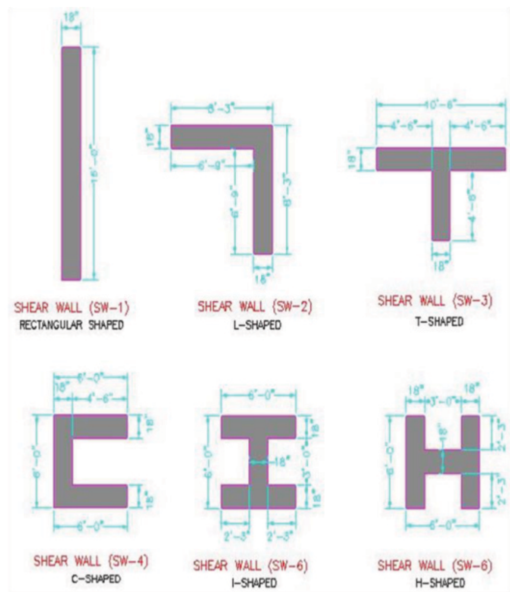

Fig. 3. Cross Sections of Various Shear Walls

Various structural analysis parameters used in the design and analysis of the model building are detailed below:

TABLE I . PROPERTIES OF SHEAR WALL

Unit weight of concrete	= 150 pcf
Modulus of elasticity of concrete	= 2850 ksi
Poisson's ratio	= 0.2
Coefficient of thermal expansion	= 5.5 x 10e–6
Conc. Compressive Strength, f'c	= 2500 psi
Yield strength of rebars fy	= 40000 psi
Shear strength of shear rebars fys	= 40000 psi

Fig.3 shows the six different shapes of the shear walls with the following cross-sections. Area of each shape of shear wall is assumed to be constant. Moreover, different structural properties, moment of inertia (I) in both axes, length (L) of walls in both axes, tensional constant (T) and polar moment of inertia (J) are calculated for each shape of shear wall as shown in the fig. 4 to 9.

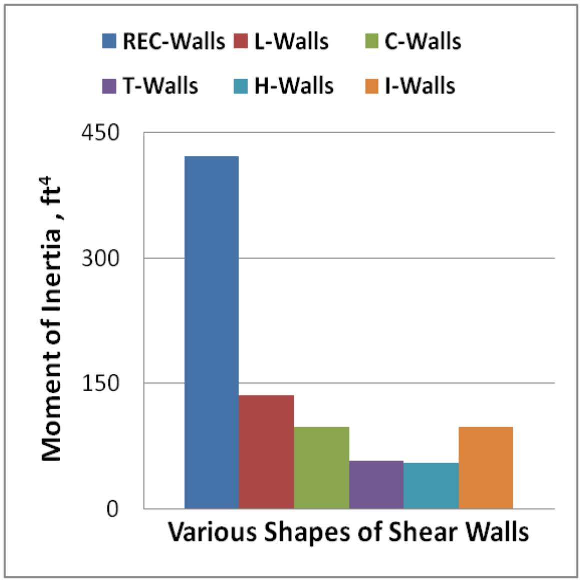

Fig. 4. Moment of Inertia of Shear Walls along X-Axis

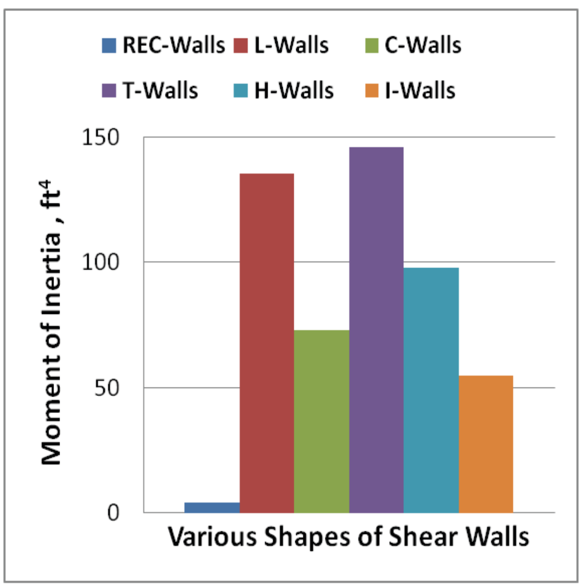

Fig. 5. Moment of Inertia of Shear Walls along Y-Axis

Fig.4&5 show the values of moment of inertia, I in x and y axes for all six different shapes of the shear walls. The rectangular shape gives the maximum value of I in the direction of x-axis and gives the minimum value in y-axis, due to the size of shape along that axis. While the T-shape gives the totally opposite values of moment of inertai along both the axes. All other shapes are also give different values depending upon the size along that axis. Fig.6&7 describe the values of length, L in x and y axes for all six different shapes of the shear walls. The I-shape gives the maximum value of length in x-axis and minimum value in y-axis, due to the size of the shape at that axis.While H-shape gives the oppposite of values for length in both axes as compare to the I-shape shear wall.

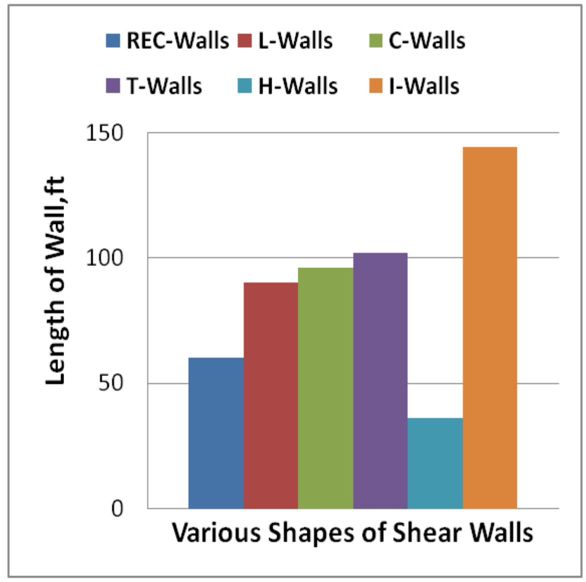

Fig. 6. Lenghts of Shear Walls along X-Axis

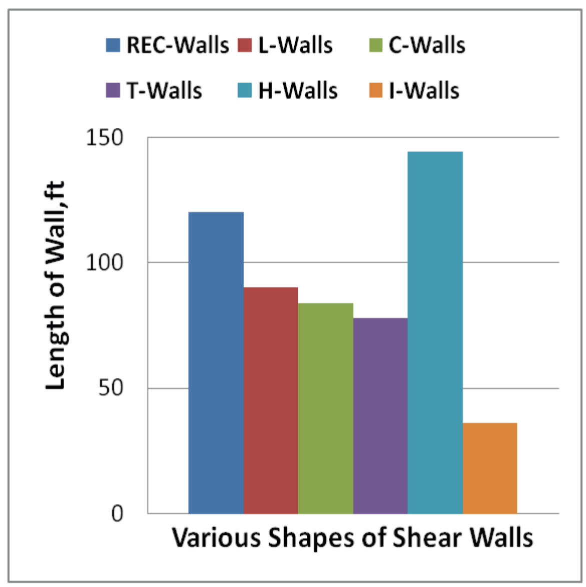

Fig. 7. Lenghts of Shear Walls along Y-Axis

Fig.8 shows the values of torsional constant, T for all six different shapes of the shear walls. This is the only structural propoerty for which all shapes give the nearly same value.

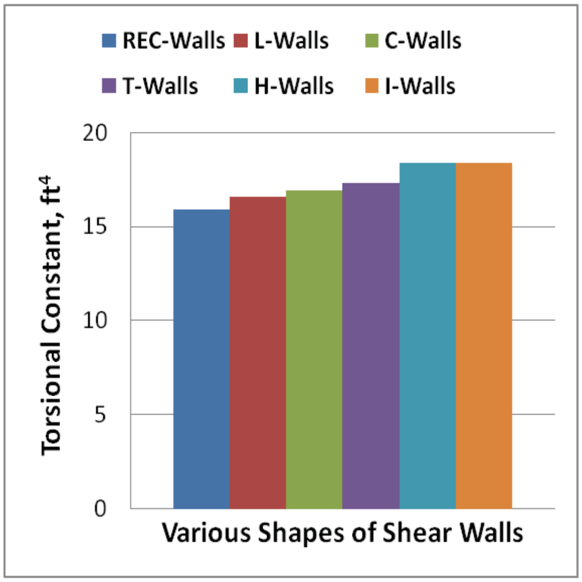

Fig. 8. Torsional constant for Shear Walls

Fig.9 shows the values of polar moment of inertia, J for all six different shapes of the shear walls. For this property, again the rectangular shape gives the maximum value.

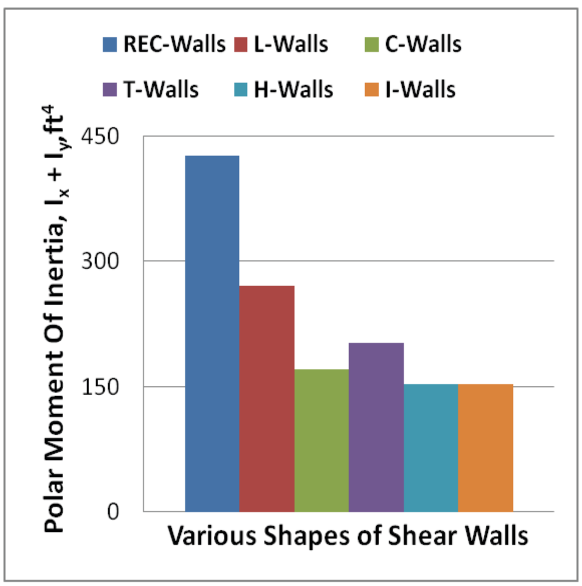

Fig. 9. Polar Moment of Inertia for Shear Walls

IV. Loading Conditions

Dead loads are defined as gravity loads that will be accelerated laterally with the structural frame under earthquake motion. Live loads are defined as gravity loads that do not accelerate laterally at the same rate as the structural frame when the structure undergoes earthquake motion. Two different values of live loads are used for first nineteen storey and for the top one as shown in the Fig.10.

Dead Loads	
Unit weight of concrete	= 150 pcf
4½ inches thick brick wall weight	= 45 psf
9 inches thick brick wall weight	= 90 psf
Superimposed dead load	= 50 psf
Live Loads	
Live load on 1st to 19th floor	= 50 psf
Live load on roof (20th floor)	= 20 psf

Earthquake load consists of the inertial forces of the building mass that result from the shaking of its foundation by a seismic disturbance. Other severe earthquake forces may exist, such as those due to land sliding, subsidence, active faulting below the foundation, or liquefaction of the local sub grade as a result of vibration. Whereas earthquakes occur, their intensity is relative inversely proportion to their frequency of occurrence; severe earthquakes are rare, moderate ones more often, and minor ones are relatively frequent.

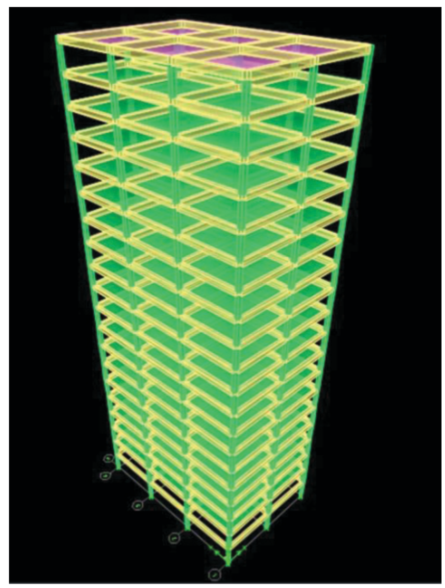

Fig. 10. Model of 20 storey building with different live load at roof

V. Modeling & Analysis

The building has been modeled in Etabs software. Fig.11 &12 show the deformed shape of the building under gravity loads. Seven separate models have been prepared with each shape of shear walls at the locations of all columns 9 (as in fig.1) as a separate model. Then analysis of each model in separate Etabs file has been run. Finally, results for various seismic parameters have been obtained and discussed for each case.

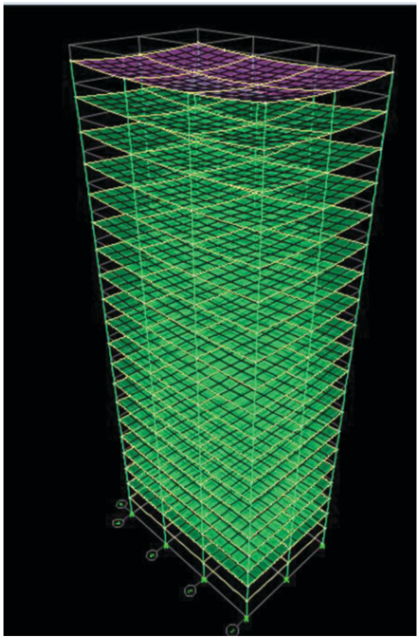

Fig. 11. 3-D view of deformed shape of 20 storey building under gravity loads

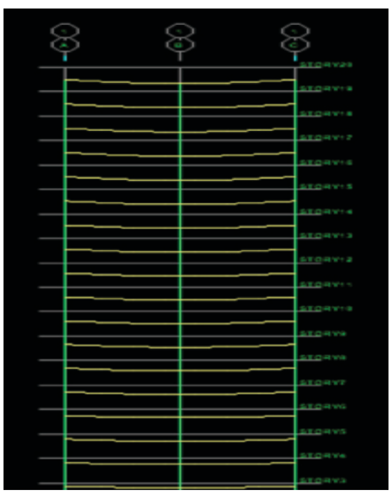

Fig. 12. Sideview of deformed shape of 20 storey building under gravity loads

I. RESULTS AND DISCUSSIONS

Results for various seismic parameters; storey drifts, storey displacement and storey shears are obtained and plotted for each shape of shear wall.

A. Storey Drifts

Storey drifts is computed against lateral forces along both x and y axes and then plotted against each shape. The comparisons are plotted for each shape of shear wall, when introduced separately into the frame and are highlighted one by one in the subsequent section.

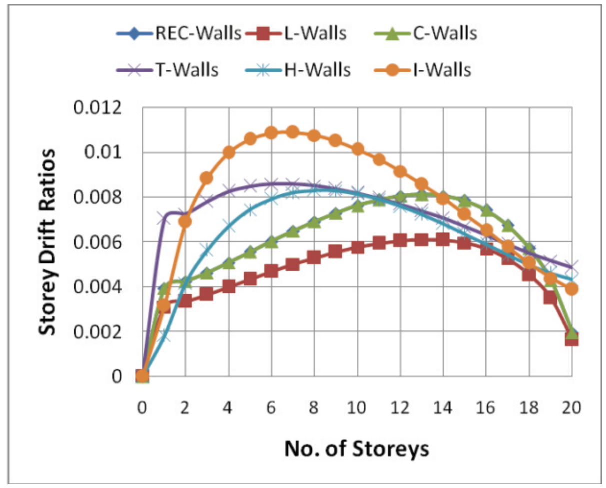

Fig. 13. Storey Drifts along X-Axis (EQ in X-Direction)

Fig.13 compares storey drifts for all shapes of shear walls and describes the response of storey drifts along x-axis against the same direction of lateral loading. I-shape shear wall gives the maximum value for the storey drift in x-axis. The storey drift has maximum value for the 8th floor. After 10th floor, the storey drift response in x-axis for all shapes start decreasing. The H-shape gives the middle response for storey drift in x-axis. While, L-shape shear wall gives the minimum value for storey drift in x-axis against the lateral loading in same axis.

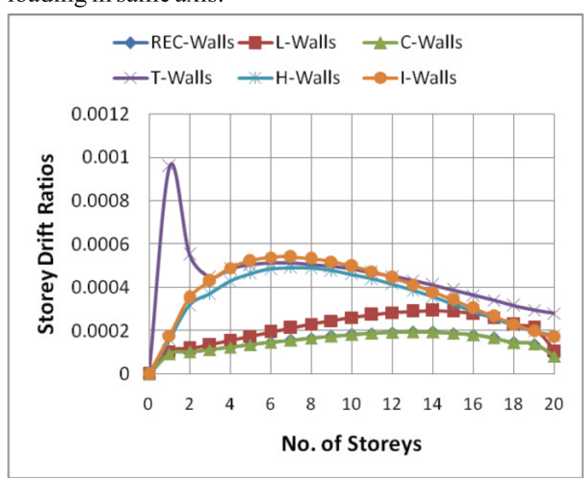

Fig. 14. Storey Drifts along Y-Axis (EQ in X-Direction)

Fig.14 shows storey drifts response along y-axis against the lateral loading in opposite x-axis. In this case, again H- shape gives the middle values almost for every floor of RC building. I-shape shear wall gives the maximum values like the previous case but for the storey drift in y-axis against lateral loading in x-axis, the C-shape shear wall gives the minimum values for all floors of RC building.

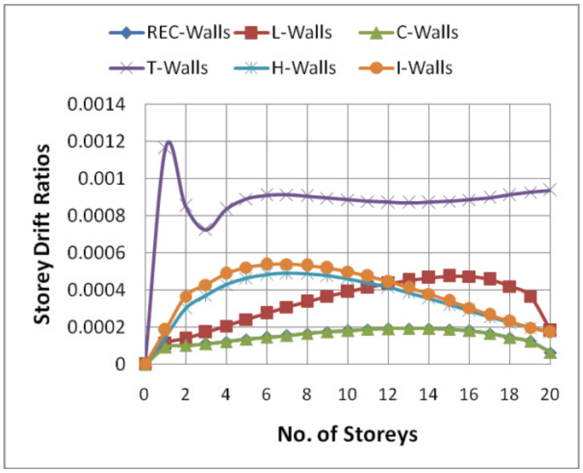

Fig. 15. Storey Drifts along X-Axis (EQ in Y-Direction)

Fig.15 shows storey drifts along x-axis due to lateral loading applied in the opposite y-axis. Like the previous two cases, in this case again H-shape shear wall gives the middle values for storey drift in y-axis for all floors. T-shape shear wall gives the maximum values and and C-shape shear wall gives the minimum values for all floors reduce as compared to the other shear wall shapes,

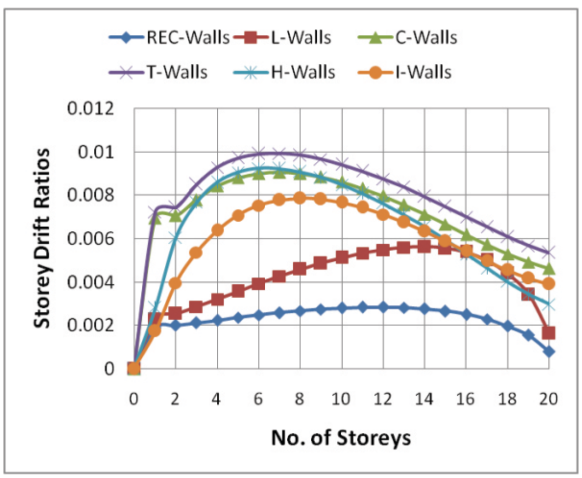

Fig. 16. Storey Drifts along Y-Axis (EQ in Y-Direction)

Fig.16 shows storey drifts along y-axis due to lateral loading applied in the same y-axis. Unlike the previous three cases, in this case H-shape shear wall gives the higher values for storey drift in y-axis for all floors. T-shape shear wall gives the maximum values and Rectangular shape shear wall gives the minimum values for all floors reduce as compared to the other shear wall shapes.

A. Storey Displacements

Since columns are extremely less stiff as compared with the stiffness of RC shear walls, therefore, they permit enlarge displacements at all floors of tall RC buildings, when compared with the displacements allowed by the shear walls. It is also proved that Rectangular and L-Shape wall restrict displacements to lower most values.

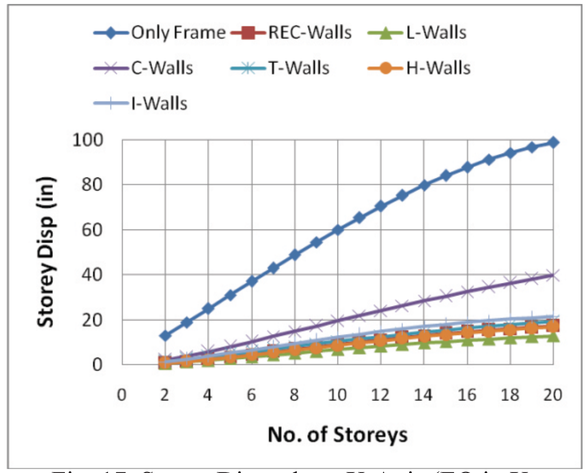

Fig. 17. Storey Disp. along X-Axis (EQ in X-Direction)

Fig.17 shows storey displacement along x-axis due to lateral loading applied in the same x-axis. The framing of RC building without any shear wall gives the maximum value for the storey displacement. All framing of RC building with any type of shear wall gives much low value, due to the stiffness of the vertical load carrying members. L-shape shear wall gives the most minimum value of storey displacement in x-axis.

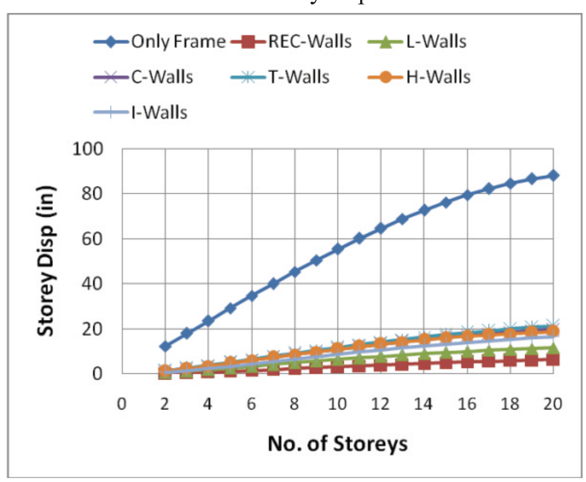

Fig. 18. Storey Disp. along Y-Axis (EQ in Y-Direction)

Same trend can be observed in fig.18, which shows storey displacement along y-axis due to lateral loading applied in the same axis. Like the previous case, building without shear wall gives the maximum value of storey displacement in y-axis as compare to the other cases. Rectangular shape shear wall gives the minimum value of storey displacement for all floors as compared to the other shear wall shapes.

A. Storey Shear

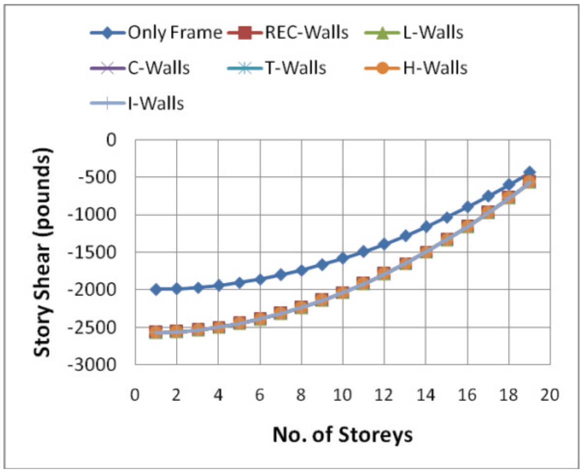

Fig. 19. Storey Shears along X&Y-Axes

As per BCP-07 formulas, base shear is mainly dependent upon the gravitational loading i.e. fixed and service dead loads. Since dead loads of columns are less than those of shear walls, they allow reduced storey shears as compared with shear walls. Also, storey shears are seen to have constant values for all shapes of shear walls due to the same x-sectional area assumed for each type of shear wall shape. Fig.19 shows the storey shear response against different shapes of shear wall in both x & y axes. The framing without any shear wall gives the less negative values as compare to the other cases.

VII. CONCLUSIONS

In this study, various shapes of shear walls i.e. Rectangular, L, T, C, H and I are incorporated in the structural farming of 20 storey tall RC building. In order to find the optimize structural framing with respect to the safest, economical and desirable shape of shear wall. Following are the conclusions of the present investigation:

1. Shear walls play an important role in reducing the enlarged seismic parameters i.e. storey drifts, storey displacements and storey shears with respect to the code specified values/limitations.
2. The higher the moment of inertia of a shear wall along a plane perpendicular to the direction of lateral loading, the higher is its tendency towards resisting seismic impacts and vice versa.
3. Rectangular and L-shaped walls are most effective in resisting seismic forces along both orthogonal directions and reduce seismic forces remarkably.
4. H-shaped and T-shaped walls show less resistance towards lateral loading.
5. Each shape of shear wall produces the same amount of storey shears in both axes (Shear force at each storey level) which clearly concludes that shape of shear wall has no impact on reduction of storey shears.
6. Since dead load of shear walls is greater than that of columns, therefore, storey shears are enlarged after inclusion of shear walls in building frame but this effect is tolerated by enlarged stiffness of shear walls as compared with columns.

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