SEISMIC ANALYSIS OF STEEL PLATE SHEAR WALL AND CONCENTRIC BRACED FRAMES

Manasa Shetty
Asst.Professor, Department of Civil Engineering, MallaReddy Engineering College (Autonomous) Maisammaguda, Dhulapally, Secunderabad, Telangana, India 500100.

M.Uday Bhaskar
Asst.Professor, Department of Civil Engineering, MallaReddy Engineering College (Autonomous) Maisammaguda, Dhulapally, Secunderabad, Telangana, India 500100.

Jugal Kishore M
Asst.Professor, Department of Civil Engineering, Kallam Harnadhareddy Institute of Technology (Autonomous), Guntur, Andhra Pradesh, India 522019

Abstract:
Steel Plate Shear Walls (SPSW) were utilized for the seismic retrofitting of various enduring structures at the initial times of advancement. Ductility is the important property of a material that is intended to be employed in the seismic localities. This characteristic of steel enabled its essentiality in the utility of Steel Plate Shear Walls in these areas. The prevalent thesis emphasizes the conduct of a framed building with steel plate shear walls and different types of bracings. This work involves the analysis of a few multi-storied structures with SPSW and bracings by employing the Codal coefficient method conforming to part 1 of Indian Standard 1893. Modeling of SPSW is done using the Strip model in the SAP 2000 (V.14) software which is the famous Finite Element Analysis software. The consequences in a structure due to the involvement of SPSW, different concentric braced frames, contrasting SPSW and X-bracing and the variation of the aspect ratio of SPSW with respect to bending moments, shearing forces, axial loads of beams and columns and story drifts are predominantly discerned in this study. SPSW structure is emerged as ideal among all the concentric braced frames and SPSW.

Keywords*: Aspect ratio, Codal coefficient method, Concentric braced frames, Steel Plate Shear Walls, Strip model, X-bracing.*
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1. INTRODUCTION

The structures made by utilizing steel exhibits greater performance to withstand the seismic loads. This performance is mainly attributable to ductility of steel. Due to this property, a forewarning is generated prior to the complete collapse of structure. In case of earthquakes, the loads are highly elevated and in order to successfully oppose these uncommon loads, the buildings must possess adequate stiffness as well as lateral strength. Also, steel members perform poorly with respect to

compression due to which these should be concocted with concrete [1]. In order to secure economic and structural gains like minimizing materials usage and speedy buildings, steel and concrete concocted buildings are also utilized [2]. The components that are employed in the buildings to oppose these loads and to show superior conduct in compression are usually shear walls and framed braces [3].

Shear walls are described as the walls similar to the building elements of vertical alignment that are exposed to lateral loadings in their planes. These shear walls include slender steel plates with beams and columns which are termed as SPSW. The mechanism and conduct of shearing

resistance of SPSW are symmetrical to vertically aligned plate girders i.e., indirect through diagonal tension. The internal opposing forces in SPSW are diagonal tension forces. Though there are few disadvantages like low flexure stiffness, numerous benefits like steady hysteretic features make the SPSW's utility effective [4]. Un-stiffened, stiffened and concocted concrete and steel are the primary sorts of SPSW. Based on the conduct of steel plates, these are again categorized in to compact and non-compact.

The yielding of the compact SPSWs occurs prior to the initiation of buckling which is comparatively thick in contrast to lean ones. The design of this type is uneconomical and the modeling is done by utilizing a complete shell element as well as isotropic substance. Non-compact SPSWs are of un-stiffened type having lean plates which buckle due to less lateral loads being virtually elastic. To withstand the external shearing forces, the resistance is furnished due to tensile field occurred diagonally. The modeling of these lean

SPSWs is done by employing either shell elements or strip modeling whereas strip modeling is utilized in this study which is more famous than the other.

The middle line of the components in frames which coincides at a joint converges at one point so that a vertical truss pattern is formed in order to withstand lateral loading system are termed as Concentrically Braced Frames (CBF) [5]. These are generally utilized for withstanding wind loads. CBFs produce ductile nature by inelastic actions of the bracings i.e., tensile yield and compressive buckle. Hence, these braces were termed as ‘fuses’ [6]. Numerous bracing patterns analyzed in the current study are diagonal bracing, X-intersected bracing, K-bracing and X-bracing.

The purpose of this study is to analyze the seismic conduct of SPSWs in which the major goals are:

1. To analyze the conduct of a framed structure in the presence and absence of SPSW.
2. To discern the effect of diverse braced systems on a framed structure.
3. To compare the SPSW and the ideal braced system obtained from above.
4. To deduce the conduct of SPSW in a framed building by changing the aspect ratio.

2. LITERATURE REVIEW

Berman and Michel [7] presented a renewed technique to analyze the SPSWs. This work involves the measuring of infill plate depth through expressions perceived by analyzing strip modeling in the plastic zone.

Alinia and Dastfan [8] studied the consequences that occurred due to beam-columns on the complete conduct of SPSWs. Outcomes discerned that flexure firmness shows null impact whereas torsion rigidity exhibits dominant impact on elastic buckling in shear and extensional firmness lightly shows its impact on the after buckling resistance.

Fariborz and Erfan [9] presented certain formulae to calculate shearing resistance taking into account the consequences of firmness as well as the resistance of the edge components of SPSW in the presence and absence of stiffening elements. This study involves analyzing the non-linear conduct of displacements by imposing a single steady load and the outcomes are contrasted with numerous existing studies.

Topkaya and Kurban [10] conducted an analysis of a particular type of SPSW having steady characteristics along with its height. 3-D linear FEAs have been utilized to derive the preliminary time spans of buildings and these have been contrasted with measures given in design parameters.

Viswanath et al. [11] analyzed seismic resistance of fortified concrete 4-storied structure retrofitted with numerous types of CSB by employing STAAD Pro.

Madhar [12] analyzed tube-shaped CBF by imposing seismic loads using FEM and depicted that structure with CBF fails at middle span plastic hinge. He deduced a fine FEM to assess the hysteretic conduct of CBFs by imposing cyclic loads.

Yipeng et al. [13] perceived the seismic conduct of repaired lean SPSW by using a single bayed 2-storied frame which is imposed with the less cyclic reverse loaded system. In this study, the frame is deteriorated and then repair is done with anchoring method which is again led to deterioration by imposing loads.

Ali [14] analyzed and designed twin shear lapped bolt systems in X-shaped CBF. In this, a hollow CBF is used which is made by the cold method and quasi-static trials are conducted by imposing a cyclic loading system on 6 X-braced samples.

Jia-Chun et al. [15] discerned the conduct of excess load bearing type SPSW by imposing cyclic loading system and produced this SPSW with yielding load which is more than 30lakh N. Here, less yielding type of steel is preferred for shearing web plate in SPSW and firmness deterioration, ductile nature and energy losing features were examined.

Alireza et al. [16] analyzed some seismic load resisted strategies that are newly made and perceived better seismic conduct. In this, the designing strategy and dynamic nonlinearity conduct of frames involving SBS were considered on 3 different storied structures positioned in 3 various types near the beam-bracing coincidence point.

3. STUDY AREA

3.1 Strip modeling

This modeling is processed in two approaches. The approach given by Thorborn involves the strips positioned at consistent angles, normally 45 degrees and Rezaii’s approach involves multiple strips positioned at multi-angles with horizontal. This technique fully depends upon the diagonal tensile field response which is produced within no time after the plate buckles. It is suggested by Canadian code, the CAN/CSA-S16-01 [17] for analyzing as well as designing the process of SPSW. While analyzing using this method, steel plates have been swapped with numerous struts in the tensile field. Figures 1 and 2 portray the strip models introduced by Thorborn and Rezaii respectively.

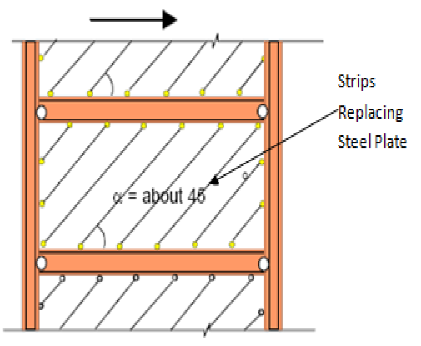

Figure 1. Thorborn’s model

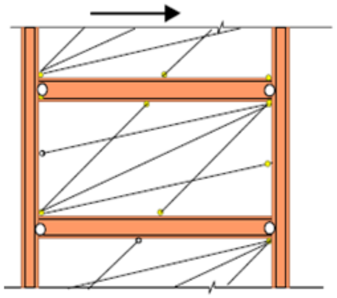

Figure 2. Rezaii's model

3.2 Mechanism of Concentrically braced systems

Imposing load from left to right on a structure with CBF results in tension in left bracing as well as compressive nature is seen in the right bracing as shown in Figure 3. Due to the conduct of CBF, buckling is observed in the right bracing whereas yielding takes place in the right bracing while beam-column is elastically stable. In the former phenomenon, compression resistance goes on reduces as it is generally non-ductile in nature while the latter one is ductile in nature.

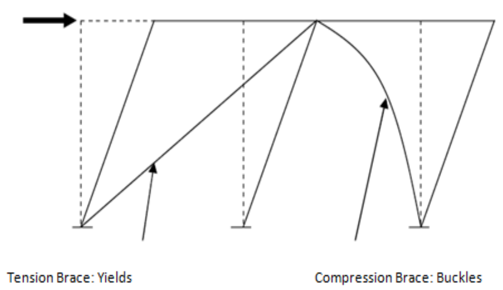

Figure 3. Mechanism of CBF loaded towards the right

Changing the course of loading i.e., right to left, tensile nature is noticed in the bracing in which compression buckling is seen earlier and yielding in tension provides ductile conduct. Meanwhile, compressive nature is noticed in which tensile yielding is seen earlier. Hence, it can be said that when a structure with CBF is exposed to seismic vulnerability, tensile yield and compressive buckle occurs alternatively in the bracings. During this cycle, beam-columns show elastic conduct. This cycle should continue for numerous loadings exhibiting braced edge connections and braced components with no faults and fractures respectively.

3.3 Codal coefficient method

Numerous analyzing methodologies are available to analyze an SPSW structure. As we modeled SPSW by employing strip modeling, the only available option to analyze SPSW structure is by Seismic Coefficient Method (SCM) which is a statically equivalent methodology. SCM follows part 1 of the Indian code 1893 [18] and the steps in the procedure are load considerations, design horizontal seismic coefficient (A_h), fundamental natural period (Ta) and distribution of design force.

4. ANALYSIS

4.1 Structure with SPSW

An analysis is carried out on a G+6 storied structure shown in Figure 4 located in zone 4 having a total height of 2250cm and floor height as 150cm in the presence and absence of SPSW of 6mm thick to estimate its conduct on beams and columns by imposing cyclic loading system.

Initially, the seismic weight of the structure for each floor is estimated and using SCM, calculated force is distributed separately for every story. Bend moments and shearing forces in beams, axial forces in columns and drift varying with the storey are estimated by entering the calculated in the SAP software.

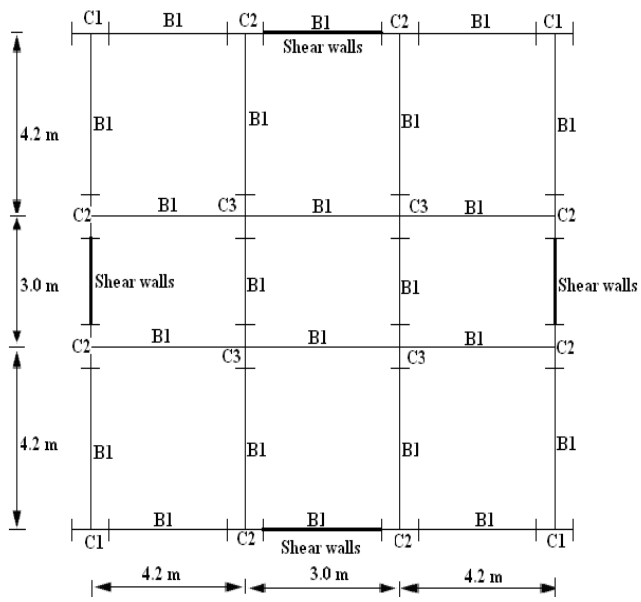

Figure 4. Plan of G+ 6 Storied Structures with SPSW

4.1.1 Bending moment in beams:

The variation of bend moments (BM) of SPSW is presented in Figure 5. Outcomes discern that for a structure with SPSW, BM is high in lower storied beams than those of higher storied ones. It is attributable to the uniform as well as reversed pull brought by vertical elements of the diagonal tensile field of SPSWs located on either side. It is also noticed that BM estimates for middle storied beams are lower than high and low storied ones. This is due to the pull exerted by SPSW which is situated solely on the top side of the ground beam as well as the lower side of the upper beam [20]. Also, the structure having no SPSW shows a very slight variation in BM.

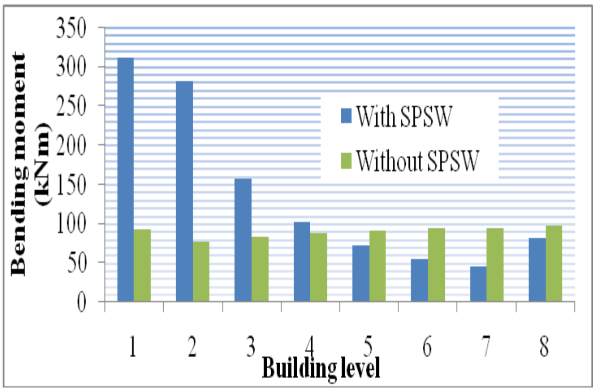

Figure 5. Bending Moment Variation in Beams

4.1.2 Shear force in beams:

Taking one beam in each building level into account, analysis is forwarded and the shearing force (SF) estimates of beams are portrayed in Figure 6. SF in beams follows a similar pattern as that of BM in a structure with SPSW. Plinth level beams have shown enormous estimates of SF due to SPSW and thus required to do anchorage effectively for footings [20]. Meanwhile, structure with the absence of SPSW shows inflation pattern initially and then deflates.

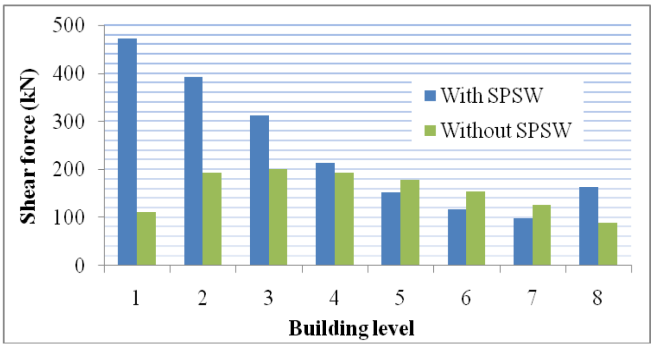

Figure 6. Shear Force Variation in Beams

4.1.3 Axial force in columns:

By taking into account one column in each floor level, axial forces on the columns are estimated in the analysis and the outturns are portrayed in Figure 7. Here, the axial force goes on deflating from lower stories to higher ones in SPSW structure as well as in structure with no SPSW. Moreover, at each level, this force is higher for SPSW structure. This is attributable to the impact of the shear wall [21].

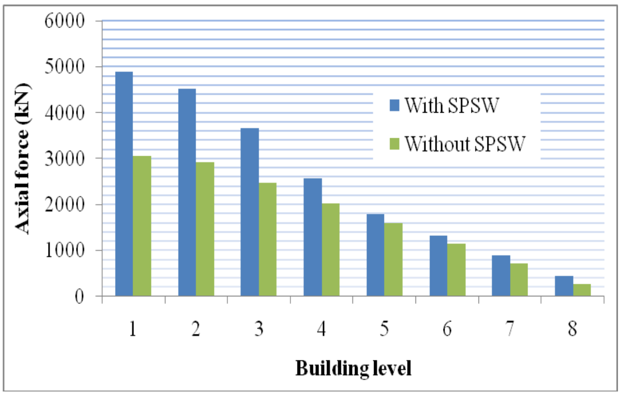

Figure 7. Axial Force Variation on Columns

4.1.4 Storey drift:

The story drift measures for all floor levels are mentioned in Figure 8. It is discerned that at ground level, drift value is the same for both SPSW and normal structure. These estimates follow the inflated trend towards higher stories for both structures and are higher for structures without SPSW. Thus, SPSW is beneficial to limit drift in stories [22].

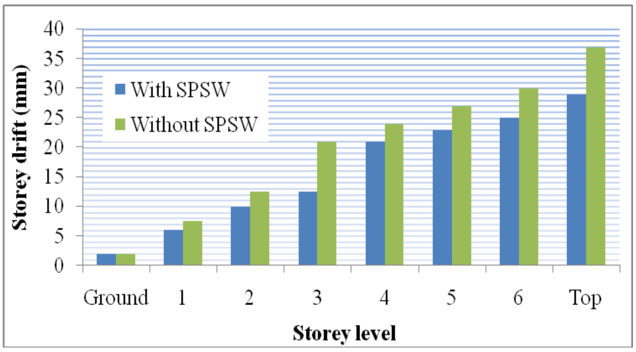

Figure 8. Storey Drift Variation

4.2 Structure with different CBFs

To observe the conduct of different CBFs, analysis is done on a G+4 storied structure of zone 4 having story height as 300cm. Contrasting numerous bracings is done mainly in terms of maximal displacements, axial forces, SF, BM in columns and displacement reduction percent.

4.2.1 Maximum lateral displacement for CBF structure:

Maximal lateral displacement estimates for diverse bracings are portrayed in Figure 9. These estimates are extremely high for a structure having no bracing because these braces use some amount of energy via inelastic distortions using the ductile nature. It is also perceived that these values are minimal for X shaped braced frame and are taken as ideal since these deflated measures manage seismic failure [23]. These displacement measures go on inflating with a rise in the building level.

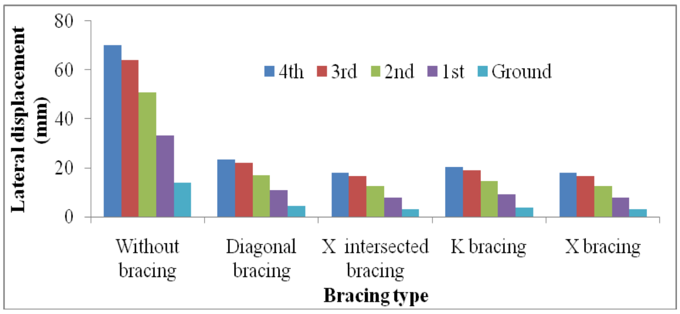

Figure 9. Lateral Displacement Variation for Diverse CBFs

4.2.2 Maximum axial forces in a column for CBF structure:

Figure 10 portrays the maximal column forces for numerous CBFs. Generally, braces inclusion in structures allows columns to handle more axial forces. It is discerned that higher story columns possess higher values. Moreover, X shaped bracing exhibits higher measures compared to all other bracings.

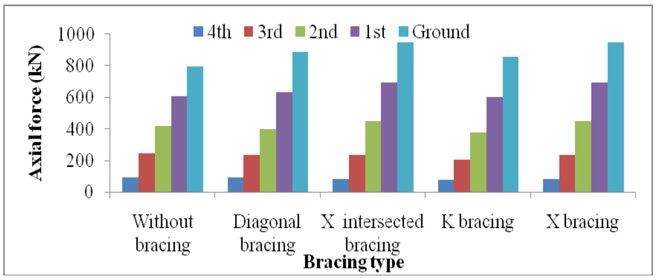

Figure 10. Maximal Axial Force in Columns with Diverse CBFS

4.2.3 Maximum shear force in a column for CBF structure:

Figure 11 portrays the maximal SF estimates for columns of CBF structure. It discerns that structure with the absence of CBF has larger SF than those with CBFs. Among diverse CBFs, X shaped bracing exhibits the least values of SF.

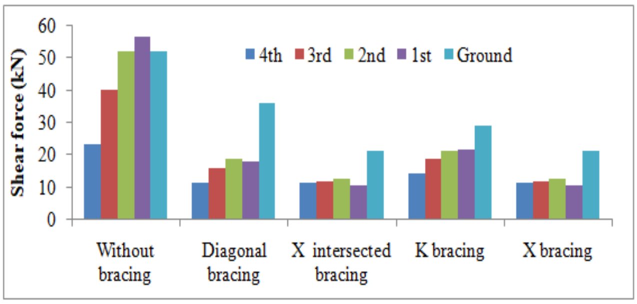

Figure 11. Maximal Shear Force in Column for diverse CBFs

4.2.4 Maximum column moment for CBF structure:

Maximal BM of columns for numerous bracings is portrayed in Figure 12.

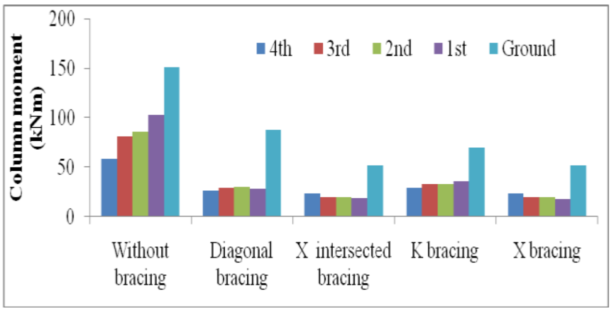

Figure 12. Maximal Column Moment for Diverse CBFs

This follows the same pattern as that of SF for CBF structure. Also, the X-brace type exhibits lower column moments in contrast with all other CBFs.

Contrasting all the bracing types, X shaped bracing exhibits ideal estimates for various parameters mentioned above and is the most preferred CBF in seismic view. Hence, a comparison is made between X-braced and SPSW structures.

5. COMPARISON OF SPSW AND X-BRACED STRUCTURE

For this analysis, the G+9 storied structure of zone 4 is chosen. 3-dimensional view of SPSW of 1.2cm thick and X braced structure is presented in Figure 13(a) and 13(b).

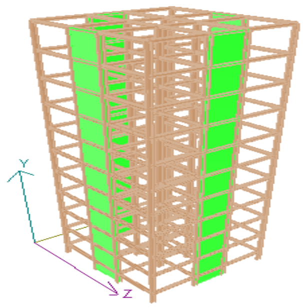

Figure 13 (a). 3D view of the structure with SPSW

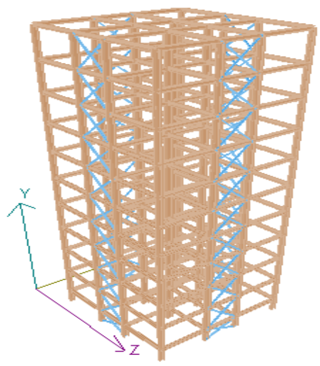

Figure 13 (b). 3D view of the structure with X-bracing

5.1 Beam bending moment and Shear force

BM and SF of beams vary in SPSW and X-braced structures and is portrayed in Figure 14 and 15 respectively. Both the structures follow a similar trend of deflating these estimates. Although SPSW structure portrays lower estimates than X shaped CBF, both the structures exhibit very minute variance in BM and SF that need not be considered when contrasted. This could be attributable to SPSW's diagonal tension which is equivalent to X-bracing's energy dissipation. G represents Ground while R means Roof.

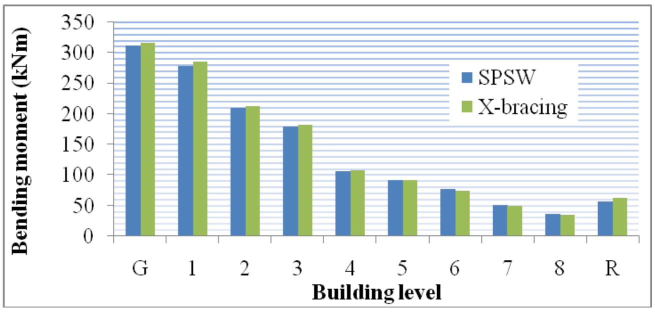

Figure 14. Beam Bending Moments in SPSW and X-Bracing

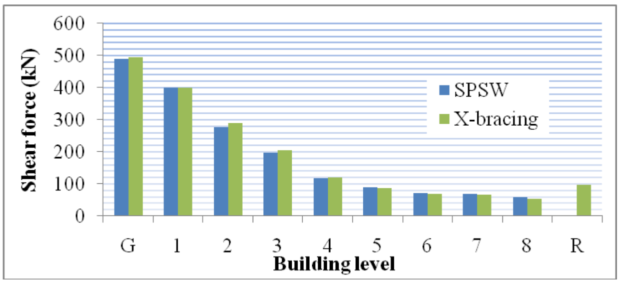

Figure 15. Beam Shear Forces in SPSW and X-Bracing

5.2 Column axial forces

Figure 16 exhibits the axial forces in columns of SPSW and X-braced structure. These force estimates follow the inverse pattern of SF and BM. The minute variance of axial forces is observed between both the structures due to which this variance can be neglected and can be said that both perform equally.

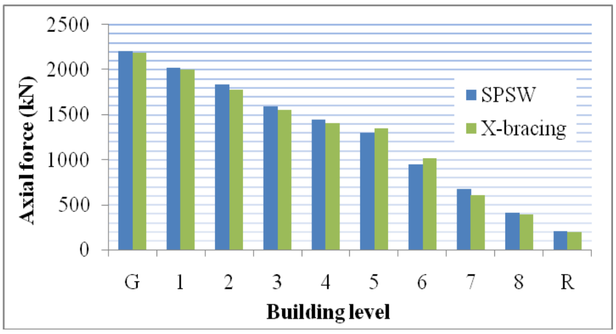

Figure 16. Column Axial Forces in SPSW and X-Bracing

5.3 Storey drift of SPSW and X-brace

Drift estimates of all the building levels of SPSW and X brace are portrayed in Figure 17.

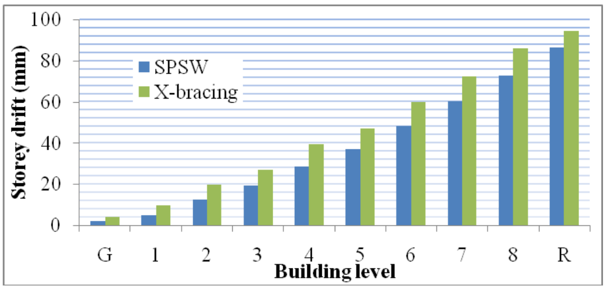

Figure 17. Storey Drift in SPSW and X-Bracing

In this, it is perceived that structure with SPSW has more low drift measures than X braced ones though X brace also procures lower drifts [24]. This means SPSW is more efficient in restricting drift in floor levels.

6. ANALYSIS OF SPSW WITH VARYING ASPECT RATIO

Altering the magnitudes of SPSW influences the conduct of the structure. Aspect ratio means the division value of width with respect to the height of SPSW. In order to analyze in this means, 4 structures having diverse aspect ratios of 0.833,1, 1.33 as well as 1.67 were considered. In this, positioning and a height of 300cm have been maintained the same whereas breadth is altered from 250-500cm with a rise of 50cm. 3-dimensional view of structure analyzing here is portrayed in Figure 18.

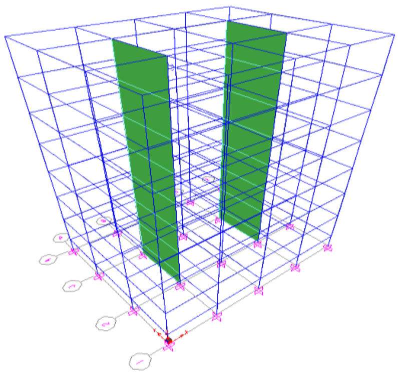

Figure 18. 3D View of SPSW Structure with Varying Aspect Ratio

6.1 Contrasting bending moments and shear forces of beams

The BM and SF estimates of SPSW having diverse aspect ratios are portrayed in Figure 19. It is perceived that both variances of BM and SF are directly proportional to the variance of aspect ratio i.e., deflates with declined aspect ratios and vice versa.

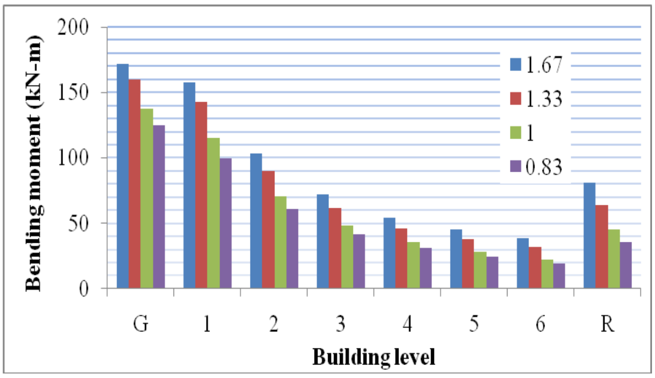

Figure 19. Bending Moment in Variance with Aspect Ratio

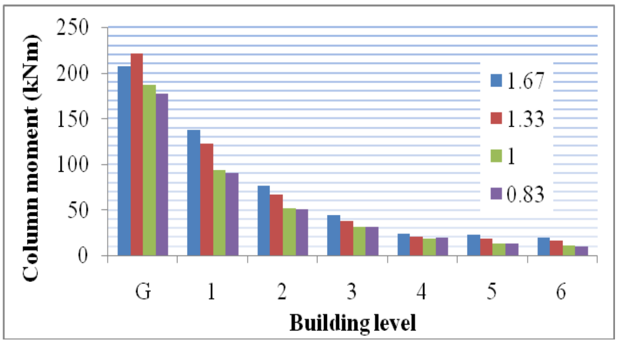

Figure 22. Column Moment in Variance with Aspect Ratio

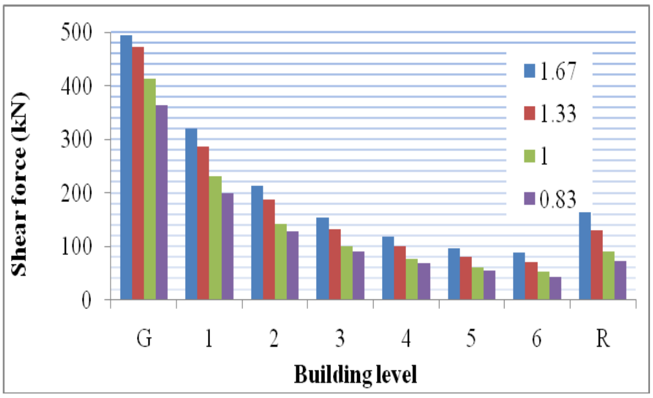

Figure 20. Shear Force in Variance with Aspect Ratio

6.2 Contrasting column forces and moments

Figures 21 and 22 exhibit the column forces and moments for SPSW in variance with aspect ratio. Outturns perceive that both the estimates incline with inflation in the aspect ratios.

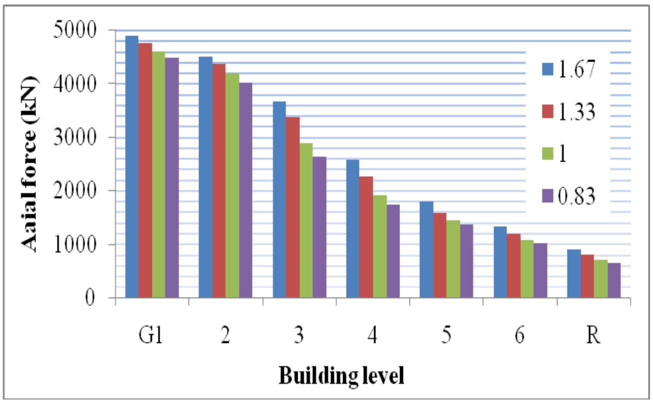

Figure 21. Column Force in Variance with Aspect Ratio

6.3 Contrasting drift in stories

The estimates of drift in all the floor levels for SPSW structure in variance with aspect ratio is portrayed in Figure 23. From this, it has been perceived that drift is direct to aspect ratio at ground level i.e., rises with inflation in aspect ratio and vice versa. Meanwhile after the bottom level, drift in stories falls down by elevating aspect ratio.

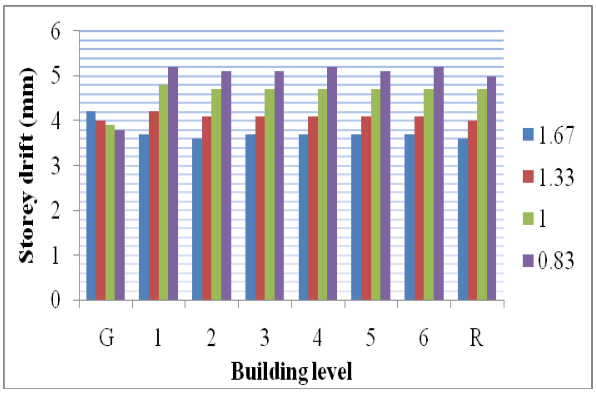

Figure 23. Storey Drift in Variance with Aspect Ratio

7. CONCLUSIONS

On the basis of the above analyses in the prevalent work, the inferences taken out are:

1. Flexure and shear requirements are excess for bottom level floors due to which efficient anchorage is essential whereas bending moment is found least for mid-stories than that of upper as well as lower ones for structures involving SPSWs.
2. Due to the involvement of SPSWs, columns become capable to manage more axial loads in low-level stories.
3. SPSWs resist the drifting of stories and these drift estimates rise with a tallness of structure.
4. Steel braces act against swaying due to which lateral displacements are low. These also minimize shearing and flexural requirements on structural components while the axial loading system acts as a medium for transferring lateral loads.

5. The decrement of displacement in percent for X-brace is excessive in contrast with diverse braced structures. X-brace allows columns to hold increased loads while limits the column moments and shear demands. On account of this, X-brace is evolved as supreme among other concentric braces.
6. SPSW possesses more efficiency than X-brace in terms of story drift whereas both exhibit very minute variance in terms of bending moments, shearing forces and axial forces in the structural components.
7. Increment in the aspect ratio of SPSW inflates the demand of beam bending moments and shearing forces and column forces and moments.
8. The higher aspect ratio of SPSWs turns down the drifting of stories while at the plinth level, this phenomenon is reversed.
9.

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