International Journal of Advanced Research Methodology in Engineering & Technology, ISSN 2456-6446
Volume 1, Issue 4, July 2017

# Experimental Investigations of Seismic Performance of Steel Plate Shear Walls on Multi-Story Frame

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***Abstract*— As population density is increasing yearly, construction of tall buildings along with proper design against the lateral load is adopted. Now day's earthquakes are frequently acquiring in the world so construction of earthquake resistant buildings is more focused. In earthquake resistant buildings shear wall play more important role than other structural elements. In recent years steel plate shear walls (SPSW) are more economical than RCC shear wall in resisting the lateral load such as earthquake loads and wind loads. In this present work Experimental investigation of "Multi-Story frame with and without steel plate shear wall" has been done and different setup of steel plate shear walls is used. The experimental model of G+2 (Aluminum model with standard dimensions) which is prepared is fixed to the shake table. The results so obtained are compared with previous dissertation works for the main parameters such as Displacement, Velocity and Accelerations and also compared the main parameters with different set of SPSW arrangements.**

***Keywords*— *Steel plate shear wall (SPSW), Displacement, Velocity, Acceleration, Aluminum material, Seismic behavior.***

## 1. EARTHQUAKE

Waves which are produced from the earth vibrations disturb the earth's surface called Earthquake. Earthquake is form of energy which neither created nor destroyed but it will be transformed from earth crust to building. It is a need of understanding the constructing, behavior of earthquake and creating earthquake safe structures where 60% of India lying under earthquake zone. In Indian standards since 1970 version of the zone map subdivided India into five zones-I, II, III, IV and V. The map has been revised again in 2002 as-II, III, IV and V here the zone I is merged in zone II. In India many earthquakes acquired with highest magnitude of 8.7 in Assam on 12th june1897 of maximum intensity of XII with deaths of 1,500 and lowest magnitude of 6 in Jabalpur on 22th may1997 of maximum intensity of VIII with deaths of 38.In Karnataka, According to IS1893 (Part1):2002 Bengaluru, Chitradurga and Mysore lying under zone II and Belgaum, Bijapur, Dharwad, Karwar and Mangalore lying under zone III.

1.1Effects of forces present in structures

Vibration of ground is completely based on earthquake. Therefore, the motion of structures always presents at the base. The roof will stay at the original position even though the base move with the vibrations. Since the columns and walls are connected to roof there is movement of roof along with the columns and walls. So, tendency to remain same in the previous position is called inertia. There is a difference between motion of roof and ground because columns and walls are flexible. When earthquake vibration occurs, there is a backward force to the building and force to roof experienced called Inertia force.

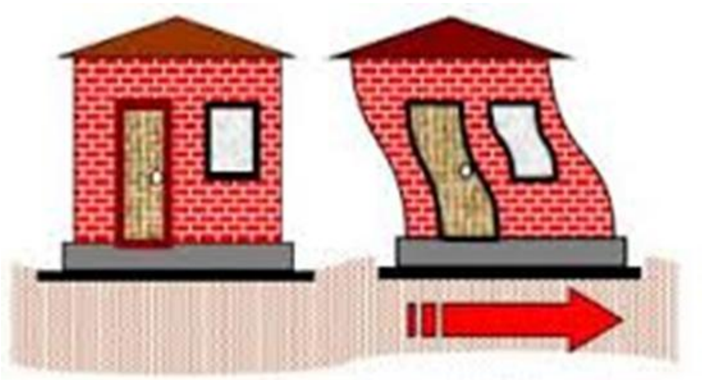

Figure 1: Effect of Inertia in a building when shaken at its base

Fig 1. The movement of building during earthquake

1.2 Horizontal and vertical shaking

The motion of ground from earthquake in 3 axis along X, Y and Z axis. As we know that horizontal motion is along X and Y axis and the vertical motion is along Z axis. Movement of building in all 3 axes is possible along front and backward motion during the time of earthquake. All buildings are designed for gravity loads which are in vertical axis of Z. This load can be added or subtracted to the structures at the time of earthquake. Design of any structures has done by including the perfect factor of safety so it will perform well against the earthquake.

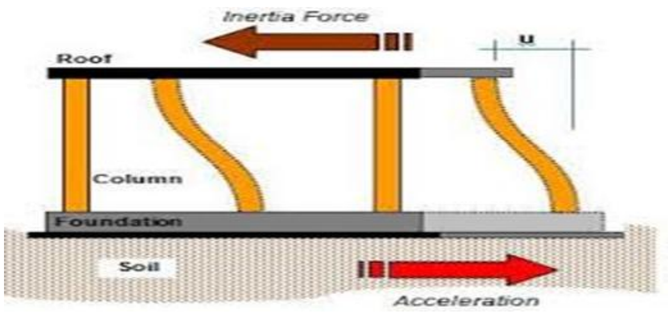


Fig 2. The movement of column in earthquake

1.3 SHEAR WALLS

It is the structural member which resists the lateral force and it is parallel to plane of wall. Where the deformation is more along bending for slender walls shear wall resists the loads due to cantilever action through that column. Thickness of the shear walls can range from 150mm to 400 mm. providing this shear walls are the best choice in the different countries like New Zealand, USA etc.

Diverse types of shear walls

1. RC Shear Wall

2. Plywood Shear Wall

3. Mid ply Shear Wall

4. RC Hollow Concrete Block Masonry Wall

5. Steel Plate Shear Wall

**2 BRIEF LITERATURE REVIEW**

**Asheena Sunny et.al (2015)**

The Authors have studied the behavior of SPSW for the replacement of conventional shear wall along with cutouts for architectural reasons, for installation of cooling system. By cutout in SPSW there is a reduction in lateral load resistance and the variation of stress distribution is also may occur. The analysis has been done by the ANSYS 14.5.One of the setup was single storey steel frame without steel infill plate and another setup with steel infill plate. The analysis is made with different shape of cutout and different size of cutout. In the Finite Element Analysis the material properties of Beam, Column and Infill plate is take as Elastic modulus 2.1X105(MPa), Yield Strength 240 (MPa) and Poisson's ratio 0.3.At the last Displacement vs time and Von-mises stress vs time graphs are drawn for with and without infill plate and they have concluded that by using steel infill plate 79% of displacement is reduced and 35% of stress is reduced. The cutouts are directly proportional to the displacement and stress. The steel plate of circular cutout is preferred than rectangular cutouts.

**Mohammed Abdul Rizwan et.al (2015)**

The Authors have described the analysis and design of steel frame building with steel plate shear wall (SPSW). In this paper G+6 story modeling made by finite element software STAAD.Pro V8i.The equivalent static analysis and response spectrum analysis is carried out and by applying parameter under zone III. The method of analysis is done by applying load combinations as in 1893(part1):2002 code. Two types of modeling have been carried out 1. Strip modeling 2. Mesh modeling. The result was found with help following parameters 1. Displacement 2.Axial force 3.Bending moment 4.maximum stresses. Comparison of result has been made with respect to these parameters. By addition of SPSW significantly reduces the displacement, bending moment, axial force and stresses as compared to building with SPSW, loading carrying capacity and stiffness of structure increases from result building with SPSW mesh frame is preferred over building with SPSW strip frame.

**B.Ramamohana Reddy et.al (2015)**

The Authors have found the solution for location of shear wall in multi-story building based on it's the elastic and elasto-plastic behaviors. This can be applied for earthquake load for building. Actual location of shear wall has been designed and this shear wall technologies is adopted to so many buildings in that one of the college building of VITS block, Deshmukhi Hyderabad city. Behaviors of building have been examined. Meanwhile they have analyzed the building by STAAD PRO Vi8 using the code of IS1893 (Part I):2002. Comparative analysis has been carried out by software and also by manual for zone II in Hyderabad. The result so obtained by the manual calculations is match with software calculations. Finally they conclude that manual design calculations are correct with location of shear wall.

**Pundkar R S et.al (2013)**

The Authors have done the analysis and design of high-rise steel building with and without steel plate shear wall (SPSW). In this paper (G+19) modeling being made with parameters of zone III. Strip modeling is made by recommended by the code of Canada the CANICSA-S16-01 and then compared with moment resisting frame (MRF), with X-braced frame. Method of analysis is done by using SAP2000V15 software code book referred is IS1893 (Part1):2002. Structural planned model with standard unit weight and loads, seismic analysis is done by response spectrum method and design of philosophy is limit state method. Result obtained compared with graph of story vs deflection (mm). Placing of shear wall in Y direction the displacement reduces, strip model as compared to X-braced frame and moment resisting frame reduce the deflection and it is referred as architectural point of view steel shear wall occupy much less space.

**3 SCOPES AND OBJECTIVE OF THE THESIS**

3.1SCOPE OF THE WORK:

Vibrations may occur in diverse ways for example vibrations from nearby quarries or bomb blasts etc. Including these, vibrations also may cause huge loss of properties and life. Therefore, it is a necessary to take precautions against the vibrations like bomb blast or quarries.

There are many methods to control the structures vibration like providing several types of dampers. In these, some of the methods can control only horizontal force and giving the more disadvantages like space to fix the dampers and initial and maintenance cost. So, providing the shear wall is the one of the best method of controlling the vibration. Therefore, in this dissertation we are adopting the Steel Plate Shear Wall(SPSW) to resist the vibrations.

From the year1980’s, they are using this system and in USA they are adopting this Steel Plate Shear Wall system since from 1994. The research work has been done based on these systems in Canada, UK and Japan by both analytically and experimentally. They have concluded that Steel Plate Shear Wall have excellent buckling strength.

Benefits of using SPSW

1. 35% reduction in seismic weight.

2. Increased floor area.

3. Project completion time can be reduced.

4. Better quality control.

5.The wall is structurally integrated by roofs/floors and other lateral wall acting across at right angles, Thereby giving the better stability for the structure in three-dimension.

**Abhishek Verman et.al (2012)**

The Authors have studied the single framed SPSW behaviours with dissimilar plate thicknesses, non-rigid and rigid framed members with moment resisting and pinned connections. They have used ANSYS software to determine deflections by pushover analysis. Relative study of shear wall for different stiffness to resist the lateral loads has done with ultimate load carrying capacity for different model has been determined. This results in the there is an increase in displacement if the load deflection curve of SPSW is smaller. The ultimate load carrying capacity carried by the pinned beam-column connections increases with increase in the plate thickness. The initial stiffness is low for the moment resisting frame of no shear plate but there is a increase in resisting the lateral load capacity.

3.2 OBJECTIVE OF PRESENT STUDY:

1. To obtain seismic response of the model with and without SPSW.

2. To determine the response of three storey symmetric shear frame model by varying amplitude and frequency.

3. To obtain the displacement, velocity and accelerations from three storey frame.

4. To obtain response of frame with SPSW in top and middle story and without in bottom storey.

5. To obtain response of frame with SPSW in top and bottom and without in middle storey.

6. To obtain response of frame with SPSW parallel to movement.

7. To obtain response of frame with SPSW perpendicular to movement.

**4 METHODOLOGY**

MATERIALS USED

4.1 Shake table equipment

The shake table is instrument which generates vibrations that will resemble the earthquake vibration. The generated vibrations are passed to the model which is fixed to shake table. In shake table the amplitude is fixed based on requirement of experiment, when 1mm amplitude is fixed, the shake table will move for 1mm distance in x direction and then come back to the original position. The frequency variation is considered from 0Hz to 25Hz in this experimental work.

Table 1 Specification of shake table

| Sl No | Properties | Details |
|---|---|---|
| 1 | Motion | Horizontal |
| 2 | Dimension | 400mmX400mm |
| 3 | Rotating table diameter | 390mm |
| 4 | Frequency control | +5% or -5% |
| 5 | Load capacity | 30kg |
| 6 | Maximum frequency | 25Hz |
| 7 | Maximum amplitude | 10mm |
| 8 | Least count | 0.05Hz |

Table 2 Properties of the experimental model

| SL.No | Properties | Details and Dimensions |
|---|---|---|
| 1 | Type | Symmetric |
| 2 | Material | Aluminum |
| 3 | Storey | 3 |
| 4 | Column dimension | 25mmX3mm |
| 5 | Slab dimension | 300mmX150mmX10mm |
| 6 | Floor to ceiling height | 385mm |

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4.2 Experimental model

The model is made by aluminum metal which resembles the conventional RCC building. The density of RCC building is 25 kg/m3, the aluminium metal density is 27 kg/m3 which is very near to RCC density. The model is made of standard dimension as mention below Table 4.2. To obtain the three mode shapes the three story model is made. The model is made as less weight and more flexible to observe the clear mode shapes. The model is assembled by nut and bolt connection. The model was fabricated in G.P.Engineering work shop and cost was 9000 rupees.

Fig 3 Experimental model

4.3 Steel plate share wall

The steel plate shear wall (SPSW) is infill wall which is laminated in building as replace of RCC shear wall. The SPSW is single panel wall which is having horizontal boundary as beam and vertical boundary as column. The SPSW is best choice than other shear wall in case of earthquake and wind force. The SPSW is fabricated in factories which show the good quality wall than RCC. Skilled labor is required for fixing of SPSW. The SPSW has excellent post buckling strength than the RCC shear wall. As per thickness plate decreases the flexible of plate increases and weight reduces which will be easy to transport.

There are three different steel plate shear walls systems.

1. Un-stiffened, thin steel plate shear walls

2. Stiffened steel plate shear walls

3. Composite concrete steel plate shear wall

Properties of steel plate shear wall

1. SPSW is stiffer than the conventional concrete shear wall.

2. SPSW sever the two main prepares one it will resist the gravity load and as well as lateral load which are created by earthquake and wind forces.

3. SPSW is single plane system which requires less maintenance cost and less time to fix to the frame.

4. SPSW will give pre-crake warning before failure

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Table 3 Properties of steel plate shear walls.

| Sl.no | Properties | Quantity | Details |
|---|---|---|---|
| 1 | Types | - | Thin steel plate shear walls |
| 2 | Front walls | 3 | 150mmX385mmX1.5mm |
| 3 | Side walls | 3 | 75mmX385mmX1.5mm |

4.4 PROCEDURE OF PROJECT WORK

Experimental procedure

The model is assembled with nut and bolts. The model is made of standard dimension which is to be fixed to shake table with nut and bolt connection. In the model the each storey is connected with accelerometer as center of mass method with help of L-shaped Iron plate as shown in the Stature 4.4. The accelerometers are connected to data acquiring system which in turn connected to system with eZ-Analysis V5.1.35 software. Circular plate operated to fix the amplitude like 1mm, 2mm and 3mm as in Stature 4.4. The various frequencies are considered 0.5Hz, 1Hz and 1.5Hz up to 13Hz continued which is operated in operating box. By keeping the frequency of 0.5 Hz the 1mm amplitude is fixed and analysis by eZ-Analysis software .From this, readings of vibrations with three sets of time which is between 0 to 3sec , 3sec to 6sec and 6sec to 9sec. The best three readings are noted. The same procedure is carried out for six sets of experiment as in below Stature (4.4 to 4.10). The data obtained from the software should be converted to Excel sheet. The Excel data input is in seism single software which gives result of acceleration, velocity and displacements vs time graph, long with maximum value of displacement, velocity and acceleration. Finally the graph is plotted.

Fig 4. The experimental setup in BMSE college

Fig 5 the model of without SPSW and intermediate open with SPSW

Fig 6 the model of adjacent open and front & rear open with SPSW

Fig 7 the model of bottom open and totally closed with SPSW

## 5 RESULTS AND DISCUSSION

By conducting the experiment 468 readings are obtained. The six set of experiment is conducted. In each set 3 amplitude sets are recorded. As mentioned above, in experiment work the excel sheet of each data are import to the seisosignal software from which the maximum values of parameters such as displacement, velocity & acceleration are obtained.

Displacement

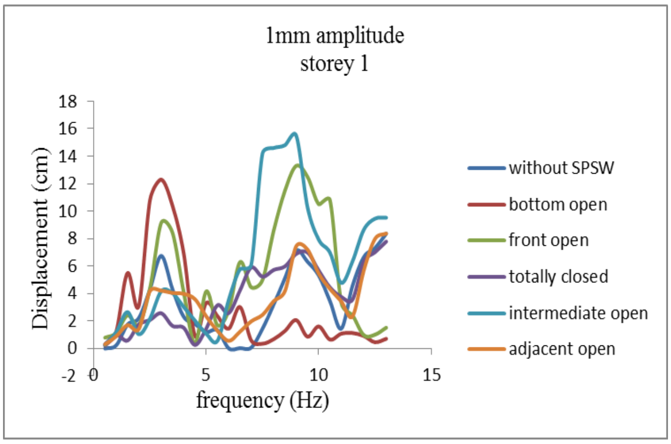


Fig 8 comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open displacement for 1mm amplitude of storey 1

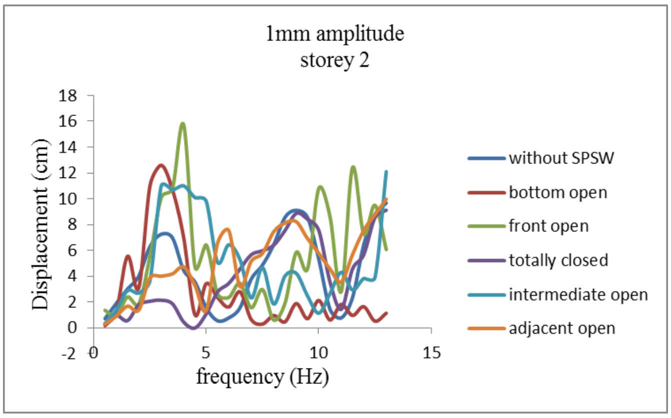


Fig 9 comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open displacement for 1mm amplitude of storey 2.

Table 4 Maximum Displacement reading of Without SPSW and totally closed SPSW for modes 1,2 & 3 of 1mm amplitude

| mode | Max. Displacement of Without SPSW(cm) | | | Max. Displacement of Totally closed SPSW(cm) | | |
|---|---|---|---|---|---|---|
| Amplitude | 1mm | 2mm | 3mm | 1mm | 2mm | 3mm |
| 1(3Hz) | 9.21 | 4.34 | 16.48 | 2.57 | 2.92 | 3.85 |
| 2(9Hz) | 10.3 | 13.5 | 15.03 | 8.99 | 8.29 | 9.7 |
| 3(13Hz) | 11.2 | 15.03 | 15.3 | 10.1 | 13.3 | 13.7 |

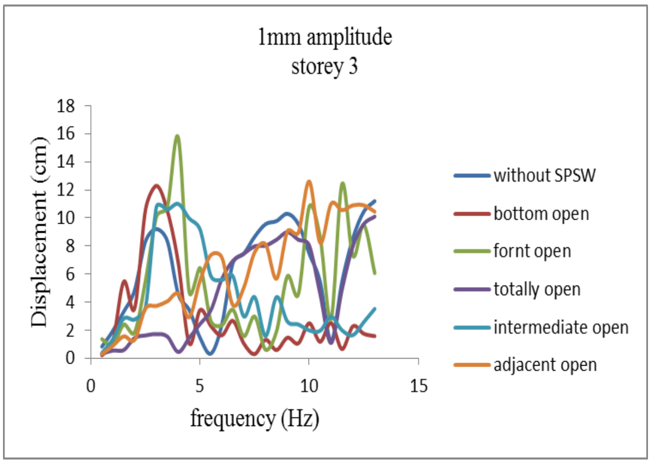


Fig 10.Comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open displacement for 1mm amplitude of storey 3

Discussion:

1. The fig 8 to 10 shows the graphs of displacement of 1mm amplitude and for the 2mm, 3mm are also shows same pattern.
2. The table 4 shows the high displacement value at 3Hz, 9Hz and 13Hz frequencies.
3. In same table 4 displacement value model of totally closed SPSW which is less displacement value at 3Hz, 9Hz and 13Hz than without SPSW out 5 setup experiment.
4. By studying all the graphs and table we can conclude that model with totally closed SPSW will reduce the displacement than other set of model and it correct method of placing SPSW.
5. The model of bottom open, front open, intermediate open give high displacement value than model with SPSW which is not resisting displacement and but adjacent model have little less displacement than without SPSW.
6. The Displacement are increasing as amplitude is increasing and the Displacement graphs is showing well pattern.

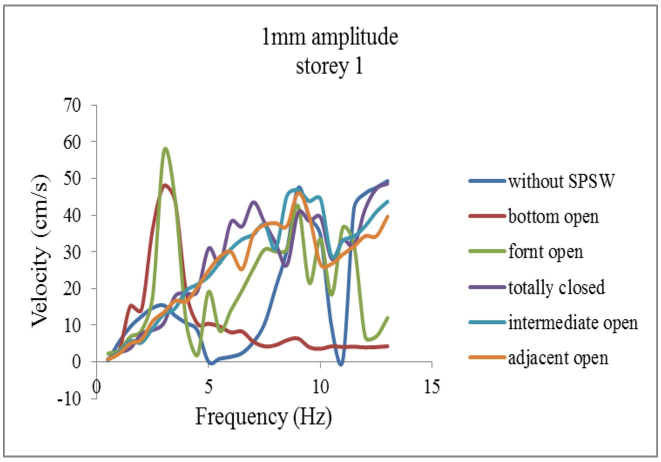


Fig 11. Comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open velocities for 1mm amplitude of storey 1

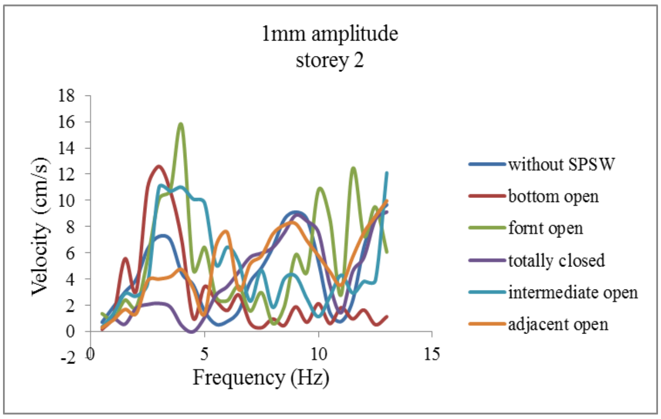


Fig 12. Comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open velocities for 1mm amplitude of storey 2

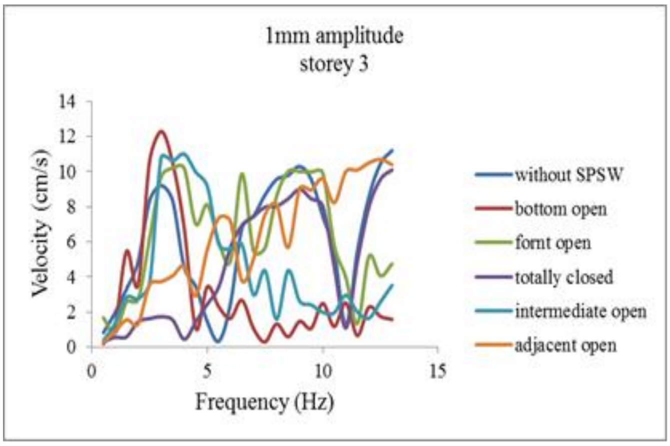


Fig 13. Comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open velocities for 1mm amplitude of storey 3

Table 5.Maximum Velocity reading of Without SPSW and totally closed SPSW for modes 1,2 & 3 of 1mm amplitude

| mode | Max. Velocity of Without SPSW(cm/s) | | | Max. Velocity of Totally closed SPSW(cm/s) | | |
|---|---|---|---|---|---|---|
| Amplitude | 1mm | 2mm | 3mm | 1mm | 2mm | 3mm |
| 1(3Hz) | 9.21 | 14.5 | 49 | 2.51 | 12.7 | 14.1 |
| 2(9Hz) | 10.3 | 53.6 | 46.8 | 8.99 | 51.8 | 37.3 |
| 3(13Hz) | 11.2 | 42.9 | 49.5 | 10.1 | 36.9 | 47.1 |

Discussion:

1. The fig 11 to 13 shows the graphs of Velocity of 1mm amplitude and for the 2mm, 3mm are also shows same pattern.

2. The table 5 shows the high Velocity value at 3Hz, 9Hz and 13Hz frequencies.

3. In same table 5 displacement value model of totally closed SPSW which is less displacement value at 3Hz, 9Hz and 13Hz than without SPSW out 5 setup experiment.

4. By studying all the graphs and table we can conclude that model with totally closed SPSW will reduce the Velocity than other set of model and it correct method of placing SPSW.

5. The model of bottom open, front open, intermediate open give high displacement value than model with SPSW which is not resisting Velocity and but adjacent model have little less Velocity than without SPSW.

6. The velocities are increasing as amplitude is increasing and the velocity graphs is showing well pattern.

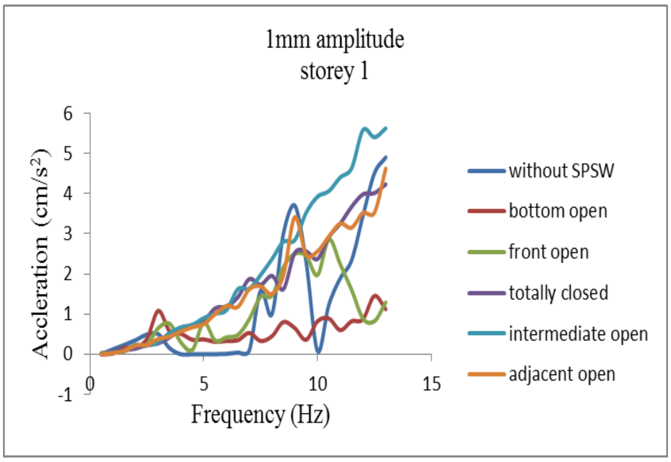


Fig 14.comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open acceleration for 1mm amplitude of storey 1

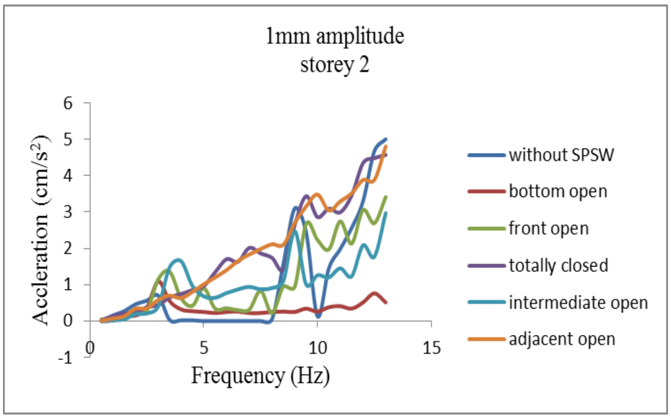


Fig 15.Comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open acceleration for 1mm amplitude of storey 2

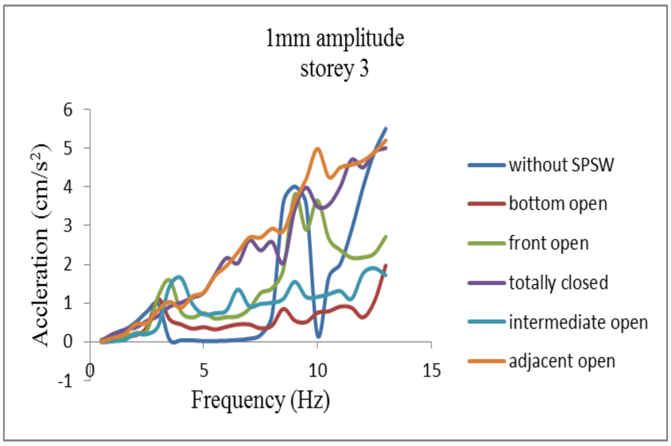


Fig 16. Comparative graph indicating without SPSW, bottom open, front open, totally closed, intermediate open and adjacent open acceleration for 1mm amplitude of storey 3

Table 6.Maximum Velocity reading of Without SPSW and totally closed SPSW for modes 1,2 & 3 of 1mm amplitude

| mode | Max. Acceleration of Without SPSW($cm/s^2$) | | | Max. Acceleration of Totally closed SPSW($cm/s^2$) | | |
|---|---|---|---|---|---|---|
| Amplitude | 1mm | 2mm | 3mm | 1mm | 2mm | 3mm |
| 1(3Hz) | 9.21 | 0.78 | 1.6 | 2.57 | 0.71 | 0.54 |
| 2(9Hz) | 10.3 | 4.07 | 2.04 | 8.99 | 2.58 | 3.86 |
| 3(13Hz) | 11.2 | 5.92 | 4.52 | 10.1 | 4.97 | 4.4 |

Discussion:

1. The fig 14 to 16 shows the graphs of Acceleration of 1mm amplitude and for the 2mm, 3mm are also shows same pattern.

2. The table 5 shows the high Acceleration value at 3Hz, 9Hz and 13Hz frequencies.

3. In same table 5 Acceleration value model of totally closed SPSW which is less displacement value at 3Hz, 9Hz and 13Hz than without SPSW out 5 setup experiment.

4. By studying all the graphs and table we can conclude that model with totally closed SPSW will reduce the Acceleration than other set of model and it correct method of placing SPSW.

5. The model of bottom open, front open, intermediate open give high Acceleration value than model with SPSW which is not resisting Velocity and but adjacent model have little less Acceleration than without SPSW.

6. The Acceleration are increasing as amplitude is increasing and the Acceleration graphs is showing increasing pattern.

## 6 CONCLUSIONS.

By studying graphs and tables of displacement, velocity and acceleration for amplitudes 1mm, 2mm and 3mm of six set model namely without SPSW, Bottom open, Front open, Totally open, Intermediate open and Adjacent open. We can conclude that

1. Without SPSW model experiment is done to gate resonant frequencies and to know the displacement, velocity and acceleration of building during earthquake. At what frequency building being damage by vibration. The 5 setup experiment

of SPSW placing in different method is conducted to reduce this damage and know good placing SPSW plates.

2. Bottom open with SPSW model experiment is giving in all the experiment results as at first mode it is giving high value and after that it will show low value. This indicates that is failing at bottom storey and the vibration are damaging building at bottom storey. So it resemble the building with bottom storey is left open for parking without any wall.

3. Front open model experiment is having SPSW at sides of building which is parallel to moment of building during earthquake. This set of model showing results very high value of displacement, velocity and acceleration in all the 3 resonant frequency which is completely damage of building in the entire three storey.

4. Totally closed model with SPSW is having plate in front, back and in both side. This set of experiment is showing reduction of displacement, velocity and acceleration at resonant frequency. This is completely reducing the vibration compared to all 5 set of experiment and this method of placing plate is correct method of placing SPSW.

5. Intermediate open with SPSW is showing results in high in some case at first and second resonant frequency and in some case at second resonant frequency. This is damage of building at second storey and sometime from first storey. This type of building resembles the office building with middle storey without wall.

6. Adjacent open with SPSW model showing good results in all three resonant frequencies. This is showing less displacement, velocity and acceleration in all the three resonant frequency. This method adaptable in some cases like in small buildings.

By studying all the each set of experiment the we can conclude that the totally closed SPSW is best method to reduce the displacement, velocity and acceleration than other methods. This is correct placing SPSW in the building.

**References.**

1. Abhishek Verman and P.R.Maiti "Push Over Analysis of Unstiffened Steel Plate Shear Wall" International Journal of Engineering Research and Development, Volume1, Issue12, July 2012

2.Pundkar R S and Alandkar P.M "Influence of Steel Plate Shear Wall on Multistory Steel Building" International Journal of Engineering Research and Applications, Vol.3, Issue4, Jul-Aug2013

3.Prashant Topalakatti and prabhu M. Kinagi, "Parametric Study of Steel Frame Building with and without steel Plate Shear Wall", Civil and Environmental Research, Vol6, No10, 2014

4. Ugale Ashish B and Raut Harshalata R, "Effect of Steel Plate Shear Wall on Behavior of Structure", International Journal of Civil Engineering Research, Vol5, No3, Jun 2014

5. Mohammed Abdul Rizwan and Tejas D Doshi "Seismic Behaviour of SPSW Steel Framed Buildings", International Research Journal of Engineering and Technology, Volume: 02, Issue: 03, June 2015

6.S.D.Ambadkar and P.S.Pajgade, "Cost Comparison of Industrial Steel Building with Steel Plate Shear Wall by Considering I-Section and Concrete Filled Section as Column Sections", International Journal of Engineering Research and General Science, Vol 3, Issue 5, Sep-Oct 2015

7. B.Ramamohana Reddy and M.Visweswara Rao, "Earth Resistant Design of a Building Using Shear Wall", International Journal and Magazine of Engineering, Technology, Management and Research, Vol 2, Issu 10, Oct 2015

8. Amrutha Rajeev, Boby Jacob and Sibin Muhamed, "Evaluation and Comparison of Behavior of Trapezoidally Corrugated Steel Plate Shear Walls", International Research Journal of Engineering and Technology, Vol-3, Iss-9, Sep-2016

9. Mohd Ozair Ullah Siddiqui and Md Mubasshir Imran, "Seismic Analysis of Steel Framed Building Including the Effect of SPSW", Imperial Journal of Interdisciplinary Research, Vol-2, Iss-11, 2016

10. Asheena Sunny and Kavitha P.E, "Study on Steel Plate Shear Wall (SPSW) with Cutout During Seismic Excitations", International Journal of Science and Research, Volume 4, Issue 8, August 2015.