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# STUDY OF BEHAVIOUR OF FLAT SLAB WITH BASE FRAME, SHEAR WALL, STEEL BRACINGS, INFILL WALL UNDER SEISMIC LOADING BY PUSH OVER ANALYSIS

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***Abstract*— Flat slabs are becoming popular now a days as they are aesthetically good in appearance and ease of construction. But they are prone to earthquake and wind forces. Lateral resisting system has to be used to increase the strength, stiffness and lateral force resistant of the structure. In the present study four different models are taken for study and those are flat slab bare frame, flat slab with shear wall, infill wall and steel bracings. They are placed in one opposite direction for study in particular direction. Response spectrum analysis are conducted on different models to study the dynamic behaviour. Based on this analysis time period, base shear, lateral displacement and storey drift is compared. Pushover analysis is also studied on different models to known the weak zones in the building. Flat slab with shear wall model is stiffer and can resist lateral force effectively.**

***Keywords*— Flat slab, infill walls, lateral resisting systems, base shear, lateral displacement, storey drift**

## I. INTRODUCTION

The India's economy is growing at much faster rate that it needs development of infrastructure facilities with increase in population. The value of land in the urban cities are increasing now a days. To cater the demand for the land the tall buildings are the only alternative in these areas. Dead loads and live loads are the most common type of gravity loads. Apart from these loads the tall buildings are also subjected to lateral forces such as wind and earthquake. Wind loads cause a severe effect on the height of the building. Earthquake loads are resulted from the movement of tectonic plates. Wind and earthquake forces would cause high stresses, and can lead to complete collapse of the building.

Using an appropriate lateral resisting structural system is too critical for good seismic performance of buildings. Moment frames are normally used as lateral load resisting structural system, other structural systems can also be commonly used like structural walls, frame walls and braced-frame system. To improve the earthquake behaviour sometimes even other structural systems like tube, tube-in tube and bundled tube systems are also used. These structural systems are used on the basis of size, loading, and other design requirements of the building. One structural system commonly used poses special challenges in ensuring good seismic performance of buildings; this is the Flat slab-column system. Flat slab is commonly used in commercial buildings. It is a modern type of structure which consists of RC slab supported by column without the provision of beams. In flat slabs monolithic casting of column and slab are done. Flat slabs are provided with drop panel and also provided with column capital to resist the shear force.

Lateral load resisting system (LLRS) such as shear walls, braced system and infill wall can be used to compensate for deficiency of capacity in the slab in flat slab buildings by reducing their overall lateral deformation and to improve their overall lateral resistance. Flat slabs can be constructed in low seismic areas without any lateral resisting system. .

## II. METHODOLOGY

- Literature survey has been carried out for Flat slab and conventional building for different lateral resisting system such as shear wall, infill wall and steel bracings.
- Modelling is done with ETABS 9.7.4 software. The different models used for study are as follows

a) Flat slab bare frame
b) Flat slab with Shear wall
c) Flat slab with Infill wall
d)Flat slab with Steel bracings

- Response spectrum0analysis is0carried out for Zone IV and using IS: 1893 (Part 1)-2002.
- The natural frequency, lateral displacement, base shear and storey drift for different models is obtained and compared
- Pushover analysis is carried out for different models and plastic hinge formation at different location is noted.
- Base shear, displacement and time period at performance point is noted.
- Based on all these results obtained conclusions are drawn.

## III. STRUCTURAL MODELLING

There are four different models considered for study and they are as follows:

A. *Types of models*

- Bare frame flat slab with drop
- Flat slab with drop panel and with shear wall
- Flat slab with drop panel and with infill wall
- Flat slab with drop panel and with steel bracings.

B. *Model Geometry*

There are five number of bays in both horizontal X-direction and vertical Y-direction and each bay is having of dimension of 6m x 6m spacing.

C. *Building height*

The height of each floor is 3.2m

*1) Material properties*

Table 1

Materials properties used for analysis

| Sl.No | PROPERTY | DETAILS |
|---|---|---|
| 1 | Concrete grade | M30 |
| 2 | Rebar grade | Fe415 |
| 3 | Density of Brick wall | 20kN/m$^3$ |
| 4 | Density of RCC | 25 kN/m$^3$ |
| 5 | Modulus of Elasticity of Concrete | 27386.1 N/mm$^2$ |
| 6 | Modulus of Elasticity of Masonry infill | 14000 N/mm$^2$ |
| 7 | Poisson's Ratio of Concrete μ | 0.17 |

*2) Properties of structural elements*

- *Size of Drop panel*

  The Flat slab dimension are taken according to IS 456:2000. Uniform top slab thickness of 2mm is provide all over the plan dimension and a drop panel of 25mm thick is provided above the column. The depth of slab above column is 45mm thick. The size of drop panel is taken to be 2.5mx2.5m. Flat slab is modelled in SAFE software and it is safe against punching shear failure.

- *Load calculations*

Four types of loads are used in analysis of structures and they are as follows:

 Dead Load (IS:875(Part I)-1987)

 Live Load (IS:875(Part II)-1987)

 Seismic Load (IS:1893(Part III)-22)

 Wind Load (IS:875 (Part III)-1987)

Dead load Self-weight of the structure is calculated by multiplying volume of the section with the density of the material.

Super-imposed dead load on slab:
Floor finishes: 1.5kN/m2
Live Load: 4 kN/m2 (IS: 875(Part 2)-1987)
Earthquake Forces
Lateral load consists of earth quake load in X and Y direction as per the IS: 1893 (Part 1)-22.
Earthquake load for the building has been calculated as per IS: 1893-22

Table 2
Data for calculation of Horizontal seismic coefficient

| Sl.No | PROPERTY | DETAILS |
|---|---|---|
| 1 | Zone (Z) | IV |
| 2 | Response Reduction Factor ( RF ) | 5 |
| 3 | Importance Factor ( I ) | 1 |
| 4 | Rock and soil site factor (SS) | 2 |
| 5 | Type of Structures | 1 |
| 6 | Damping Ratio (DM) | 0.05 |

- Load combinations

It is the responsibility of the structural engineer to design the safe and serviceable structure. To do that we have to predict the magnitude of various loads that will acting on the structure during its lifetime. We should also account for the probability of various loads acting simultaneously. Some percentage of different loads will be acting together in their lifetime to cause a serious effect on the structure

*D. Modelling in ETABS*

ETABS 9.7.4 software is used for the analysis of the building. Plan and 3D view is shown in fig

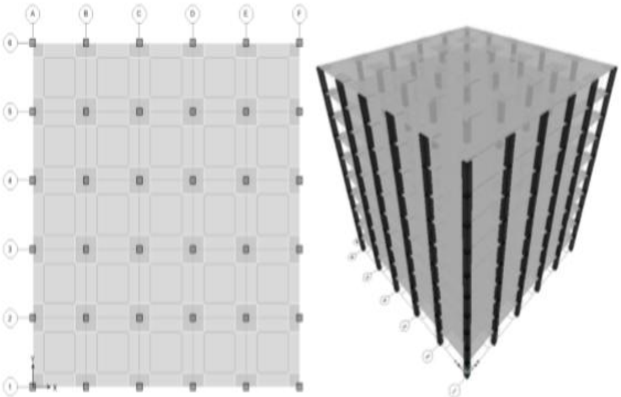

*Fig. 1 Plan and 3D view of the model.*

There are four different models used to study the response spectrum and pushover analysis. It consists of Flat slab bare frame. Another three models consist of flat slab with shear wall, infill wall and steel bracings on only two opposite sides of the building.

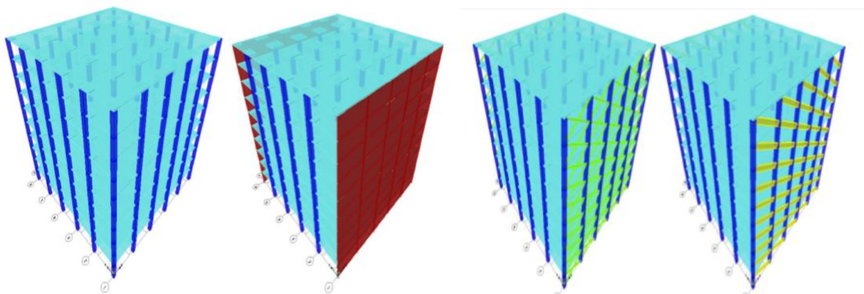

*Fig.2 Flat slab with Bare frame, Shear wall , Steel bracings , with Infill wall.*

**IV Results and discussions**

After the analysis of different model's flab slab in ETABS 9.7.4 software by response spectrum analysis the results are obtained in terms of the Time period, maximum storey displacement, Base shear and storey drift in different directions. Pushover analysis is also carried out for different models of flat slab and pushover curve is obtained. Plastic hinges formation for different models and at different locations and different types such as immediate occupancy, life safety and collapse prevention level is studied

*A. Time period:*

Table 3
Time period for different models

| Modes | Bareframe (seconds) | Shear Wall (seconds) | Infill Wall (seconds) | Steel Bracings (seconds) |
|---|---|---|---|---|
| 1 | 2.346056 | 2.264912 | 2.368197 | 2.353265 |
| 2 | 2.346056 | 0.713081 | 0.783802 | 0.750371 |
| 3 | 2.251836 | 0.388144 | 0.728967 | 0.724465 |
| 4 | 0.722219 | 0.297455 | 0.669569 | 0.636728 |
| 5 | 0.722219 | 0.254546 | 0.383197 | 0.381047 |
| 6 | 0.684044 | 0.247222 | 0.256585 | 0.245321 |
| 7 | 0.379817 | 0.171031 | 0.23586 | 0.234569 |
| 8 | 0.379817 | 0.125631 | 0.219592 | 0.208505 |
| 9 | 0.352603 | 0.097186 | 0.158683 | 0.157807 |
| 10 | 0.233803 | 0.086744 | 0.147157 | 0.140348 |

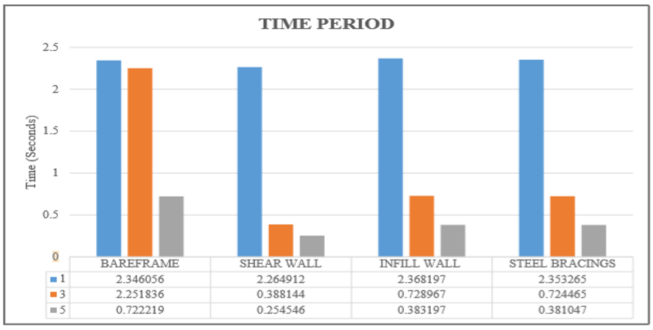


*Fig.3 Bar chart for Time period (Seconds) for Different models*

The time period of different models is shown in figure. The time period for infill wall is more as compared to other models for first mode. In case of bare frame which is symmetrically about both the axis shown small decrease in time period for next mode. For shear wall, infill wall and steel bracings which is unsymmetrically about both the axis, there is drastic decrease in time period for next modes. The time period for 1st mode are nearly close to each other for flat slab with different lateral resisting system. The time period for 3rd mode is decreased by 82.75%, 67.64% and 67.80% for flat slab with shear wall, infill and steel bracings as compared to flat slab bare frame. The time period for 5th mode is decreased by 64.82%, 46.95% and 47.22% for flat slab with shear wall, infill and steel bracings as compared to flat slab bare frame. Time period depends on the mass and stiffness of the structure. It is directly proportional to the mass and inversely proportional to the stiffness. Time period of flat slab bare frame is more as it is not stiffer. By the addition of lateral resisting system, the time period of the structure decreases as it becomes stiffer. So, for flat slab with shear wall, infill wall and steel bracings have less time period as compared to flat slab bare frame. As shear wall is stiffer than steel bracings than stiffer than infill wall, the time period is less for shear wall than less for steel bracings than less for infill wall.

*B. Base shear (kN)*

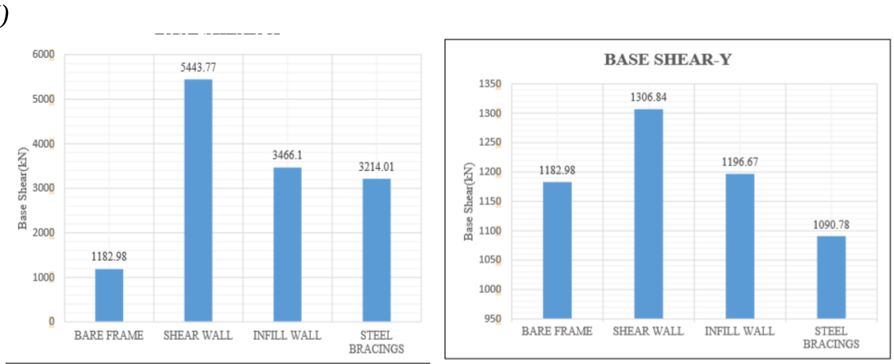


*Fig.4 Base shear (kN) in X-direction and Y direction*

The above two bar graph shows base shear for flat slab with different lateral resisting system in both X and Y direction. In case of X-direction the base shear for flat slab with shear wall, infill wall and steel bracings increased by 78.26%, 65.86% and 63.19% as compared to bare frame. In case of Y-direction the base shear for flat slab with shear wall and infill wall increased by 9.47%, 1.14% as compared to bare frame. For flat slab with steel bracings the base shear decreased by 7.77% as compared to bare frame. Base shear depends on the seismic weight of the structure. By addition of lateral resisting system the seismicweight of the structure increases. As flat slab with shear wall has more seismic weight than other lateral resisting system so the base shear is more for shear wall building. Base shear for steel bracing structure is less as compared to shear wall and infill wall which infers that steel bracing are lighter than shear wall and infill wall.

*C .Displacement (m)*

Table 4
Displacement of different models in X-direction

| Height(m) | TYPE OF MODEL X-DISPLACEMENT(m) | | | |
|---|---|---|---|---|
| | Bareframe (m) | Shear Wall (m) | Infill Wall (m) | Steel Bracings (m) |
| 32 | 0.0264 | 0.0025 | 0.0097 | 0.0084 |
| 28.8 | 0.0252 | 0.0022 | 0.0093 | 0.008 |
| 25.6 | 0.0236 | 0.002 | 0.0087 | 0.0075 |
| 22.4 | 0.0214 | 0.0017 | 0.0079 | 0.0068 |
| 19.2 | 0.0188 | 0.0014 | 0.007 | 0.006 |
| 16 | 0.0158 | 0.0012 | 0.0059 | 0.0051 |
| 12.8 | 0.0124 | 0.0009 | 0.0048 | 0.0041 |
| 9.6 | 0.0087 | 0.0006 | 0.0035 | 0.003 |
| 6.4 | 0.0049 | 0.0004 | 0.0023 | 0.0019 |
| 3.2 | 0.0016 | 0.0002 | 0.001 | 0.0008 |
| 0 | 0 | 0 | 0 | 0 |

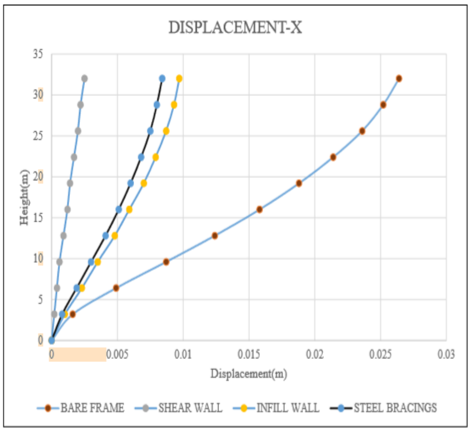


*Fig.5 Displacement of different models in X-direction.*

In case of X-direction the top lateral displacement for flat slab with shear wall, infill wall and steel bracings decreased by 90.53%, 63.25% and 68.18% as compared to flat slab bare frame.

Lateral displacement of any structure depends on the stiffness of the structure. If the structure is stiffer then lateral displacement will be less. By provision of lateral resisting system increases the stiffness of the structure. As shear wall, infill wall and steel bracings are lateral resisting system, they decrease the lateral displacement of the structure. As shear wall is stiffer than other lateral resisting system so it drastically decreases the lateral displacement.

There is no lateral resisting system in Y-direction so there is not much difference in lateral top displacement for flat slab with different lateral resisting system in case of Ydirection.

*D Storey Drift (mm)*

Table 5

Storey drift of different models in X-direction.

| Height(m) | TYPE OF MODEL X-DRIFT (m) | | | |
|---|---|---|---|---|
| | Bareframe (m) | Shear Wall (m) | Infill Wall (m) | Steel Bracings (m) |
| 32 | 0.000523 | 0.000076 | 0.000143 | 0.000127 |
| 28.8 | 0.000697 | 0.000084 | 0.000202 | 0.000177 |
| 25.6 | 0.000857 | 0.00009 | 0.000256 | 0.000223 |
| 22.4 | 0.000992 | 0.000094 | 0.000301 | 0.000261 |
| 19.2 | 0.001105 | 0.000096 | 0.000337 | 0.000292 |
| 16 | 0.001201 | 0.000094 | 0.000366 | 0.000316 |
| 12.8 | 0.00127 | 0.00009 | 0.000387 | 0.000333 |
| 9.6 | 0.001272 | 0.000082 | 0.000399 | 0.000342 |
| 6.4 | 0.001107 | 0.000071 | 0.000406 | 0.000347 |
| 3.2 | 0.00054 | 0.000052 | 0.000298 | 0.000258 |
| 0 | 0 | 0 | 0 | 0 |

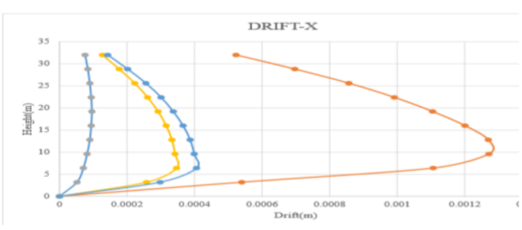


*Fig.6* Storey drift of different models in X-direction

In case of X-direction the storey drift in X-direction for flat slab with shear wall, infill wall and steel bracings decreased by 92.44%, 68% and 72.67% as compared to bare frame.

Storey drift is defined as the relative horizontal displacement of one level relative to other level which may be above or below it. The storey drift in any storey should not be more than 0.004 times the height of the building. The storey drift is more in the region from 2nd storey to 4th storey for flat slab bare frame. By addition of lateral resisting system the stiffness of the structure increases which in turn decreases storey drift. The shear wall structure is stiffer as compared to other lateral resisting system so the storey drift is least for that. The storey drift has to be limited, as the non-structural elements such as partitions, cladding and pipework's have to bear the deflections during the earthquake without damage. Here the storey drift are within the limits in both X and Y direction

Table 6

Storey drift of different models in Y-direction

| Height(m) | TYPE OF MODEL Y-DRIFT (m) | | | |
|---|---|---|---|---|
| | Bareframe (m) | Shear Wall (m) | Infill Wall (m) | Steel Bracings (m) |
| 32 | 0.000523 | 0.000437 | 0.000525 | 0.000478 |
| 28.8 | 0.000697 | 0.000622 | 0.000698 | 0.000635 |
| 25.6 | 0.000857 | 0.000788 | 0.000859 | 0.000782 |
| 22.4 | 0.000992 | 0.000922 | 0.000994 | 0.000905 |
| 19.2 | 0.001105 | 0.001034 | 0.001109 | 0.001009 |
| 16 | 0.001201 | 0.001132 | 0.001205 | 0.001096 |
| 12.8 | 0.00127 | 0.001213 | 0.001274 | 0.001159 |
| 9.6 | 0.001272 | 0.001247 | 0.001276 | 0.001162 |
| 6.4 | 0.001107 | 0.001134 | 0.001111 | 0.001011 |
| 3.2 | 0.00054 | 0.000592 | 0.000544 | 0.000493 |
| 0 | 0 | 0 | 0 | 0 |

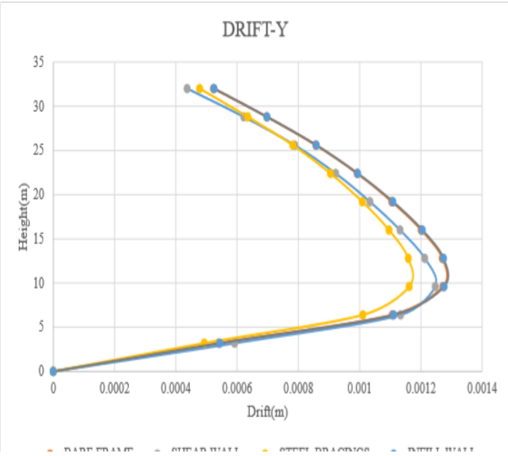


*Fig.7* Storey drift of different models in Y-direction

The storey drift in Y-direction is more in the region from 2nd storey to 4th storey for flat slab bare frame and flat slab with different lateral resisting system and they all are nearer to each other as there is no lateral resisting in Y-direction.

D. *Pushover results*

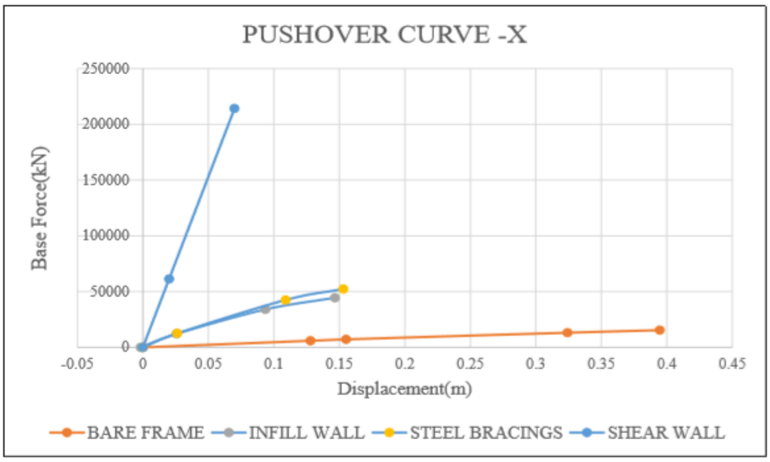


*Fig.8* Pushover curve for different models in X-direct

The figure shows the pushover curve for flat slab with different lateral resisting system in X-direction. The performance base shear value for flat slab with shear wall, infill wall and steel bracings increased by 77.62%, 65.16% and 68.21% as compared to flat slab bare frame. The displacement at performance point for flat slab with shear wall, infill wall and steel bracings decreased by 93.60%, 66.2% and 66.2% as compared to flat slab bare frame. The time period at performance point for flat slab with shear wall, infill wall and steel bracings decrease by 88.54%, 65.8% and 67.9% as compared to flat slab bare frame. With the inclusion of lateral resisting system in flat slabs, the stiffness of the structure is increased. Shear wall structure is stiffer than other lateral resisting system. So, the base shear at performance point is more for shear wall structure. Also, the time period, lateral displacement, spectral acceleration and spectral displacement at performance point is least for shear wall structure as compared to other lateral resisting system due to its stiffness. The performance base shear value for flat slab with infill wall and flat slab with steel bracings is closure to each other as ability of resisting the load is same for both systems

E. *Comparison of performance point in Y-direction*

Table 7

Comparison of performance point in Y-direction

| Sl.No | Details | Flat slab Bare frame | Flat slab with shear wall | Flat slab with Infill wall | Flat slab with Steel bracings |
|---|---|---|---|---|---|
| 1 | Spectral acceleration(m/s$^2$) | 0.135 | 0.15 | 0.136 | 0.136 |
| 2 | Spectral displacement(m) | 0.172 | 0.169 | 0.172 | 0.173 |
| 4 | Base shear (kN) | 9437.398 | 11087.182 | 9507.243 | 9549.059 |
| 5 | Time period (seconds) | 2.234 | 2.219 | 2.234 | 2.233 |
| 6 | Displacement (m) | 0.219 | 0.213 | 0.218 | 0.220 |

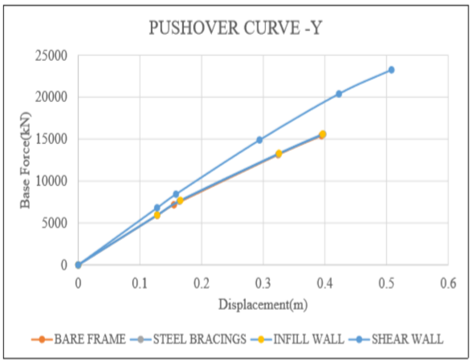


*Fig.9 Pushover curve for different models in Y-direction.*

The figure shows the pushover curve for different lateral resisting system in Y-direction. The spectral acceleration, spectral displacement, time period and displacement are nearer each other for bare frame and different lateral system at performance point as there is no lateral resisting system in that direction. The base for value for flat slab bare, flat slab with infill wall and flat slab with steel bracings are very close to each other. The shear wall has ability to increase the base shear value in Y direction. The base shear for flat slab with shear wall at performance point increase by 14.88% as compared to flat slab bare frame.

F. *Inference from the plastic hinge formation*

Table 8

Performance point for Flat Slab infill wall

| Flat Slab with Infill Wall | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Step | Displacement (m) | Base Shear (kN) | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | D-E | >E | Total |
| 1 | 0.0257 | 12147.60 | 666 | 48 | 6 | 0 | 0 | 0 | 0 | 0 | 720 |
| 2 | 0.0936 | 34072.56 | 644 | 20 | 50 | 4 | 0 | 2 | 0 | 0 | 720 |
| Performance point(Base shear, displacement) :- 27804.964kN, 0.074m | | | | | | | | | | | |

Table 9

Performance point for Flat Slab bare frame

| Flat Slab Bare Frame | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Step | Displacement (m) | Base Shear (kN) | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | D-E | >E | Total |
| 2 | 0.1552 | 7170.81 | 684 | 0 | 0 | 36 | 0 | 0 | 0 | 0 | 720 |
| 3 | 0.3243 | 13144.9 | 684 | 0 | 0 | 32 | 0 | 4 | 0 | 0 | 720 |
| Performance point(Base shear, displacement) :- 9437.398kN, 0.219m | | | | | | | | | | | |

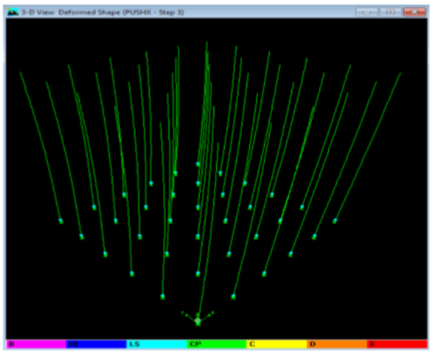

*Fig.10 Plastic hinge formation for Flat slab with bare frame at performance point*

The table shows the formation of plastic hinge at step 3. The base shear for step 3 is more than the performance base shear. The maximum number of hinges at step 3 is in range of LS-CP level. The difference in base shear value for performance base shear and step 3 is 3707kN. There is a four number of plastic hinges formation at step 3 level. As the difference between them is more, the four hinges can form at LS-CP level. The design base shear is very much less than the performance base shear. So the structure is safe.

In case of flat slab with shear wall the performance base shear is very much less than the design base shear. So all the plastic hinges are in the elastic range. The structure is very much stiff by addition of shear wall to the flat slab.

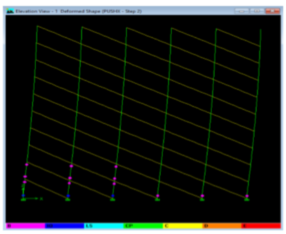

*Fig.11 Plastic hinge formation for Flat slab with Infill wall at performance point*

In table plastic hinge formation is at step 2. The maximum number of hinges at step 2 are in the range of IO-LS level. There is a difference of 6767kN base shear value between performance base shear and step 2. There are two plastic hinge formation at collapse level. The large difference in base shear value will accommodate the two-collapse plastic hinge in immediate occupancy level. As the maximum number of hinges are in immediate occupancy level the structure is safe.

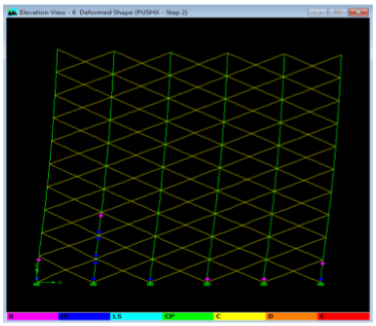

*Fig.12 Plastic hinge formation for Flat slab with steel bracings at performance point*

Table 10

Performance point for Flat Slab steel bracings

| Flat Slab with Steel Bracings | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Step | Displacement (m) | Base Shear (kN) | A-B | B-IO | IO-LS | LS-CP | CP-C | C-D | D-E | > E | Total |
| 1 | 0.0262 | 12536.13 | 670 | 34 | 16 | 0 | 0 | 0 | 0 | 0 | 720 |
| 2 | 0.109 | 42536.60 | 652 | 46 | 14 | 6 | 0 | 2 | 0 | 0 | 720 |
| Performance point(Base shear, displacement) :- 29681.55kN, 0.074m | | | | | | | | | | | |

In table, plastic hinge formation is at step 2. Due to large difference in performance base shear to base shear at step 2, the two collapse plastic hinges can form at life safety level. So, the structure is safe from collapse.

It can be concluded from the above plastic hinge formation that if the plastic hinges are in elastic range then structure is very stiff. If the plastic hinge forms in immediate occupancy level then or life safety level then with minor repairs to non-structural elements can regain the strength of the structure. And if the plastic hinge forms in collapse prevention level then major repairs can increase the strength of the structure. In case of flat slab bare frame, the plastic hinges are formed at the bottom of the structure in LS-CP level due to lateral loads. So, we have to increase the strength of the structure by adding any lateral resisting system. By the addition of shear wall to the structure, the structure strength increased drastically to high level. So there is no strengthening for flat slab with shear wall structure. By the addition of infill wall and steel bracings the plastic hinges are formed in IO-LS level. So, from this study we can say that the by addition of lateral resisting system to the flat slabs have increased the strength of the structure.

Pushover analysis of the structure helps to know the weak points in structure before construction. Based on the results obtained from the analysis we can point out the weak point and retrofit the structure.

## IV. Conclusions

1. The Seismic weight affect the base shear in the building. Flat slab with shear wall has more seismic weight so base shear is more as compared to other lateral resisting system.
2. In case of X-direction the top lateral displacement for flat slab with shear wall, infill wall and steel bracings decreased by 9.53%, 63.25% and 68.18% as compared to bare frame. The flat slab with shear wall shows very small displacement in X-direction as it is very stiff.
3. The top lateral displacement for different models in Y-direction are nearer to each other as there is no lateral resisting system in that direction.
4. Modelling of masonry infill wall as equivalent diagonal strut has increased the strength and stiffness of the structure.
5. The time period is least for flat slab with shear wall building as it is very stiff.
6. The performance base shear value for flat slab with shear wall, infill wall and steel bracings increased by 77.62%, 65.16% and 68.21% as compared to flat slab bare frame. The performance base shear is more for flat slab with shear wall in X direction as it is stiffer.
7. In case of flat slab bare frame, the maximum number of plastic hinges are in life safety- collapse prevention level. Retrofitting some elements will regain the strength and stiffness of the structure.
8. As the flat slab with shear wall in X-direction is very stiff, all the plastic hinge formation are in elastic range.
9. In case of flat slab with infill wall, the maximum hinges are in immediate occupancy-life safety level. Hence the structure is safe.

10. Hence shear wall, infill wall and steel bracings are most effective retrofitted technique or lateral resisting system for improving the seismic performance of the building.

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