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Behavior of Infilled Frame with Braced Soft Storey Using Non-linear Static Pushover Analysis

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***Abstract*— The past earthquakes in which many concrete structures are severely damaged have indicated the need for evaluating the seismic adequacy of existing buildings. Thus, the structural engineering community has developed a new generation of design and seismic procedures that incorporate performance based design of structures. The main focus of the present investigation is to evaluate the seismic performance of eccentric steel braced soft storey Infilled frames using Nonlinear Static Pushover analysis. For this purpose incremental lateral load is applied to the frame and the pushover curves are plotted which indicate the positions of capacity curve of the frame and seismic demand curve depending on magnitude of shaking. This graph can suggest the seismic performance of a system and its adequacy against the design earthquake. In this study an attempt is also made to optimize the cross section of steel section (ISMC) to be used as bracings and inclination of eccentric bracings with floors to understand the seismic capability of these frames for design basis earthquake to maximum considered earthquake for zone 5 and soil type1.Formation of plastic hinges and their transformation from elastic level to immediate occupancy level, life safety level, collapse prevention level and finally collapse level under incremental lateral load. SAP 2000(V14.2) is finite element software used to carry out the Static nonlinear Pushover analysis providing the desired information.**

***Index Terms*— Soft Storey, Seismic evaluation, masonry infill, Pushover analysis, SAP2000 (14.4.2), Lateral Displacement, Base Shear, Earthquake Analysis, IS 1893:2002 provisions.**

I. INTRODUCTION

Earthquakes are perhaps the most unpredictable and devastating of all natural disasters. The Earthquake cause not only destruction of human casualties, but also has a tremendous economic impact on the affected area. The earthquake may be defined as a wave like motion generated by a forces in constant great disorder under the surface layer of the earth, travelling through the earth’s crust. A soft storey is one in which a multi-storey building have one or more floors are open storey possessing much lower stiffness (soft) compared to the rest due to erroneous structural design. These floors can be especially dangerous during earthquakes, because they cannot withstand with the lateral forces caused by the swaying of the building during shaking. As a result, the soft storey may fail, which is known as a soft storey collapse. A soft-storey building is a structure which has more stiffness and high rigidity of upper stories and an open, flexible first storey. This design is commonly found in buildings where the first storey contains a parking of vehicles, garage or an open commercial area such as retail shopping, for stores and a large space for meeting room or a banking hall and the upper floors house offices or apartments with large number of infill’s in both directions. If all stories have approximately equal strength, the entire building would bend when earthquake begins. This will also put an additional stress on connection between the first and second storey and can cause the building to be collapse.

While the unobstructed space of the soft storey may be aesthetically or commercially desirable, it also means that there are few opportunities to install Steel bracing’s, specialized bracings which are designed to distribute lateral forces so that a building can withstand with the swaying characteristic of an earthquake. In many buildings, the ground floor or storey is designed for different uses than the upper floors or levels. Low rise residential structures may be built over a parking garage which has large doors on one side. Hotels may have tall ground floors to allow for a grand entrance or ballrooms.

1.1 Soft Storey recommendation as per Indian Earth Quake code

Indian Earthquake Code (IS 1893-2002) is based on FEMA-310. According to this code, the stiffness of a storey should not be less than 60% of the adjacent storey above or should not be less than 70% of the average stiffness of the three stories above. The Indian Earthquake Code requires a pushover analysis by referring ATC-40 for the determination of ductility demands. However, accepting that this method may not be very applicable, it suggests an amplification factor of 2.5 to be used for amplifying the member forces for the design of the soft story’s columns and beams. Alternatively, an amplification factor of 1.5 to be used for the same purpose is suggested for a symmetric shear walls are arranged in plan of such buildings.

Traditionally seismic design of a structure assumes that the lower stories of a building are stronger than the upper stories. If the lower storey is less strong than the upper storey, the structure will not resist to earthquakes in the expected fashion. When a weak storey is encountered, the lateral earthquake force exerts increased stresses, resulting in low capacity storey drift and leading to collapse of weak floor. Though such floors are mostly the bottom most storey owing to functional requirements in some structures they could even form intermediate or topmost floor. Further, one of the upper stories can be designed such that its columns are less stiff than the rest, perhaps due to architectural constraints. Failures of the entire floor which is softer than the rest called soft storey collapse is a common feature of almost all big earthquakes. Concrete and Masonry Shear walls are commonly used to increase the in-plane shear resistance of RC-framed buildings subjected to earthquake loading. Steel bracings of RC frames has recently been used or shown to a suitable alternative to the shear wall.

1.2 Modeling of infill walls:

In the case of an infill wall located in a lateral load resisting frame the stiffness and strength contribution of the infill are considered by modeling the infill as an equivalent compression strut. Because of its simplicity, several investigators have recommended the equivalent strut concept. In the present analysis, a trussed frame model is considered. This type of model does not neglect the bending moment in beams and columns. Rigid joints connect the beams and columns, but pin joints at the beam to column junctions connect the equivalent struts. The elastic in-plane stiffness of a solid unreinforced masonry infill panel prior to cracking shall be represented with an equivalent diagonal compression strut of width, a, given by Equation. The equivalent strut shall have the same thickness and modulus of elasticity as the infill panel it represents.

$$a = 0.175\,(\lambda_1 h_{col})^{-0.4}\, r_{inf}$$

Where,

$$\lambda_1 = \left[\frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fe} I_{col} h_{inf}}\right]^{\frac{1}{4}}$$

Where

h_{col} = Column height between centerlines of beams, m .

h_{inf} = Height of infill panel, m.

E_{fe} = Expected modulus of elasticity of frame material, N/mm^2.

E_{me}= Expected modulus of elasticity of infill material, N/mm^2.

I_{col} = Moment of inertia of column, m^4.

L_{inf} =Length of infill panel, m.

r_{inf} =Diagonal length of infill panel, m.

t_{inf} =Thickness of infill panel and equivalent strut, m.

□ = Angle whose tangent is the infill height-to- length aspect ratio, radians.

λ_1=Coefficient used to determine equivalent width of infill strut.

The compression struts representing infill stiffness of solid infill panels may be placed concentrically across the diagonals of the frame, effectively forming a concentrically braced frame system as show in the Fig 1.1

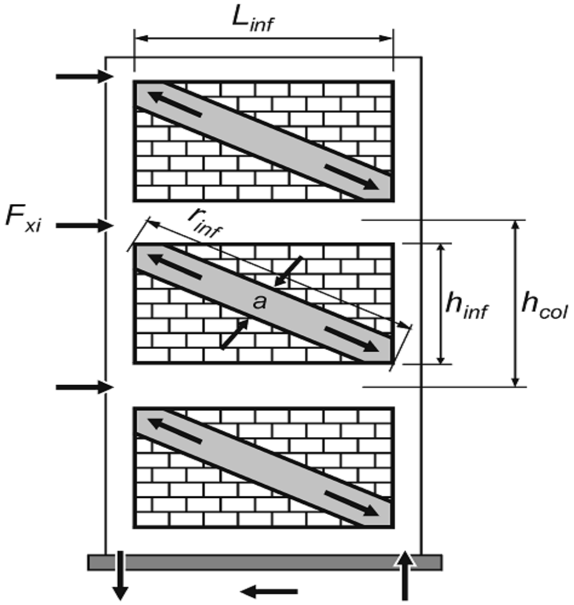


Fig 1.1: Compression Strut Analogy-Concentric struts.

1.3 **Modeling of steel bracing:**

In the present study Eccentric inverted V-bracing are modeled as steel bracing element for pushover analysis. This type of model does not neglect the bending moment in beams and columns. Rigid joints connect the beam and Fuse, but Steel bracings connected by the pin joints to the fuse on beam and at the column base.

II. METHODOLOGY OF PRESENT WORK

The main focus of the present exploration is to estimate the seismic concert of plane infilled frames as soft storey at different floors with and without bracings by using Nonlinear Static Pushover analysis. As it is known that inclusion of soft storey in an infilled frame gives rise to higher magnitude of forces in other structural members and that may initiate earlier collapse of structure, the eccentric steel bracings are adopted to replace the masonry that is absent in the soft storey to study its feasibility in mitigating soft storey behavior.

The feasible utility of eccentric steel bracings at location of soft storey will avoid obstructions in the functional requirement. The objective is to understand the non-linear behavior of Infilled reinforced concrete frames such as solid Infilled frames, Bare frame, soft storey frames and braced soft storey frames of four bay G+11 storey as total 26 types of frame models with location of soft storey at different floors and bays. These frame models subjected to earthquake loadings of much higher magnitude that takes the structural frame to a level beyond the elastic limit and even up to collapse stage. For this purpose incremental lateral load is applied to the frame and the pushover curves are plotted which indicate the positions of capacity curve of the frame and seismic demand curve depending on magnitude of shaking. This graph can suggest the seismic performance of a system and its adequacy against the design earthquake. In this study an attempt is to optimize the cross section of steel section (ISMC) to be used as bracings and inclination of eccentric bracings with floors (Which allows more space for movement of car parking in ground floor as soft storey) and to understand the seismic capability of these frames for design basis earthquake to maximum considered earthquake for earthquake zone 5 and soil type1. Capacity-demand spectrums are plotted for all 26 frame models of four bay G+ 11 storeys. Formation of plastic hinges and their transformation from elastic level to immediate occupancy level, life safety level, collapse prevention level and finally collapse level under incremental lateral load. In the process the study publicized the importance of various parameters in pushover analysis such as effects of $C_{A,}$ C_V importance of performance point in pushover curve, base shear carried by system, amount of ductility experienced, etc., SAP 2000(V14.2), finite element software is used to carried out the Nonlinear Static Pushover analysis providing the desired information.

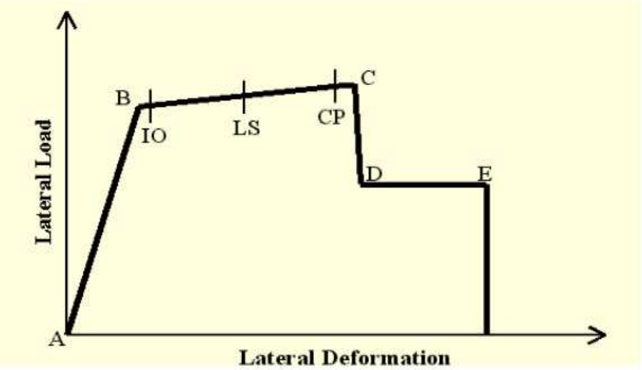


Fig 1.2: Properties and Acceptance Criteria for Pushover Hinges

III. DESIGN AND ANALYSIS OF INFILL

A typical G+11 storey multi-storey residential building, with four bays in longitudinal as well as in transverse direction is considered as shown in Fig 2. The grade of concrete used for column is $M_{30,}$ for Beams & Slabs M_{25} and that of steel i.e. for main bars Fe500 & for rebar's Fe415. As per IS 456: 2000, the modulus of elasticity is taken as $5000(f_{ck})^{0.5}$. The unit weight of concrete and Poisson's ratio are taken as 25 KN/m^3 and 0.2 respectively. For masonry E_{mf} is taken as $550f_m$, where f_m is characteristics strength of brick infill taken as 4.0 N/mm^2. Floor and roof slab is taken as 150mm thick. The wall thickness is taken as 230mm. the live load on roof and floors are taken as 1.5 KN/m^2 and 3.0 KN/m^2 respectively. Sizes of Beam are 200x600 mm and that of Column 400x400 mm. The building is located in zone v, soil type is hard, damping coefficient is 5% and the building is OMRF.

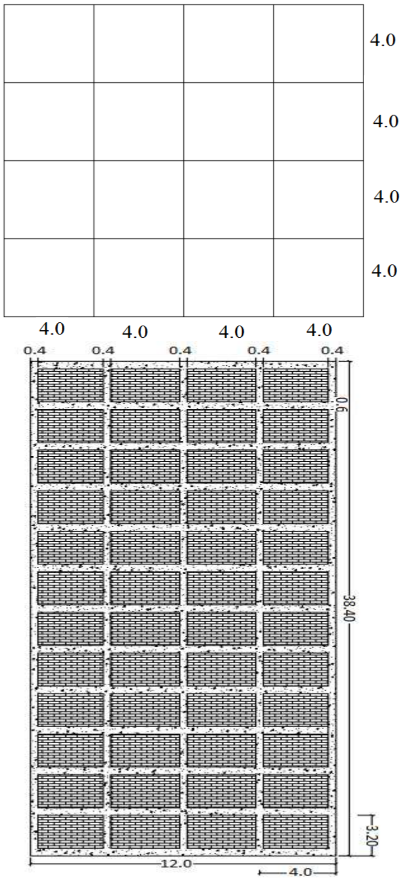


Fig 2.1: Elevation and Plan of Solid Infilled Frame

Various types of models as shown in Fig 2.2, 2.3, 2.4, 2.5, 2.6 & 2.7.

a) Model-1 Building with Bare Frame
b) Model-II Building with Solid Infilled Frame
c) Model-III Building with Soft Storey @ Ground Floor
d) Model-IV Building with Soft Storey @ Ground Floor with Bracings
e) Model-V Building with Soft Storey @ First Floor
f) Model-VI Building with Soft Storey @ First Floor with Bracings

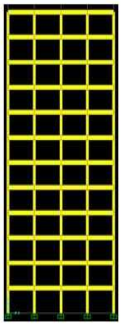


Fig 2.2: Bare frame (BF)

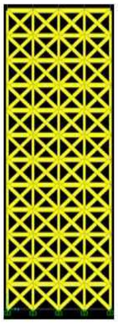


Fig 2.3: Solid Infilled frame (IF)

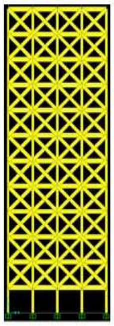


Fig 2.4: Model-III

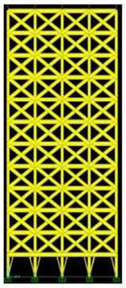


Fig 2.5: Model-IV

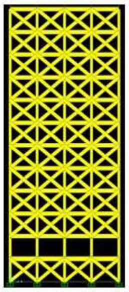


Fig 2.6: Model-V

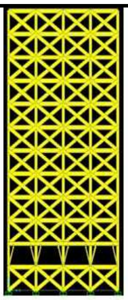
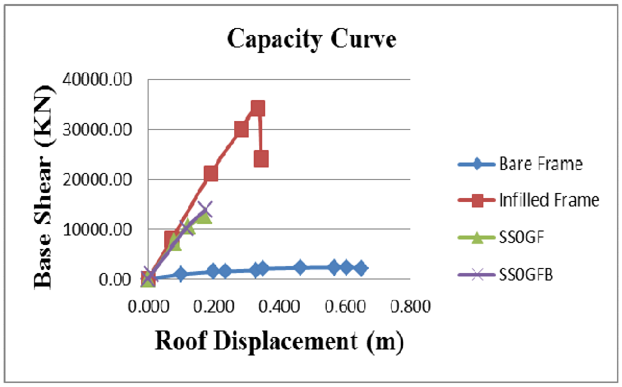


Fig 2.7: Model-VI

IV. RESULTS & DISCUSSION

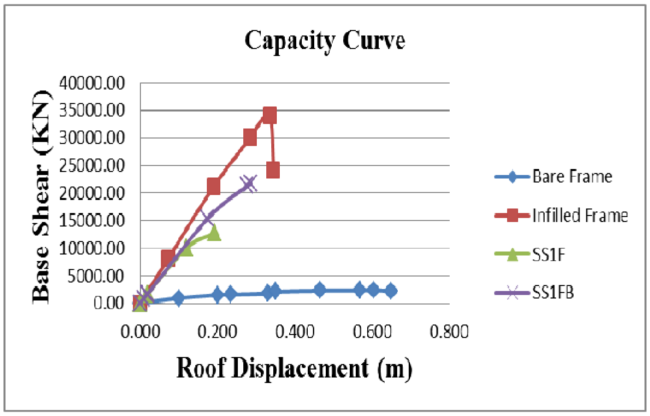
Behavior of soft story with and without bracings

Graph 1: Capacity curves of G+11 Storey Four Bay Frame With and Without Bracings in soft storey at GF compared with Solid Infilled frame and bare frame



Graph 1.

Graph 2: Capacity curves of G+11 storey four bay frame with and without bracings in soft storey at first floor compared with Solid Infilled frame and bare frame



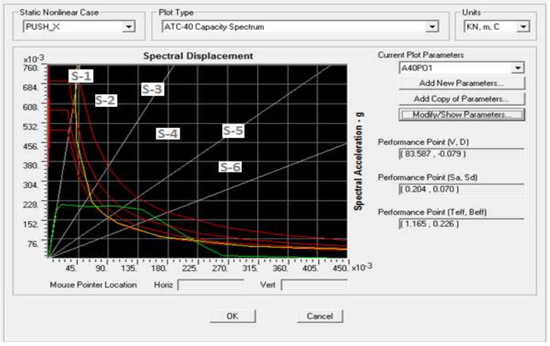
Graph 2.

Following observations can be made from these above graphs (1 to 2)

1. Ultimate base shear of solid infilled frame is found to be almost 14 times as that of bare frame (Ratio R1=13.97) and Roof displacement is reduced to half that of bare frame (Ratio R1=0.55) proving the efficiency of infilled frame in with standing lateral forces for four bay G+11 storey infilled frame models considered.
2. Occurrence of soft story in an Infilled frame (refer to here as soft story frame) in any floor generally reduces its capacity (base shear).
3. The reduction in capacity depends on the location of soft storey i.e. absence of total masonry is considered in which floor.
4. The most critical location of soft storey is found to be at ground floor which reduces the capacity to almost that of bare frame.
5. The capacity of soft storey frame improves gradually as soft storey location shifts from ground floor to 1st floor, 1st floor to 2nd floor, 2nd floor to 3rd floor, 3rd floor to 4th floor, etc.,
6. Soft story at eleventh floor hardly affects the capacity of infilled frames.
7. When the bracing is provided for offsetting the soft storey action at ground floor and 1st floor the ultimate base shear (Ratio R2=1.09 & 1.19) and roof displacement (Ratio R2=1.0 & 0.90) showed improved results than that of corresponding soft storey frame models considered.

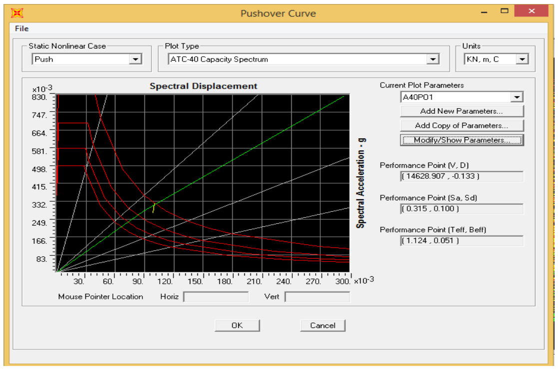
Capacity Demand spectrums of G+11 storey four bay Bare Frame and Solid Infilled frames

It is seen from pushover curve for Model-I & Model-II that, the performances of 4 bay G+11 storey storey frames of soft storey at ground floor under given earthquake is that, the demand curve tends to intersect the capacity curve (i.e. point of performance) in the range of limited safety performance S-4(i.e. in between life safety level S-3 and collapse prevention level S-5) but when the same frames with soft storey at ground floor are provided with bracings and subjected to given earthquake, the demand curve tends to intersect the capacity curve (i.e. point of performance) in the range of damage control performance S-2(i.e. in between life safety level S-1 and collapse prevention level S-3). Hence due to consideration of bracings at ground floor in place of soft storey the elastic response and security margins is greatly enhanced. So margin of safety against collapse is high. The superior performance of 4 bay G+11 storey frames of soft storey at ground floor with bracings against earthquake effect is clearly depicted which is similar to that of Solid infilled frame.



Static Nonlinear Case: PUSH_X
Plot Type: ATC-40 Capacity Spectrum
Units: KN, m, C
Current Plot Parameters: A40P01
Performance Point (V, D): (83.587 , -0.079)
Performance Point (Sa, Sd): (0.204 , 0.070)
Performance Point (Teff, Beff): (1.165 , 0.226)

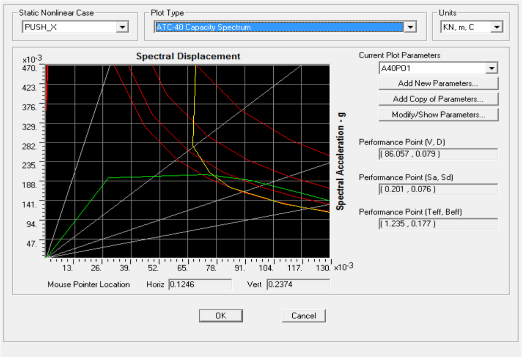
Performance Point of Bare Frame Model-I



Static Nonlinear Case: Push
Plot Type: ATC-40 Capacity Spectrum
Units: KN, m, C
Current Plot Parameters: A40P01
Performance Point (V, D): (14628.907 , -0.133)
Performance Point (Sa, Sd): (0.315 , 0.100)
Performance Point (Teff, Beff): (1.124 , 0.051)

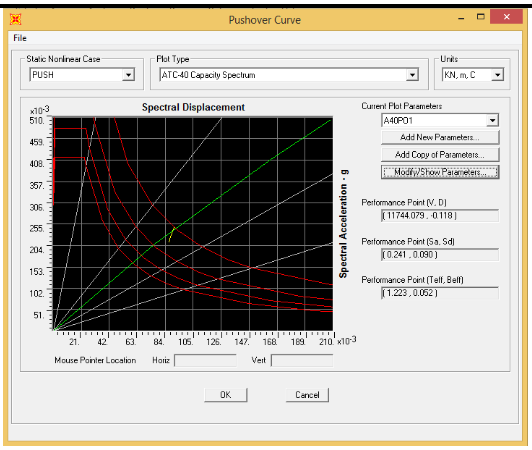
Performance Point of Solid Infilled Frame Model-II

It is seen from pushover curve for Model-III & Model-IV that, the performances of soft storey lies in the upper floors like 1st floor of 4 bay G+11 storey frames under given earthquake, the demand curve tends to intersect the capacity curve (i.e. point of performance) in the range of damage control performance S-2(i.e. in between life safety level S-1 and collapse prevention level S-3) for both cases of soft storey with and without bracings. Hence provision of bracings in place of soft storey at the upper floors of 4 bay G+11 storey frames for the consideration of better performance against earthquakes is not much beneficial (as there is not much scope of importance with reference to Capacity Demand Spectrum).



Static Nonlinear Case: PUSH_X
Plot Type: ATC-40 Capacity Spectrum
Units: KN, m, C
Current Plot Parameters: A40P01
Performance Point (V, D): (86.057 , 0.079)
Performance Point (Sa, Sd): (0.201 , 0.076)
Performance Point (Teff, Beff): (1.235 , 0.177)
Horiz: 0.1246
Vert: 0.2374

Performance Point of SSGF Model-III



Static Nonlinear Case: PUSH
Plot Type: ATC-40 Capacity Spectrum
Units: KN, m, C
Current Plot Parameters: A40P01
Performance Point (V, D): (11744.079 , -0.118)
Performance Point (Sa, Sd): (0.241 , 0.090)
Performance Point (Teff, Beff): (1.223 , 0.052)

Performance Point of SSGFB Model-IV

V. CONCLUSION

In the present investigation an attempt has been made to evaluate the performance of braced soft storey infilled frame models of 4 bay G+ 11 storeys using static pushover nonlinear analysis. The seismic analysis is carried out using the Response spectrum method in seismic zone V of India. The conclusions drawn from the present analysis are presented in this chapter. Besides, scope for future study has been listed.

Based on the study carried out fallowing conclusions are drawn.

Ultimate base shear of solid infilled frame is found to be almost 14 times as that of bare frame (Ratio R1=13.97) and Roof displacement is reduced to half that of bare frame (Ratio R1=0.55) proving the efficiency of infilled frame in with standing lateral forces for four bay G+11 storey infilled frame models considered.

Occurrence of soft story in an Infilled frame (refer to here as soft story frame) in any floor generally reduces its capacity (base shear) and the reduction in capacity depends on the location of soft storey i.e. absence of total masonry happens in which floor.

The most critical location of soft storey is found to be at ground floor which reduces the capacity to almost that of bare frame.

When the bracing is provided for offsetting the soft storey action at ground floor the resulting ratios of ultimate base shear are R2=1.09 and roof displacement are R2=1.0 this shows that Provision of bracings in place of soft storey improves Capacity to more than twice that of corresponding soft storey frame model.

Provision of bracings in place of masonry which is absent in soft storey at different locations and different patterns of stilt floor is found to improve the base shear capacity, results are tabulated below

The performances with respect to Capacity Demand Spectrum of 4 bay G+11 storey Bare frames under the given earthquake is such that, the demand curve tends to intersect the capacity curve (i.e. point of performance) in the range of Limited Safety Performance **S-4** (i.e. in between Life Safety Level **S-3** and Collapse Prevention Level **S-5**) but when corresponding Solid Infilled frames under the given earthquake are considered, the demand curve tends to intersect the capacity curve is in the range of Damage Control Performance **S-2**(i.e. in between immediate occupancy performance level **S-1** and Life Safety Level **S-3**). Hence due to presence of infill in the frame the elastic response and security margins are greatly enhanced. So margin of safety against collapse is high.

The performances with respect to Capacity Demand Spectrum of 4bay G+11 storey frames of soft storey at ground floor under given earthquake is such that, the demand curve tends to intersect the capacity curve in the range of Immediate Occupancy Performance Level **S-1** but when the same frames with soft storey at ground floor are provided with bracings and subjected to given earthquake, the demand curve tends to intersect the capacity curve in the range of Damage Control Performance **S-2**(i.e. in between **S-1** and **S-3**). Hence due to consideration of bracings at ground floor in place of soft storey the elastic response and security margins is greatly enhanced. So margin of safety against collapse is high.

The performances with respect to Capacity Demand Spectrum of soft storey at different locations of upper floor and different patterns of floor of 4 bay G+11 storey frames under given earthquake is such that, the demand curve tends to intersect the capacity curve in the range of Damage Control Performance **S-2**(i.e. in between **S-1** and **S-3**) for both cases of soft storeys with and without bracings. Hence provision of bracings in place of soft storey at the upper floors of 4bay G+11 storey frames for the consideration of better performance against earthquakes is not much beneficial (as there is not much scope for improvements with reference to Capacity Demand Spectrum).

The formation of plastic hinges for Bare frame, Solid Infilled frame and Soft storey frame models commences with column bases of lower storey, continues to beam ends and then propagates to columns and beams of upper stories. Hinges at column bases start collapsing early but all the other hinges formed are at the Life Safety level. So during earthquake columns collapse earlier than beams. This is probably due to same cross sections provided for beams and columns in the present study. However an earthquake resistant structure must have beams weaker and column stronger so as to stabilize the structure during earthquakes.

The formation of plastic hinges for braced soft storey frame models commences near the fuses in the beam then propagates to the column bases and continues to the beam ends and column bases of uppers stories. So during earthquake beams collapse earlier than columns this is a desirable behavior of an earthquake resistant structure. This type of behavior can be seen in braced soft storey frame models of present investigation.

Provision of bracings in place of masonry which is absent in soft storey at different locations and different patterns of stilt floor is found to be effective with respect to the enhancement in Base Shear Capacity, Capacity Demand Spectrum and the desirable failure mechanism resulting in earthquake resistant structures.

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