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Pushover Analysis of Building Structure

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ABSTRACT: Structures in mega urban areas are under genuine risk due to flawed and untalented outline and development of structures. Once in a while structure originators are more worried in building distinctive load safe individuals without knowing its need and its execution in the structure. Distinctive setup of development may likewise prompt huge variety in limit of a similar structure. Nonlinear static sucker investigation gives a superior view on the execution of the structures amid seismic occasions.This comprehensive research evaluates as well as compares the performances of bare, different infill percentage level, different configuration of soft storey and Shear wall consisting building structures with each other and later depending upon the findings, suggests from which level of performance shear wall should be preferred over the infill structure and will eventually help engineers to decide where generally the soft storey could be constructed in the structures. Above all a better of effects of pushover analysis could be summarized from the findings. Masonry walls are represented by equivalent strut according to pushover concerned codes. For different loading conditions, the performances of structures are evaluated with the help of performance point, base shear, top displacement, storey drift and stages of number of hinges form.

KEYWORDS: Performance, pushover analysis, infill percentage, shear wall, soft storey, equivalent strut, storeydrift

I. INTRODUCTION

In most recent couple of years the across the board harm to strengthened solid working amid tremor created interest for seismic assessment and retrofitting of existing working in Dhaka. Also, the greater part of our structures worked in recent decades are seismically insufficient in view of absence of mindfulness with respect to basic conduct amid tremor and hesitance to take after the code rules. Among various edge frameworks, Rigid Joint is most developed edge framework in South Asia which is otherwise called segment pillar joint casing framework. It has an impediment to develop the structure till 30 stories as it were. This edge structure is temperate to development so it winds up plainly famous among general individuals yet has a genuine harm in joint under the seismic occasions. This structure framework hold the popularity framework by segment shaft joint and amid seismic occasions those guide inclined toward split because of defective and improper plan and development. Exactness of configuration may fall due not considering infill rate and delicate story and its fluctuating design impacts which fundamentally change the execution of the casing framework. Other than that development of shear-divider may prompts over plan so an answer is required to get ideal level amid configuration stage. Infill could be specified by workmanship divider which increment the solidness of the floor and the building general. Infill may make Soft story impacts and turns into a reason for decimation. Delicate story term is utilized to demonstrate having a story a great deal less unbending than the stories above or underneath, is especially helpless to tremor harm as a result of substantial, unreinforced openings on their particular floor and in their normally RC outline structure. These openings regularly utilized as parking spots, substantial windows, far reaching anterooms and business put in private and business structures Figure 1. Without legitimate outline, such structures are substantially less ready to withstand the horizontal strengths that push a structure side to side, for example, those seismic tremors produce. Auxiliary building is consuming with progression of science, research and innovation by including distinctive new examinations, terms and parameters. A few nonlinear examinations are presently accessible which were not played out a couple of years back because of absence of learning, innovation and effortlessness. One of the mentionable nonlinear however static examination is Pushover investigation, which manages static load cases just yet consider nonlinear attributes of materials. This investigation has been produced in the course of recent years and has turned into the favored examination method for plan and seismic execution assessment purposes as the methodology are moderately basic and consider post versatile conduct. This nonlinear static examination where the parallel burdens is expanded keeping vertical burdens consistent, to keeping up a predefined dissemination design along the tallness of the working, until a fall instrument creates and this execution based approach requires a horizontal burdens versus twisting investigation. The sucker investigation is a strategy to watch the progressive harm conditions of a building. In any case, the technique includes certain approximations and disentanglements that a few measure of variety is constantly anticipated that would exist in seismic request forecast of

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sucker examination. Sucker investigation of limited component was performed by ETABS 9.7.2 where the insufficiencies of this examination are the accompanying elements.

1. The analysis considers the inelastic deformation and ductility of the members.
2. The sequence of yielding of sections in members and redistribution of loads in the building are observed.

The structural engineering profession has been using the nonlinear static procedure (NSP) or pushover analysis described in FEMA-356 and ATC-40, when pushover analysis is used carefully it provides useful information that cannot be obtained by linear static or dynamic analysis procedure.

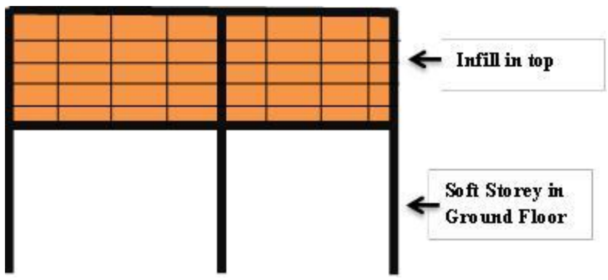

Figure 1: Formation of Soft storey in Ground Floor

This research paper is an improved and extended version of research study of previous published paper in European Academic Research of the same corresponding author.The purpose of this extended research is to investigate as well as compares the performances of bare, different infill percentage level, different configuration of soft storey and Shear wall consisting building structures with each other and later depending upon the findings, suggests from which level of performance shear wall should be preferred over the infill structure and will eventually help engineers to decide where generally the soft storey could be constructed in the structures. Force unit is KN while displacements are measured in mm.

II. METHODOLOGY

As stated before, pushover analysis is a static, nonlinear procedure in which the magnitude of the lateral force is incrementally increased, maintaining the predefined distribution pattern along the height of the building. With the increase in the magnitude of the loads, weak links and failure modes of the building are found. Pushover analysis can determine the behavior of a building, including the ultimate load and the maximum inelastic deflection. Local Nonlinear effects are modeled and the structure is pushed until a collapse mechanism gets developed. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve. It gives an idea of the maximum base shear that the structure was capable of resisting at the time of the earthquake. For regular buildings, it can also give a rough idea about the global stiffness of the building. In soft storey the displacement will be maximum in nature as they have no sufficient strength to take loads from above storey but as the soft storey is shifted bottom to top of the structure the results may be found reverse where strength will eventually increases.7 storied frame structures are simulated and checked with the help of finite element software ETABS 9.7.2 to perform the pushover analysis to meet the objectives of this study. Each and every storey is kept soft storey for different case to get the changing trend. Earth quake effect is assigned by the software which is done by UBC 94. Wind load is calculated according to Bangladesh National Building Code (BNBC) by developing an excel sheet to get point loads. Dead load and live load are taken according to standard practice among the professional designers and engineers. Standard load combinations are taken according to BNBC. To perform the pushover ATC -40 is reviewed whole through the study. All three types of hinges required for performing pushover analysis of RC structure are chosen from the experimental data and experience. Allowable hinge deformation at different performance level for beams and columns is computed and established. All three types of hinges are assigned to each element according to required type. Structure are then subjected to push over analysis which include progressive damage of elements with plastic deformation of the hinge assigned on the element of the structure as the structure is laterally pushed through. After simulation the structural response will be used to give the light on changing characteristics.

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III. DETAILS OF PUSHOVER ANALYSIS

Pushover analysis provides a wide range of application options in the seismic evaluation and retrofit of structures. Mainly two guidelines are available for this analysis- FEMA and ATC 40. This paper mainly follows the procedures of ATC 40 in evaluating the seismic performance of residential building consisting shear wall in Dhaka. Here the pushover analysis of the structure represents a static nonlinear analysis under constant vertical loads and gradually increasing lateral loads. Equivalent Static lateral loads approximately represent seismic generated forces. Analysis is carried out till to failure of the structures. This analysis identifies weakness in the structure so that appropriate retrofitting could be provided in governing element. Basically, demand and capacity are the two component of the performance based analysis and design where demand is a representation of the seismic ground motion and capacity is a representation of the structure ability to resist seismic demand. The performance is dependent in a manner that the capacity is able to handle the seismic demand. Once the capacity curve and demand displacement are defined, a performance check can be done. In our study, nonlinear static pushover analysis was used to evaluate the seismic performance of the structures. The numerical analysis was done by ETABS 9.7.2 and guidelines of ATC-40 and FEMA 356 were followed. Overall evaluation was done using base shear, deflection, storey drift, storey drift ratio and stages of number of hinges form. Plastic hypotheses was used to mark the nonlinear behavior according to which plastic deformations are lumped on plastic hinges and rest of the system shows linear elastic behavior(Li 1996). The discrete structural performance levels are- Immediate Occupancy (S-1), Life Safety (S-3), Collapse Prevention (S-5) and Not Considered (S-6)

Whereas intermediate structural performance ranges are the Damage Control Range (S-2) and the Limited Safety Range(S-4) Figure 1.This definition of performance ranges are served by FEMA 356, 2000. The model frame used in the static nonlinear pushover analysis is based on the procedures of the material, defining force – deformation criteria for the hinges used in the pushover analysis. Figure 2 describes the typical force-deformation relation proposed by those documents.

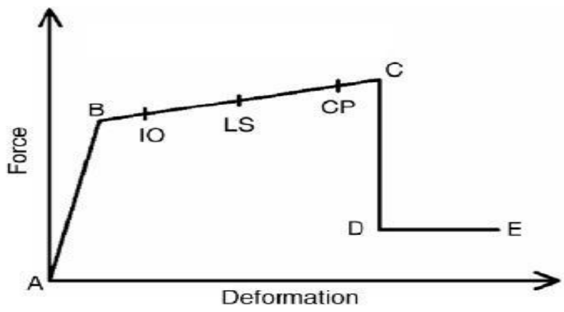

Figure 2: Force-Deformation for pushover analysis

Five points labeled A, B, C, D and E are used to define the force deflection behavior of the hinge and these points labeled A to B – Elastic state, B to IO- below immediate occupancy, IO to LS – between immediate occupancy and life safety, LS to CP- between life safety to collapse prevention, CP to C – between collapse prevention and ultimate capacity, C to D- between C and residual strength, D to E- between D and collapse >E – collapse. In ETABS 9.7.2 those points could be identified by color bands to understand how plastic hinges form in each stage Figure 3 where IO, LS and CP mean immediate occupancy, life safety and collapse prevention respectively.

Figure 3: Force-Deformation for pushover analysis

IV. DETAILS OF STRUCTURAL MODELS

For Numerical modeling, a sample RC three dimensional building is selected. The structure is seven storeys high, with a storey height of 3 meters. The bay lengths are 5m- 5m in both directions Fig. 4. In order to concentrate on the effects caused by the distribution of infill the prototype bare frame structure is regular throughout its bay length in both directions. The column sizes are 400 X 400 mm for all position and the slab thickness is 125 mm. All beams are of same size with a width of 300 mm and depth including slab thickness of 500 mm. The concrete strength is assumed

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to be 4000 psi with yield strength 60000 psi where Modulus of Elasticity (Young's Modulus) is 3600 ksi. Masonry infills were modeled as equivalent diagonal strut with width of 485 mm and thickness of 125 mm. The masonry infill has compressive strength of 1 MPa. The model is assumed to be situated in Dhaka city so according to Bangladesh National Building Code (BNBC) seismic zone 2 is taken. Assuming standard occupancy structure and exposure category A, equivalent seismic loads are determined. The geometry and material characteristics together with the fact of that the infill is in direct contact with the fact reflect common practices of Bangladesh were infilled frames are not engineered to resist the seismic event properly. Most two common form of Shear wall, found in Bangladeshis modeled to evaluate the performance of shear wall and bare frame combination with respect to infill structures. Parallel and periphery shear wall were modeled using 10 inch wall with compressive strength of 4000 psi and Modulus of Elasticity of 3600 ksi. Shear walls were modeled taking the half-length 2.5 m of each bay to resist the lateral loads only.

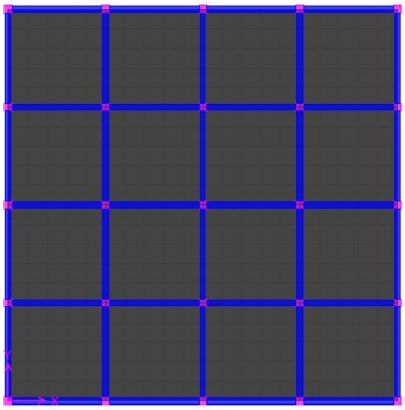

Figure 4. Typical Plan of the example building taken for this study

Moment hinges (M3) were assigned to both ends of beams and axial hinges (P-M-M) were assigned to the column ends. Geometric non linearity (P-Δ) and large displacement is considered with full dead load and when local hinges fail redistribution of loads is allowed by unloading whole structure. The gravity loads used included self-weight of the members and loads of floor finish and live loads were applied to BNBC. All partition walls were assumed to be located directly on beams. The performance points marked by collapse and representing ultimate displacement capacity of the structure were evaluated at each step of the analysis according to guidelines of ATC-40 and FEMA 356.

V. METHOD OF REPLACEMENT OF INFILL

The approaches presented by Paulay and Pristlay (1992) and Angel et al.(1994), and later adopted by R. Shahrin & T.R. Hossain (2011) lead to a simplification in the infilled frame analysis by replacing the masonry infill with an equivalent compressive masonry strut as shown in Figure 5-(a).

$\lambda 1H = = H [(E_m t \sin 2\theta) / (4 E_c I_{col} h_w)]$ ¼ …… (1)

where t is the thickness of masonry wall. Main stone (1971) considers the relative infill-to-frame flexibility in the evaluation of the equivalent strut width of the panel as shown in Eq 2

$a = 0.175D (\lambda 1H)-0.4$ ……… (2)

If there are opening present, existing infill damage, and/or FRP overlay, however, the equivalent strut must be modified using

$A_{mod} = a (R1)i(R2)i \zeta 1$ ……….(3)

Where,

(R1)i= reduction factor for in-plane evaluation due to presence of openings

(R2)i= reduction factor for in-plane evaluation due to existing infill damage

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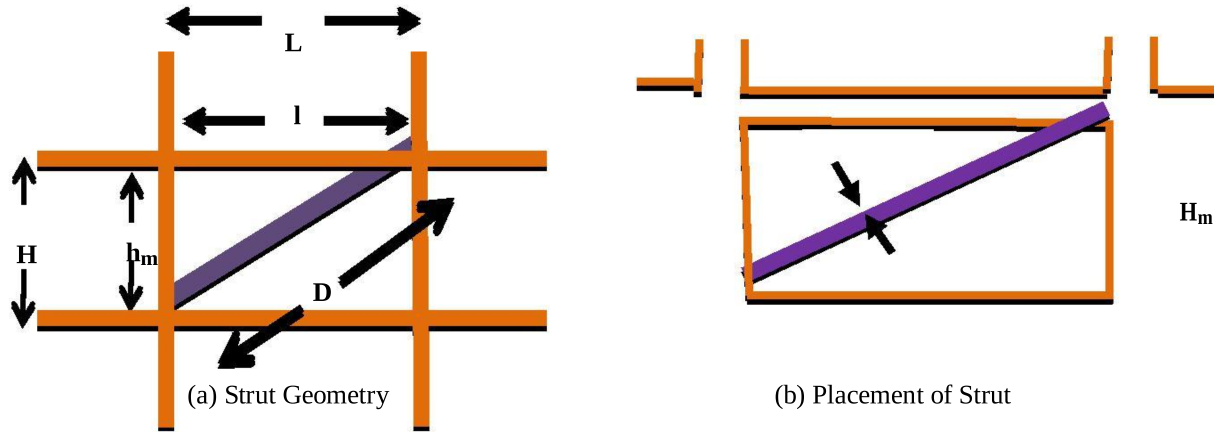


(a) Strut Geometry (b) Placement of Strut

Figure 5: (a) Strut Geometry (b) Placement of Strut

Credit: R. Shahrin & T.R. Hossain (2011)

$\zeta 1$= strength increase factor due to presence of FRP overlay

Although the expression for equivalent strut width given by Eq 4 was derived to represent the elastic stiffness of an infill panel, this document extended its use to determine the ultimate capacity of in filled structures. The strut was assigned strength parameter consistent with the properties of the infill it represents. A nonlinear static procedure commonly referred to as pushover analysis, was used to determine the capacity of the infilled structure. The equivalent masonry strut is to be connected to the frame members as depicted in Figure 3. Where the bold double sided arrow represents the location of the strut in the structural model. The infill forces are assumed to be mainly resisted by the columns, and the struts are placed accordingly. The strut should be pin

connected to the column at a distance l_{column} from the face of the beam. This distance is defined in Eq 3 and Eq 5 and is calculated using the strut width, a, without any reduction factors.

$l_{column} = a/ \cos\theta_{column}$ ..…….. (4)

$\tan\theta_{column} = \{h_m-(a/\cos\theta_{column})\}/l$ ……... (5)

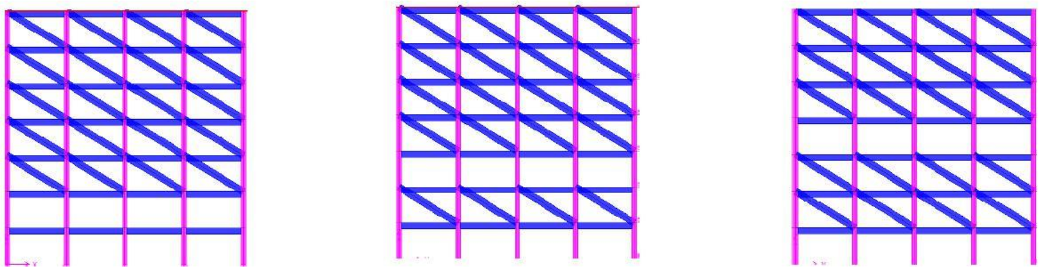
The strut force is applied directly to the column at the edge of its equivalent strut width. Figure 5-(b) illustrates these concepts. Modulus of elasticity of the masonry units was chosen considering the ACI/ASCE/TMS masonry code as 1200 ksi.

VI. Cases for Study

To meet the board objectives of the research, the research study is planned and oriented in such a way so that understanding becomes easy and meaningful. Depending upon the infill percentage so many probable cases may arise but few in this study 25% interval is taken in 4 X 4 span than a general trend may be established so a few cases are taken such as bare, 100 % infill, 75% infill, 50% infill and 25% infill where each of the case represent a probable infill configuration. On the side, as shear wall cases are taken for study and comparison so two basic shear-walls are categorized into two groups: periphery shear-wall and parallel shear-wall. Finally to investigate the effects of soft storey will be identified as well so for this typical 6 story is oriented into 6 separate soft storey configuration Figure 6. As the objective is the elaborate study of pushover on these cases so each and every cases is assigned into a group so that the analysis is performed properly Table I. To observe the effects of shear-wall solely the shear wall with bare frame is simulated in this research Figure 7

Table I
Research Cases Categories

Infill Percentage Cases	Soft Storey Cases	Shear-wall cases
Bare Frame	GF Soft	Parallel SW
25% Infill	1st Floor Soft	Periphery SW
50% Infill	2nd Floor Soft	
75% Infill	3rd Floor Soft	
100 % Infill	4th Floor Soft	
	5th Floor Soft	



(a) Ground Floor Soft Storey (b) 1st Floor Soft Storey (c) 2nd Floor Soft Storey

Figure 6: Elevation view for (a) GF Soft Storey (b) 1st Floor Soft Storey (c) 2nd Floor Soft Storey (d) 3rd Floor Soft Storey (e) 4th Floor Soft Storey and (f) 5th Floor Soft Storey

The load deformation responses of the numerical model specimens were followed through to failure by means of the capacity curve. The curve was gained using pushover analysis, where the loading profile used was a triangular one com-menstruate to the dominate first mode distribution of the seismic loads. For the pushover analysis, 3 load cases were considered:

- PUSH1 – applying the gravity loads associated to load combinations which also contain seismic loadings.
- PUSH2 – applying lateral loads in the X-X direction.
- PUSH3 – applying lateral loads in the Y-Y direction

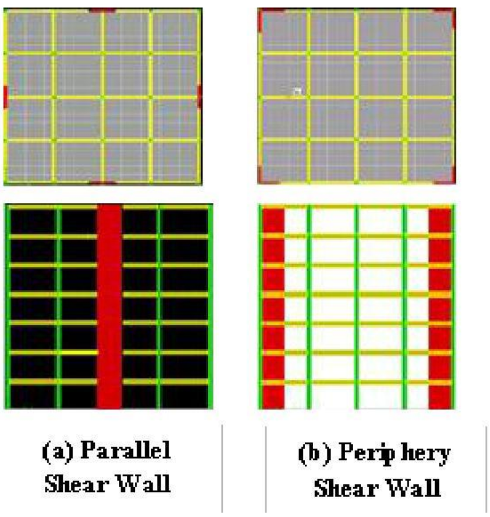


Figure 7: (a) Plan and elevation view for bare frame with Parallel shear wall (b) Plan and elevation view for bare frame with Periphery shear wall

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VII. RESULTS AND DISCUSSIONS

Outcomes of analysis are organized to summarize how the structural responses differ with different infill percentage, construction of shear-wall in two opposite format and finally soft storey consisting building by pushover analysis. For that the performances of structures are evaluated with the help of base shear, performance point, deflection, storey drift and stages of number of hinges form for different cases which were evaluated under systematic review process.

7.1 Comparison of Performance point and base shear:

Seismic performance in terms of base shear, performance point and top displacement increase with shifting of soft storey upward in the structure. Performance point is much higher for shear wall consisting bare frames than any other configuration which propose bare frame could be a choice while using any types of shear wall Figure 8.

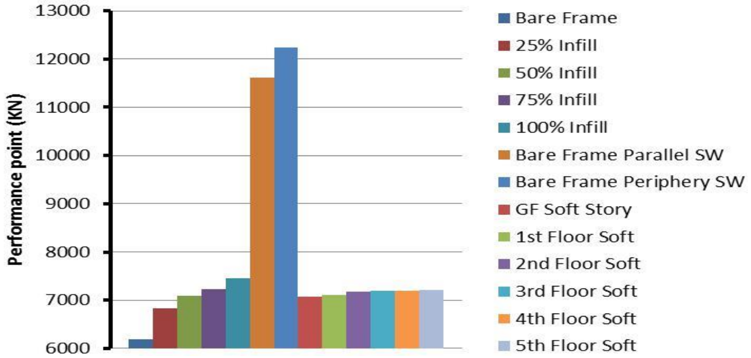


Figure 8: The comparison of performance point between different soft storey cases

General bare frame has very low resistance against lateral force even from any soft story case. As the soft story shifted above the performance also increased. Considering this point soft story could be setup in upper floor to improve the lateral load bearing capability relatively. Similar scenario is reflected in base shear too which is nothing but upper point of the performance point Figure 9.

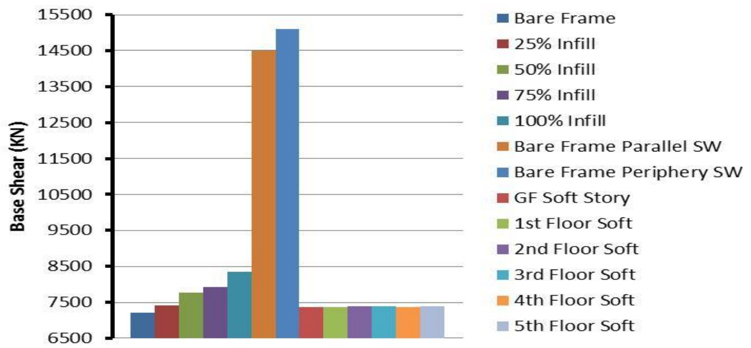
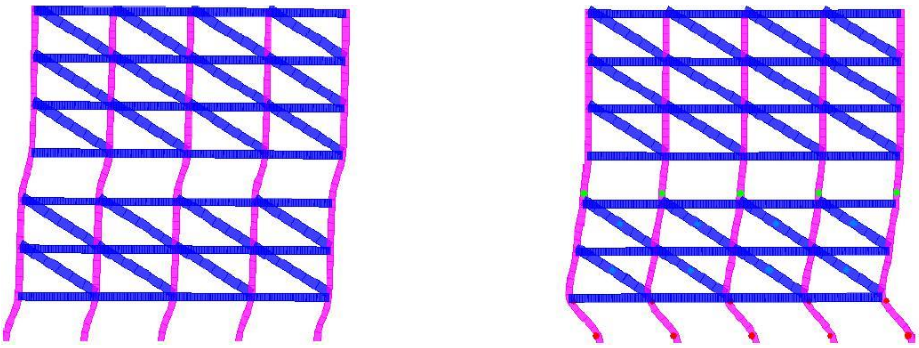


Figure 9: The comparison of base shear between different soft storey cases

The difference of performance point and base shear increases with shifting of soft storey upward and constructing the shear wall. It seems early formation of soft storey is not desired in the structures of highly seismic risk areas. On the other hand a special tendency is seen in performance and base a shear category that is in middle of the structure providing soft storey is not so bad because it is the point from which the shifting good effect goes downward again but minor in results.

7.2 Number of hinges formation for different cases:

As plastic hinges are applied in column, beam and strut to create nonlinear cases, they show structural condition through several stages Fig 10. Hinges goes to collapsible condition after passing a few intermediate stages i.e. immediate occupancy and life safety. In linear static only the final displacement found by providing a constant load where the pushover sequentially increases the load from low to the governing one. By producing plastic hinges it identify the change of state of each member in each pushover step.



(a) Displacement under Linear Static Analysis (b) Displacement under Pushover Analysis (Step 2) Figure 10: Formation of plastic hinge in bare frame after performing nonlinear analysis

Formation of maximum number of hinges in early stage is not good for structure which eventually represents that early reaching to the collapsible condition Table II. Looking on the number of hinges formed one thing is cleare, higher infill ensures low number of hinge formation while shear wall significantly reduces the hinges formation than any other cases.

Table II

Number of hinges formed in Infill and Shear wall configuration

	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	Total
25% infill	920	0	0	45	0	1	3	1	970
50% infill	980	0	0	41	0	3	6	0	1030
75% infill	1039	1	1	47	0	2	0	0	1090
100% infill	1100	0	0	40	0	5	4	1	1150
Bare Frame	760	30	45	67	0	4	4	0	910
Bare Frame Parallel SW	618	58	150	80	0	4	0	0	910
Bare Frame Periphery SW	600	66	131	109	0	4	0	0	910

Whereas for the soft storey cases, it is seen that formation of plastic hinges become quite uniform by shifting of soft storey whereas here too, 3rd Floor Soft storey is the peak point of the hogging characteristics Table III. So it is proven again neither early formation nor late formation is good but formation of soft storey in middle portion of the structure may be a better choice for construction decision makers and designers. Number of hinge formed for soft cases are higher than infill and shear wall cases.

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Table III

Number of hinges formed in Soft Storey configuration

	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	Total
Ground Floor Soft	1010	0	24	67	0	2	4	3	1110
1st Floor Soft	1025	10	25	45	0	2	3	0	1110
2nd Floor Soft	1035	25	0	45	0	3	2	0	1110
3rd Floor Soft	1060	0	0	40	0	5	2	3	1110
4th Floor Soft	1060	0	0	42	0	2	5	1	1110
5th Floor Soft	1060	0	0	45	0	1	4	0	1110

7.3 Comparison of Drift of soft storey cases:

Storey drift is an important parameter to measure displacement changing characteristics which are used in performance based analysis such as pushover analysis, performed in our study. Storey drift is the total lateral displacement that occurs in a single story of a multistory building computed by Eq. 6. Gradual displacements changing ensure structural stability, uniform stiffness and less probability to evaluation of plastic hinges. Plastic hinges eventually goes to collapsible condition and cannot stand with load. To withstand against progressive loads formation of plastic hinge must be controlled by using special structural components. For the infill cases the scenario found worse as there is a sudden displacement change in the storey 1 under the specific seismic event make those cases less preferable than the shear wall cases Figure 11.

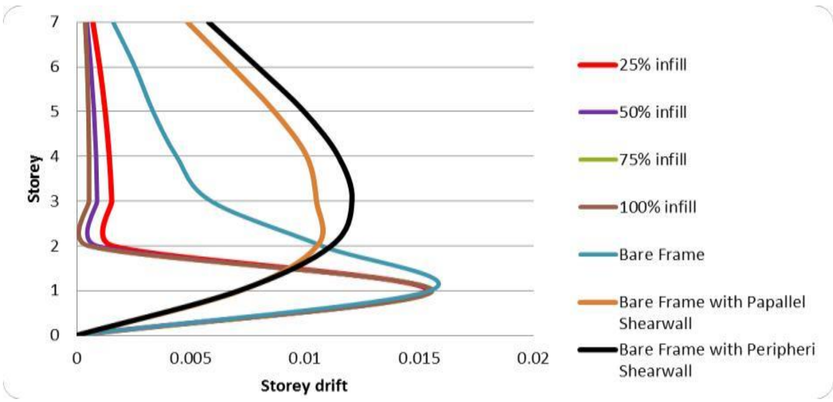

Figure 11: The comparison of story drift between different infill and shear wall cases

Whenever the drift ratios are considered the preference to the two types of shear wall get importance. Storey drift (of storey 2) = (displacement Storey 2- displacement Storey 1)/ Storey height …….. (6)

In general soft storey causes higher drift in successive upper storey of soft storey. Trend is just similar to the others structural response. 3rd storey soft floor show the last lower drift than any other. Other soft storey cases show worse condition by exhibiting much drift than 3rd storey soft case Figure 12.

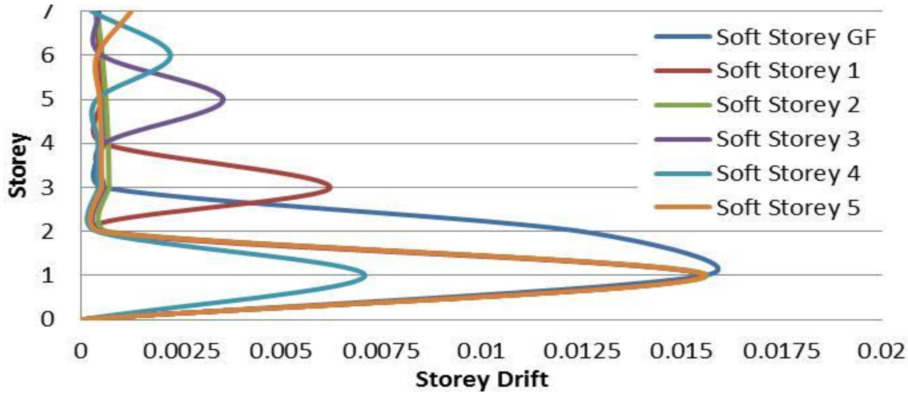

Figure 12: The comparison of story drift between different soft story cases

Gradual displacements changing ensure structural stability, uniform stiffness and less probability to evaluation of plastic hinges. Plastic hinges eventually goes to collapsible condition and cannot stand with load. To withstand against progressive loads formation of plastic hinge must be controlled by using special structural components. For the all cases except 3rd storey soft floor a summary scenario exhibit that structural performance goes to downward.

VIII.CONCLUSION

From the consideration of all the above points we conclude that, the outcomes prompt a choice that infill, shear divider and delicate story design essentially influences the execution of the structures of unbending joint. Under execution based investigation which is sucker, expanding infill builds the execution general while shear divider has greatest resistance against any parallel burdens. The correlation of execution of all delicate story cases under sucker examination uncovers that shipment of delicate story in each floor upward or descending has a huge impacts.

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