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Performance Based Analysis of RC Building Consisting Shear Wall and Varying Infill Percentage

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Abstract:

Metropolitan cities are under severe threat because of inappropriate design and construction of structures. Faulty building designed without considering seismic consideration could be vulnerable to damage even under low levels of ground shaking from distant earthquake. So, structural engineers often are more concerned about the constructing Shear wall without knowing its performance with respect to infill percentage which may lead it to an over design state without knowing the demand. Nonlinear inelastic pushover analysis provides a better view about the behavior of the structures during seismic events. This study investigates as well as compares the performances of bare, different infill percentage level and two types of Shear wall consisting building structures and suggests from which level of performance shear wall should be preferred over the infill structure. To perform the finite element simulation ETABS 9.7.2 is used to get the output using pushover analysis. For different loading conditions, the performances of structures are evaluated with the help of base shear, deflection, storey drift, storey drift ratio and stages of number of hinges form and represented with discussion.

Key words: Pushover analysis, Infill, Bare frame, Equivalent Strut,

Shear wall.

I. Introduction

Earthquake engineering is growing rapidly with time by each and every seismic event which makes it a special branch to work with both research and practice at a time. Pushover analysis has been developed over the past twenty years and has become the preferred analysis procedure for design and seismic performance evaluation purposes as the procedures are relatively simple and consider post elastic behavior. The nonlinear static analysis where the lateral loads are increased keeping vertical loads constant, to maintaining a predefined distribution pattern along the height of the building, until a collapse mechanism develops. The performance based approach requires a lateral load versus deformation analysis. The pushover analysis is a static method of nonlinear analysis. The pushover analysis is a method to observe the successive damage states of a building. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. Pushover analysis of finite element was performed by ETABS 9.7.2 where the deficiency of an elastic analysis displays the following features.

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.

Seismic codes are unique to a particular region or country. These take into account the local seismology, accepted level of seismic risk, building typologies, and materials and methods used in construction. Further, they are indicative of the level of progress a country has made in the field of earthquake engineering.

In last few years the widespread damage to reinforced concrete building during earthquake generated demand for seismic evaluation and retrofitting of existing building in Dhaka. In addition, most of our buildings built in the past two decades are seismically deficient because of lack of awareness regarding structural behavior during earthquake and reluctance to follow the code guidelines. Observing such a situation engineers are nowadays prone to construct shear wall without knowing the actual demand and requirement which may ultimately lead to a sometimes overdesigned state. The purpose of the paper is to summarize the basic concepts on which the pushover analysis is based, perform nonlinear static pushover analysis of medium height (7 storey) residential RC buildings as found in Dhaka city available and evaluate the performance of the shear wall consisting bare frame with respect to different infill configuration frame structures. Force unit is KN while displacements are measured in mm.

II. Methodology

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 [1].

7 storied frame structures are modeled and designed with the help of finite element software ETABS 9.7.2 to perform the pushover analysis to meet the objectives of this study. Ground floor was created soft storey intentionally, for all cases to represent the present trend among public. Seismic effect is computed by the software which was done by UBC 94. Wind load is calculated according to Bangladesh National Building Code (BNBC) by developing an excel sheet. 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 non-linear analysis ATC -40 is reviewed all through the study. All three types of hinges required for performing pushover analysis of RCC structure are chosen from the experimental data. 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. Later to present the objectives performance point, base shear and number of hinges form taken into account under proper jurisdiction.

III.Objectives

The main objectives of this study is to evaluate the performance of two types of shear wall in bare frame with respect to different types of infill case using performance based analysis and to compare base shear in percentage and suggest a stage from which shear wall could be preferred.

IV. Description of the nonlinear 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 components 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 1 describes the typical force-deformation relation proposed by those documents.

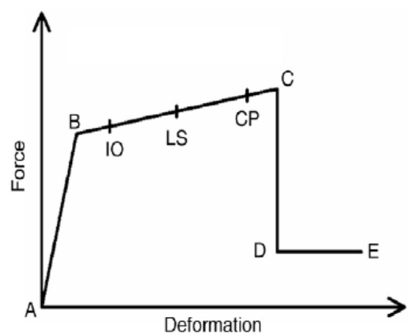


Fig 1: Force-Deformation for pushover analysis

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[2].

V. Description of the structural components

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. 2). 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 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) [3] 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 forms of Shear wall, found in Bangladesh, are 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. 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.

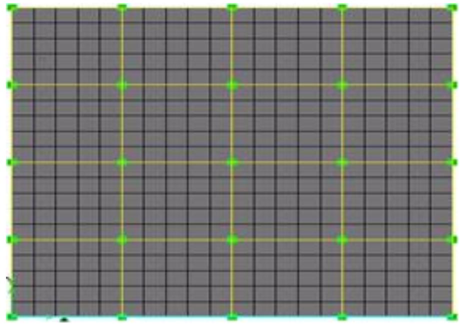


Fig 2. Typical Plan of the example building taken for this study

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[4],[5].

VI. Simulation of strut

The approaches presented by Paulay and Pristlay (1992) and Angel et al. (1994), and later adopted by R. Shahrin and T.R. Hossain (2011) [6] lead to a simplification in the infilled frame analysis by replacing the masonry infill with an equivalent compressive masonry strut as shown in Figure 3-(a).

$\lambda 1H = = H\ [(E_m\ t \sin 2\theta) / (4\ E_c I_{col} h_w)]\ ^1\!/\!_4$ …… (1)

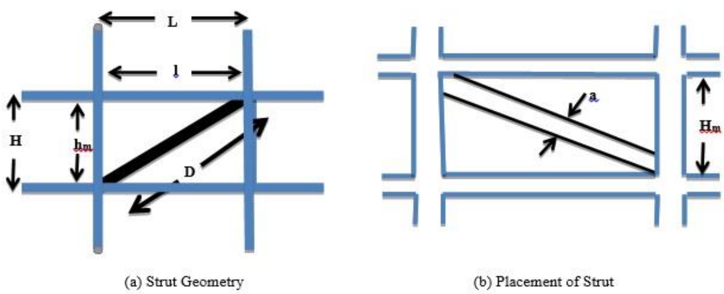


Fig 3: (a) Strut Geometry (b) Placement of Strut

Credit: R. Shahrin & T.R. Hossain (2011) where t is the thickness of masonry wall. Mainstone (1971) considers the relative infill-to-frame flexibility in the evaluation of the equivalent strut width of the panel as shown in Eq 2

$a = 0.175D\ (\lambda 1H)\text{-}0.4$……… (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
ζ1= 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 infilled 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 3-(b) illustrates these concepts. Modulus of elasticity of the masonry units was chosen considering the ACI/ASCE/TMS masonry code as 1200 ksi.

VII. Case study

As the objective is to evaluate the performance of two types of shear wall in bare frame with respect to different types of infill case using performance based analysis and then suggest a stage from which shear wall could be preferred so all the activities required for handling are divided into two types: 1. Work with varying infill percentage and 2. Observe effect of shear wall in bare frame. So cases are categories according to need.

To investigate the effect of infill distribution five different geometrical possibilities were explored: 100% infill, 75% infill, 50% infill, 25% infill and Bare frame (Figure 4). To observe the effect of shear wall with bare frame, as mentioned earlier, two different geometrical possibilities were explored: Parallel and periphery shear wall Fig 5

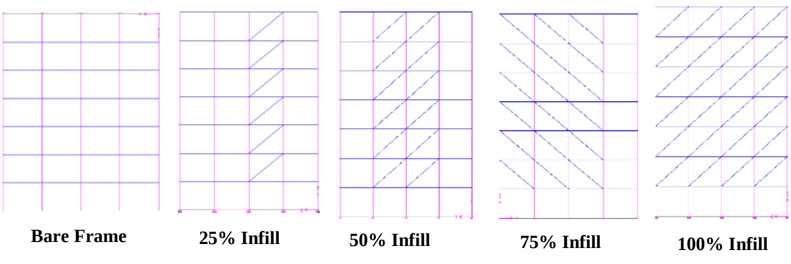
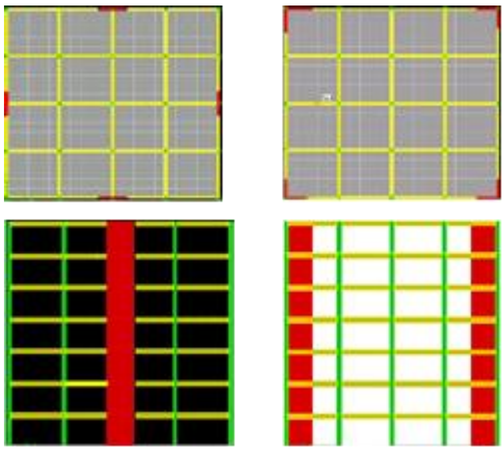


Fig 4: Elevation view for Bare Frame, 25%, 50%, 75%, 100% infill

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 commenstruate to thedominate 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.



(a) Parallel Shear Wall **(b) Periphery Shear Wall**

Fig 5: (a) Plan and elevation view for bare frame with Parallel shear wall (b) Plan and elevation view for bare frame with Periphery shear wall

VIII. Results and Discussions

After analysis, outcomes are organized to meet the study objectives. For that the performances of structures are evaluated with the help of base shear, deflection, storey drift, storey drift ratio and stages of number of hinges form. For different cases were evaluated under systematic review process which reveals that using a Shear wall in a medium height RC structure increases the performance point and base shear significantly and provides extra safety by delaying number of plastic hinges form in early stage. Comparing two different shear walls reveals that bare frame acts significantly strong if its corner columns are bounded by shear wall in both directions as to the bare frame with face to face shear wall in both directions. This study outcome also reveals that seismic performance increases with infill percentage while avoiding any soft storey forming in structure.

8.1 Comparison of Performance point and Base shear for different cases

As stated above seismic performance in terms of base shear and performance point increases with increasing infill percentage.

Case	**Performance Point (KN)**	**Base Shear (KN)**
Bare	6185	7200
25% Infill	6829	7403
50% Infill	7094	7767
75% Infill	7221	7930
100% Infill	7452	8340
Parallel Shear SW Bare Frame	11611	14500
Periphery Shear SW Bare Frame	12240	15102

Table I. Performance point and Base Shear of different cases

The difference of performance point and base shear increases with increment of infill percentage as well implement of shear wall in bare frame. At first both for the performance point and base shear gradually increases with increment in infill percentage but sudden jump in performance point and base shear causes by the construction of shear wall Fig 6 and 7. Shear wall periphery in bare frame has a better performance.

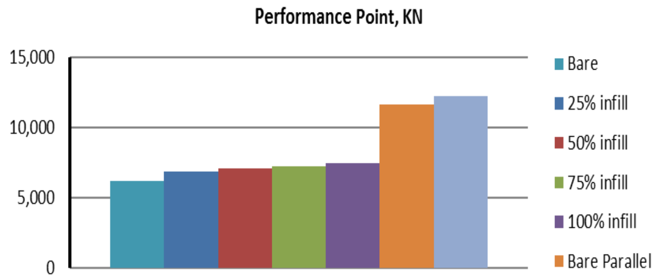


Fig 6: The comparison of performance point between different cases having 25%infill, 50% infill, 75 % infill, 100 % infill, bare frame, bare frame having parallel shear wall, bare frame with periphery shear wall

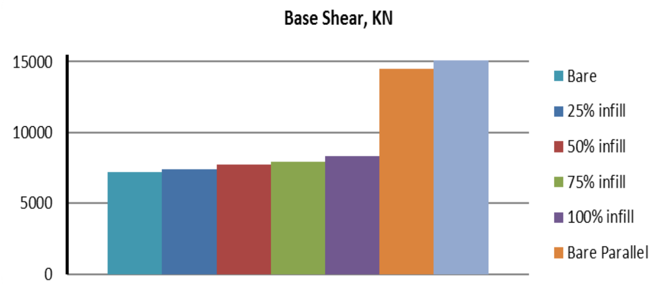
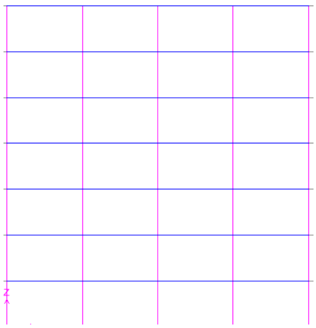


Fig 7: The comparison of Base Shear between different cases having 25%infill, 50% infill, 75 % infill, 100 % infill, bare frame, bare frame having parallel shear wall, bare frame with periphery shear wall

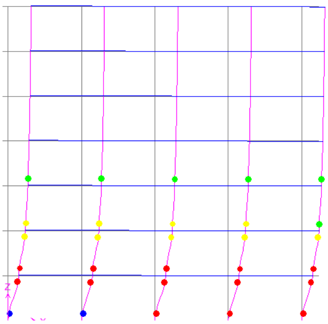
Although bare frame is weaker among all cases, with shear wall it performs stronger than any infill case. The jump in performance is approximately 40% which is impressive and suggests not considering shear wall until infill is sufficient for the structures.

8.2. Number of hinges form in different cases:

As plastic hinges are applied in column, beam and strut to create nonlinear cases, they show structural condition through several stages (Fig 8). Hinges go to collapsible condition after passing a few intermediate stages i.e. immediate occupancy and life safety.



(a) Before performing nonlinear analysis



(b) After performing nonlinear analysis

Fig 8: 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. From this point of view it is seen that for bare it is uniform whole through stage but whenever infill percentages tend to increase, the formation of maximum number of hinges in early stage becomes governing. Shear wall again dissipates the maximization in number of hinge in early stage which makes the path gradual increasing.

	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	760	30	45	67	0	4	4	0	910
Bare with Parallel SW	618	58	150	80	0	4	0	0	910
Bare with Periphery SW	600	66	131	109	0	4	0	0	910

Table II. Number of hinges formed in performance point

8.3 Storey displacement characteristics of different cases:

Storey displacements show favor to the infill frame as to bare frame (Figure 9). All the infill frames of varying percentage have lower displacement in top and overall than the bare including bear with shear wall.

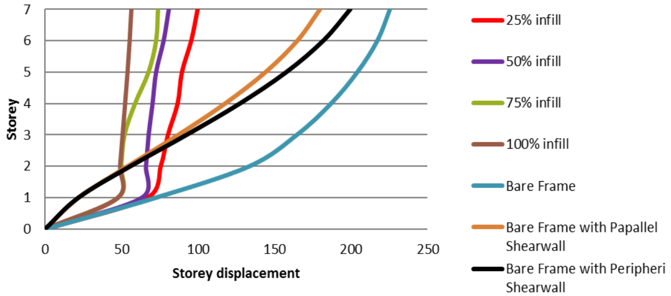


Fig 9 : The comparison of lateral displacement between different cases having 25%infill, 50% infill, 75% infill, 100 % infill, bare frame, bare frame having parallel shear wall, bare frame with periphery shear wall

Storey drift and drift ratio are the parameters which are used in performance based analysis which is pushover analysis, performed in our study. Bare frame with shear wall of both cases shows less displacement but could not reduce the displacement like shear wall. So in cases of displacement shear wall with bare frame has less control than the infill. On the other hand to storey drift reveals the controlled displacement changing characteristics of shear wall (Figure 10). Using shear wall in two specific cases found gradual increment of displacement in the name of storey drift not the sudden change like all infill cases. Storey drift which is the total lateral displacement that occurs in a single story of a multistory building computed by Eq. 6.

Storey drift (of storey 2) = (displacement Storey 2- displacement Storey 1)/ Storey height …….. (6)

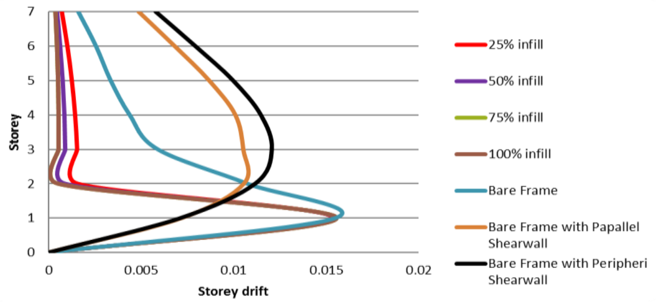


Fig 10 : The comparison of story drift between different cases having 25%infill, 50% infill, 75 % infill, 100 % infill, bare frame, bare frame having parallel shear wall, bare frame with periphery shear wall

Gradual displacements changing ensures structural stability, uniform stiffness and less probability to the evaluation of plastic hinges. Plastic hinges eventually go 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. Whenever the drift ratios are considered the preference to the two types of shear wall get importance again (Figure 11). Storey drift ratio is calculated by Eq. 7

Storey drift ratio (of storey 2) = Storey drift 2/ Storey height …….. (7)

Here in the storey drift ratio the drift changing characteristics with height could be presented properly.

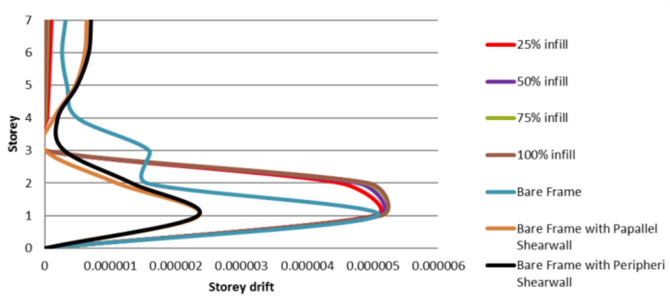


Fig 11: The comparison of story drift ratio different cases having 25%infill, 50% infill, 75 % infill, 100 % infill, bare frame, bare frame having parallel shear wall, bare frame with periphery shear wall

If the property is less that could be a parameter of structural stiffness working although the building for bottom to the top. However in top storey of the structure storey displacement is high for the shear wall cases, so drift ratio also becomes higher than the infill cases representing infill better performing in top storey. In this summary the shear wall cases show a less trend to change with storey but infill cases have significant change from storey to storey and it could take place due to increment of load with increment of storey. Above analysis illustrates different performances of all cases under push over analysis. Here, in case of base shear we obtained better results in bare frame with periphery shear wall case. Here base shears are 44%, 42%, 41%, 39%, 49%, 5% greater than other cases having 25% infill, 50% infill,75 % infill, 100 % infill, bare frame, bare frame having parallel shear wall respectively. But in context of lateral displacement we observed the case named 100 % infill behaves well. It is 76%, 42%, 30%, 301%, 219%, 255% lesser than other cases having 25%infill, 50% infill, 75 % infill, bare frame, bare frame having parallel shear wall, bare frame with periphery shear wall. Number of hinges formed in initial stage is also minimum in bare frame with periphery shear wall case. In case of performance point we obtained better performance in bare frame with periphery shear wall case.

IX. Conclusion

The performance of two cases of bare frame consisting shear wall shows much better performance than the infill cases in terms of performance point, base shear, number of hinge forms, drift and drift ratio but not the displacement. It is observed that consideration of effect of periphery shear wall in bare frame leads to a significant change in the capacity.

Investigation of frame structures with varying percentage infill shows that increasing infill percentage improves the performances of the structure significantly and makes the structures rigid in earthquake prone region. Mostly hinges are formed in beam than in column.

This study found that Periphery Shear wall in bare frame generates much better result than both Parallel Shear wall in bare frame and 100% infill so to get significant amount of performance in terms of deflection and base shear, in construction period of a high rise building in high seismic prone region, periphery Shear wall will be highly beneficial. In fact for a seven storey regular structure Periphery Shear wall in bare frame take approximately 64% more lateral loads then masonry 100% infill likewise as it was expected 100% infill frame generated better performance than 75%, 50%, 25% and bare frame. So if soft storey has to build then shear wall could be used to get a jump off in a significant performance which is even better than 100% infill. The whole outcomes could be summarized in Table III.

In conclusion it could be said that performance based analysis, pushover reveals the true scenario which could not be forecast in other analysis and that a combination of bare frame with shear wall is better in terms of performance point, base shear, storey drift and storey drift ratio but not the displacement. It seems effect of bare frame is somewhere, still remains there, and infill could bring a significant decrement in displacement. Shear wall may bring a uniform tendency in the storey drift which is important during seismic to distribute displacement uniformly all over the structure. It could be taken as a suggestion that combination of adequate percentage of infill and shear wall may bring the desired stiffness all over the structure by taking the benefit of the two structural systems in one body.

Performance Parameters	**Shear wall in bare frame**		**Changing Infill Models**	Comments
	Periphery Models	**Parallel Models**		
Performance Point	64.25% higher than 100% Infill	55.81% higher than 100% Infill	Increases with increasing Infill percentage	Shear wall with bare frame show better performance
Base Shear	81.08% higher than 100% Infill	73.86% higher than 100% Infill	Increases with increasing Infill percentage	Shear wall with bare frame show better performance
Displacement	Greater than all varying infill but less than bare frame		Decreases with increasing Infill percentage	Infill frame show better performance
Drift	Change uniformly in exponential trend; no sudden increment		Change with sudden increment; formation of sharp peak point	Shear wall with bare frame show better performance
Drift Ratio	Changes with low fluctuation between storey 1 to 3		Changes with significant fluctuation between storey 1 to 3 close with bare frame	Shear wall with bare frame show better performance

Table III. Research Scenario of the Outcomes

Dhaka, the highly populated metropolitan city densely crowded with medium to high rise RC buildings, is frequently facing earthquakes of low to medium intensity and expecting some serious seismic threats in the near future. This emphasizes the importance of using an appropriate numerical model such as one presented in this study for the actual seismic assessment of the RC constructions. There are good reasons for advocating the use of the inelastic pushover analysis for demand prediction, since in many cases it will provide much more relevant information than an elastic static or even dynamic analysis and encourage the design engineer to recognize important seismic response quantities and to use them for exposing design weaknesses.

For more inquiry about pushover analysis, its effects in RC structure, how to develop the analysis procedure, how to proceed and basic characteristics, the following links will be beneficial and informative for researchers, designers and students

1.www.bentley.com/enUS/Training
2. www.en.wikipedia.org/wiki/pPushover
3.www.cscworld.com/getattachment/...Analysis
4. www.communities.bentley.com/products/structural

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