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Pushover Analysis of Reinforced Concrete Structures with Coupled Shear Wall and Moment Frame

*Yungon Kim[1)]

[1)] *R&D Division, Hyundai Engineering and Construction, Yong-in 446-716, Korea*
[1)] *yungon.kim@hdec.co.kr*

ABSTRACT

The response of four systems with the same geometry, but different rebar layouts in a simplified 30-story office building, which generally had coupled shear wall and moment frame, was evaluated by pushover analysis. Based on the analytic results in this study, it is undesirable to reduce effective stiffness of coupling beams due to the design requirement in linear analysis because the initial system stiffness would be under-estimated and the stress distribution of system might be distorted. With the system evaluation by pushover analysis, the design optimization can be achieved by maximizing the contribution of coupling beams and by considering the interaction with frame beams.

1. INTRODUCTION

The lateral resisting system of office buildings is typically designed as a gravity frame, which assumes that core wall resists all lateral loads and moment frame resists gravity loads only. This assumption makes the behavior of structure simple to design although the behavior of core wall still remains complicated due to coupling beam, which is wall portion between vertical openings. A core wall would behave as two separate walls connecting into coupling beam if the capacity of coupling beam is not enough to transfer the demand of one wall to the other. Generally, the shear demand of coupling beam is too high to design within elastic range. In linear analysis, failure sequence due to inelastic behavior of members cannot be taken into account because the stiffness of member is constant value. Therefore coupling beam is generally

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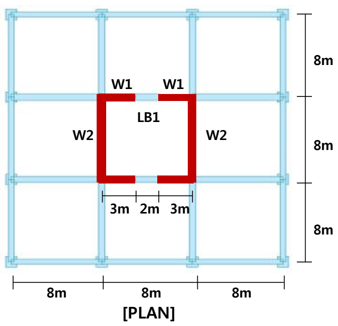
[1)] Senior Research Engineer, Ph.D

designed with reduced effective stiffness considering inelastic behavior indirectly. However, this approach could not be appropriate when checking serviceability and obtained the optimum system performance. Moreover, the shear demand without considering the lateral contribution of moment frame would not be accurate.

In this study, the system responses with four different rebar layouts of both coupling beam and moment frame (girder) were compared each other which were evaluated by pushover analysis.

2. MODEL CONFIGURATIONS

A simple analytical model was developed to evaluate the difference of the performance of structure with various member designs. The geometry of the model was summarized in Fig.1. To control the system response with respect to a specific design parameter, the member design was grouped and simplified over the height. The thickness of core wall was 600mm and the depth of coupling beam was also 600mm. The compressive strength of concrete was 24MPa except that of column. To keep the dimension of column, the strength of column in several lower stories was increased. It was used that the flexural stiffness was 0.7 of initial stiffness for wall and column and 0.35 for girder and beam within elastic range. The stiffness reduction to meet the design requirement in linear analysis was not included because effective stiffness after reaching yielding could be evaluated automatically in non-linear analysis.



Member Dimension	(Unit: mm)
Wall : W1, W2	Thk.= 600
Coupling Beam : LB1	600x600
Interior Girder : G1	600x800
Exterior Girder : G2	500x800
All Columns : C1	1000x1000

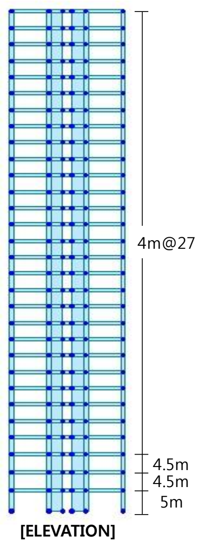


Fig. 1 Configurations of analytic model

As shown in Table 1, four different reinforcement layouts were considered with respect to the amount of the reinforcement of coupling beam (LB1) and beam (G1). In each case, the shear strength was designed to exceed the possible over-strength in flexure in order to make moment hinge prior to shear hinge.

Table 1 Reinforcement Layout according to the design parameters

Beam (G1) \ Coupling beam (LB1)		High 12-D19 (T&B) 4-D13@100	Low 4-D19 (T&B) 2-D13@200
High	9 / 6 - D25 (T/B)	**CHBH**	**CLBH**
Low	6 / 4 - D19 (T/B)	**CHBL**	**CLBL**

Note. „CHBH' : **C**oupling beam-**H**igh reinf.-**B**eam-**H**igh reinf.

3. ANALYTIC RESULTS

Pushover analysis was performed by the software developed by MIDAS IT (MIDAS Gen Ver. 7.95). In Fig.2 the system response according the different reinforcement was plotted. The load pattern for pushover was the first mode of system. Because the performance point of each case was determined by the same seismic load condition, the relative performance between cases can be compared reasonably.

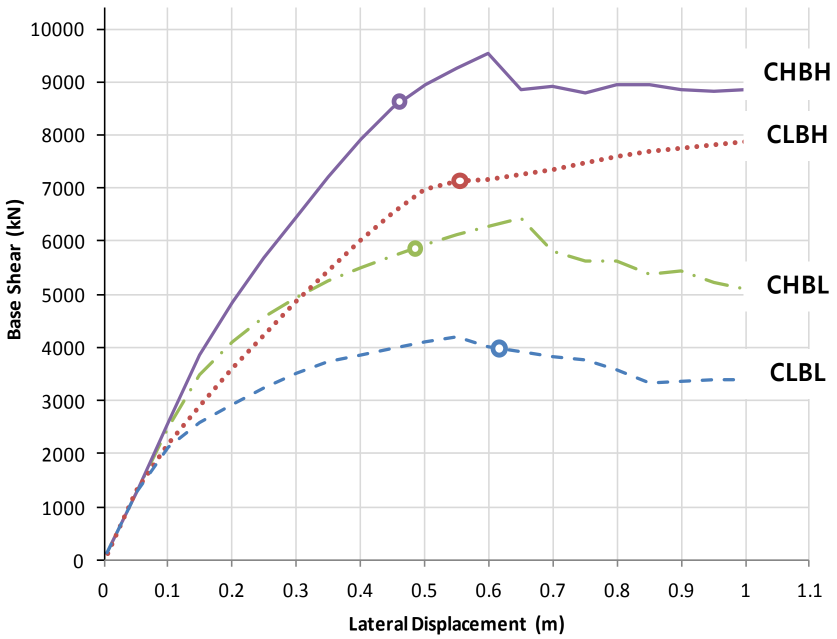


Fig. 2 Load – displacement relationship with load pattern of first mode

Table 2 Numerical values at performance point marked in Fig.1

	CHBH	CHBL	CLBH	CLBL
***V** (kN)*	8685	5904	7117	4005
***D** (m)*	0.47	0.49	0.55	0.61
***Teff** (sec.)*	5.11	6.34	6.11	8.56
Deff (%)	12.4	20.2	13.2	25.2

Note. V- Base shear, D – lateral displacement, Teff – effective period, Deff – effective damping ratio

The system responses of all cases had the same initial stiffness because they depended on geometric properties. However, the responses would be highly varied as members yielded and the system stiffness decreased and the performance points (the marked point on Fig.2) of all cases were different each other. The detailed information of performance point is presented in Table 2. Coupling-high series **(**CHBH and CHBL**)** maintained initial stiffness longer than coupling-low series (CLBH and CLBL**).** In addition, the displacements at performance point of coupling-high series were smaller. Moreover, beam-high series (CHBH and CLBH) had a greater base shear capacity at performance point than beam-low series (CHBL and CLBL). The additional capacity of beam-high series was greater when the coupling beam was lightly reinforced.

It is evident that CHBH showed the best performance, but CHBL is more effective solution than CHBH from an economic perspective because the initial system stiffness of CHBL was sustained until service load level and stress redistribution obtained by inelastic behavior of member was greater

Because it is unable to evaluate the non-linear behavior and include stress redistribution between elements in linear analysis, the effective stiffness considering inelastic behavior of elements is used indirectly. For this reason, the linear analysis with this effective stiffness would under-estimate the system stiffness inevitably, especially in service load. Because the performance of the system evaluated by pushover analysis would change depending on the load pattern, the serviceability against wind load was checked with the pattern of wind load, not the pattern of the first mode. However, overall responses were still close because the pattern of wind load pattern was similar to that of the first mode. As shown in Fig.3, the system stiffness was much higher than that at performance point, which meant that more elements remained elastic range. It implied that the effective stiffness evaluated at ultimate in linear analysis might make the system performance under-estimated. However, the system response evaluated by pushover analysis would reflect the effect of the inelastic behavior of members and serviceability could be checked reasonably. In this sample study, the displacement of all cases except CLBL still was not beyond the conventional design limit (H/500).

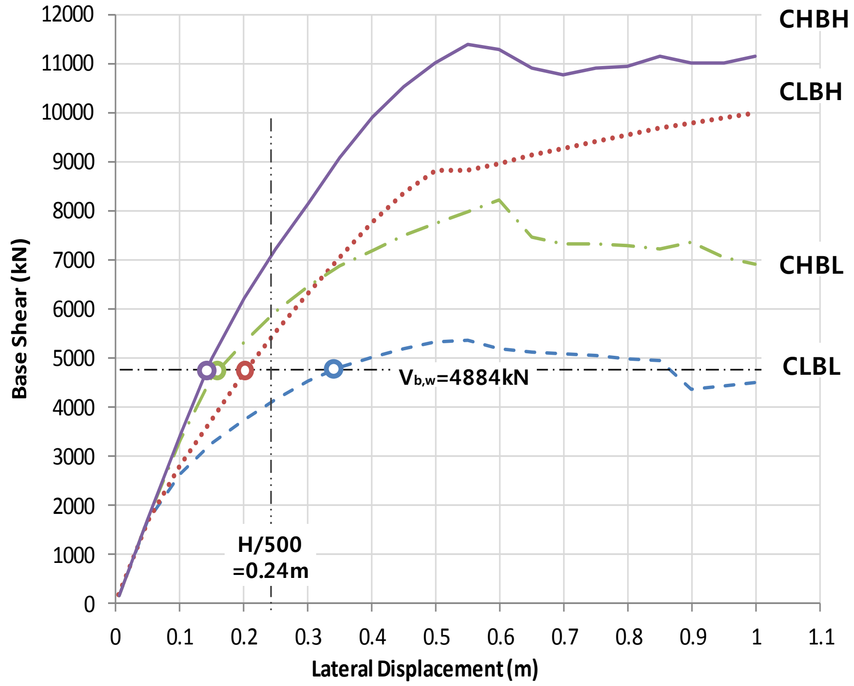
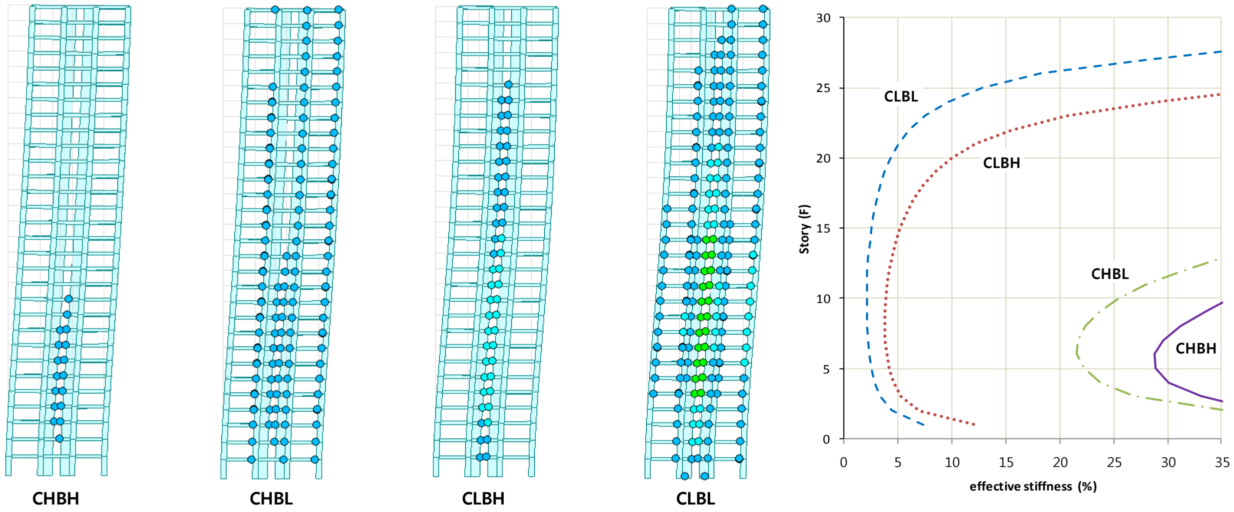
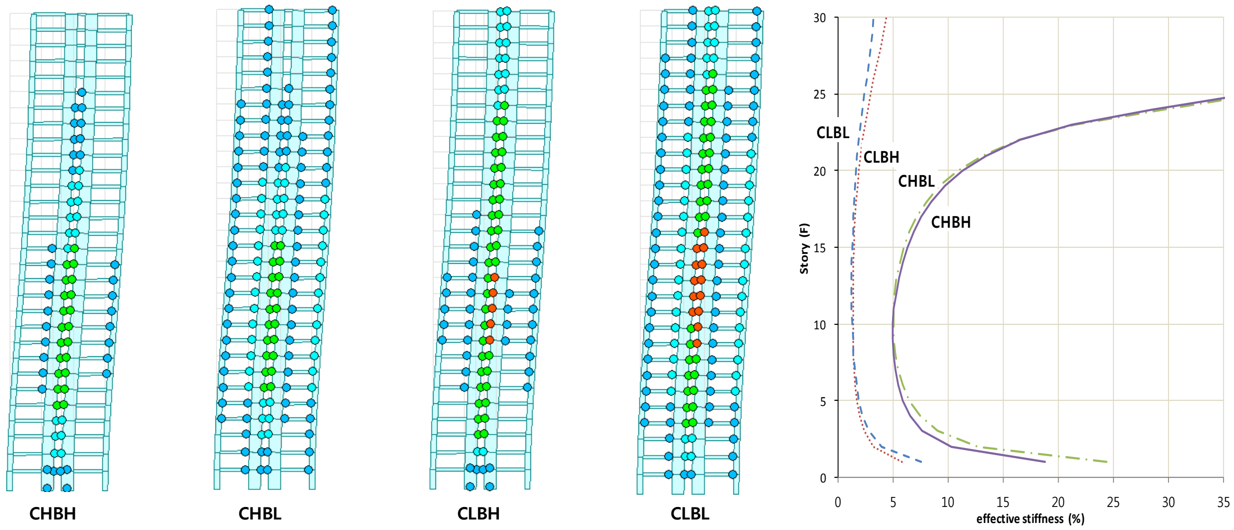


Fig. 3 Load-displacement relationship with load pattern of wind load

As shown in Fig. 4(a), most elements remained elastic in CHBH case, but many coupling beams yielded in other cases. In addition, the yielding of coupling beam started at lower-mid stories and extended to the upper stories as compared with Fig. 4 (b). It is also noted that the effective stiffness of coupling beam would not same over the height, whereas the same effective stiffness was generally assumed in linear analysis. When the frame beam was lightly reinforced (CHBL, CLBL), the number of plastic hinge in coupling beam was greater, which indicated that the actual lateral contribution of frame members might decrease the demand of coupling beam.



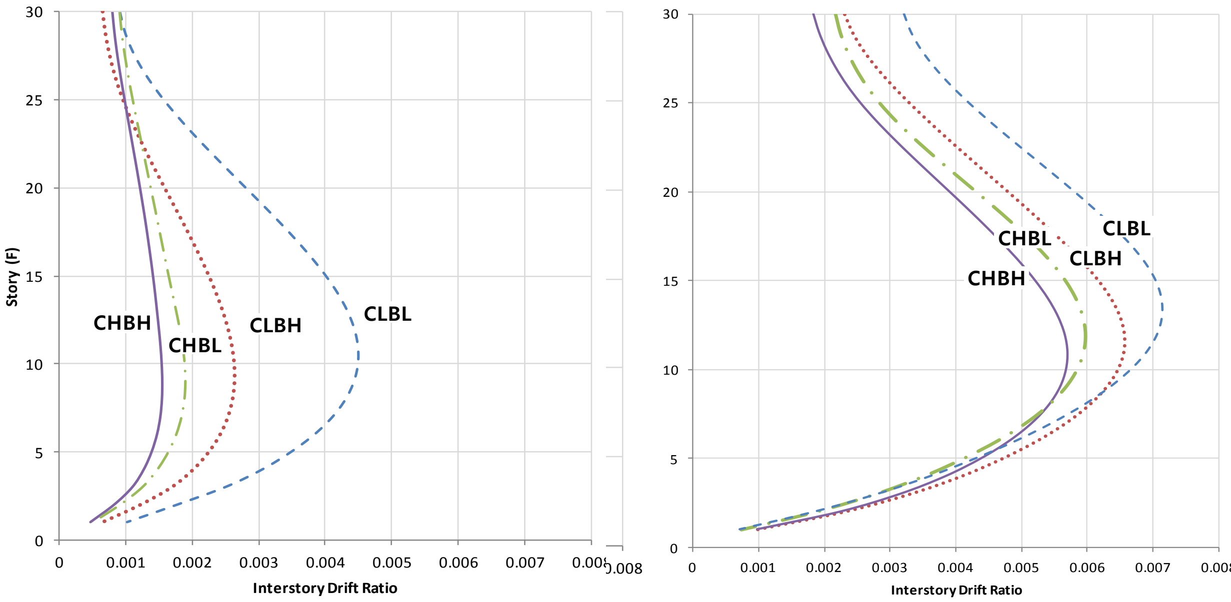
(a) at service (wind) load



(b) at performance point

Fig.4 Plastic hinge location and effective stiffness of coupling beam

As shown in Fig.5, the drift ratio depending on reinforcement of coupling beam was more sensitive than that of frame beam. It is because the lateral contribution of core wall depends on the behavior of coupling beam and the core wall resists most of lateral loads. In addition, the drift ratio was highly varied over the height depending on the elastic behavior of coupling beam. Generally, the drift ratio in upper-stories was smaller than others because the coupling beam in upper stories remained elastic or had relatively less plastic deformation.



(a) Service load (b) At performance point

Fig. 5 Inter-story drift ratio at service and ultimate load

4. DISCUSSION

Based on the analytic results in this study, several recommendations for the system performance evaluated by pushover analysis are shown in Fig. 6.

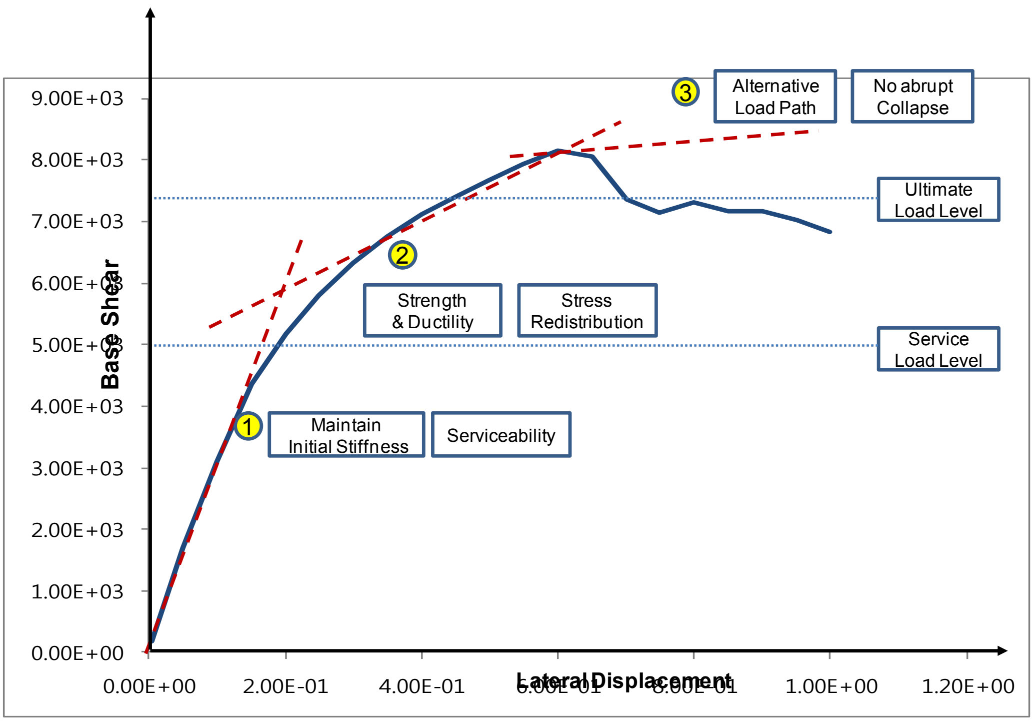


Fig. 6 Recommendations for system performance evaluated by pushover analysis

First, maximize initial system stiffness and keep it up to service load. For the coupling beam, cross-sectional area of coupling beam needs to be maximized if ductile behavior of it can be secured. In addition, the maximum shear strength of coupling beam would be provided and flexural reinforcement should be adjusted for occurring moment hinge prior to shear hinge.

Next, utilize the stress re-distribution as possible to increase the effectiveness of member design if the system capacity exceeds the required ultimate strengths calculated from all load combinations. Ductile behavior of individual elements through moment hinge should be required to obtain the stress redistribution.

Last, abrupt strength reduction (or collapse) should be prevented. Because there are always uncertainties of applied load and system capacity, so the system redundancy through alternative load path would offer system stability. For the structure with coupled shear wall and moment frame, it is desirable that either moment frame or individual wall would compensate the capacity loss although the shear capacity of core wall is decreased by failure of coupling beam.

5. CONCLUSION

The analytic models with four different rebar layouts having same geometry, which generally consisted of coupled shear wall and moment frame, were investigated. Although pushover analysis would not be practically appropriate for member design due to its non-linearity, it still has several advantages over linear analysis as follows.

1. Because coupling beam reached yielding earlier than other elements in most cases, the inelastic behavior of coupling beams should be considered as possible to optimize structural design.
2. Because the plastic hinge of coupling beam did not occur simultaneously, it would be desirable that stress re-distribution between elements be considered in coupled shear wall.
3. Although it is assumed that moment frame would resist gravity load only, it would contribute to the lateral resistance when evaluating system performance and the rotational demand of coupling beam would decrease.

4. The member stiffness for checking serviceability would be higher than stiffness determined at ultimate, so the displacement would be smaller when using stiffness evaluated by pushover analysis.

REFERENCES

ACI Committee 318 (2008), *ACI 318-08 Building Code Requirements for Reinforced Concrete* and *Commentary*, American Concrete Institute. Farmington Hills MI.

American Society of Civil Engineers (ASCE) (2000), “Prestandard and Commentary for the Seismic Rehabilitation of Building”, *FEMA 356 Report*, Federal Emergency Management Agency

Elnashai, A.S., (2001) “Advanced inelastic static (pushover) analysis for earthquake applications,” *Structural Engineering and Mechanics,*,12(1), 51-69

Fajfar. P. (1999). “Capacity spectrum method based on inelastic demand spectra,” *Earthquake Engineering & Structural Dynamics*,.28(9), 979-993.

Gupta, B and Kunnath, SK. (2000) “Adaptive spectra-based pushover procedure for seismic evaluation of structures.” *Earthquake Spectra*, 16(2), 367-392.

Kim, Y. and Cho, S., (2012) “Design of Coupling Beam considering Stress Re-distribution of System,” *Korean Concrete Institute spring 2012 convention*, 831-832

Krawinkler, H. and Seneviratna, G. (1998), “ Pros and cons of a pushover analysis of seismic performance evaluation”, *Engineering Structures, Vol. 20(2)* , 452-464

Moehle, J.P et al. (2010). “Seismic design of cast-in-place concrete special structural walls and coupling beams : A guide for practicing engineers,” (*NEHRP Seismic Design Technical Brief No. 6*)

Park, R and Paulay, T. (1975) “Reinforced concrete structures.” *John Wiley & Sons,* NY, 776 p

Paulay, T. and Priestley, M.J. N. (1992), “Seismic Design of Reinforced Concrete and Masonry Buildings,” *John Wiley & Sons*, NY, 744 p