I J C T A, 9(41) 2016, pp. 1036-1043 ISSN: 0974-5572
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EFFECT OF CURTAILMENT OF SHEAR WALLS FOR MEDIUM RISE STRUCTURES

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Abstract: Shear wall systems are one of the most commonly used lateral load resisting mechanisms employed in medium rise and high rise buildings. The lateral load resistance of a dual system comprising of moment resisting frame (MRF) and shear wall is studied. Six different cases of shear wall curtailment are considered by terminating the shear walls at intermediate heights of a G+9 storey building. The models are subjected to lateral and gravity loadings in accordance with IS provision and Response Spectrum Analysis (RSA) is carried out. The main findings of this paper led us to conclude that contrary to the common belief, curtailment of the shear walls in the top floors is not necessarily detrimental to the performance of the structure. Also the optimum level of shear wall curtailment, as suggested by Nollet & Smith, 1993 and Atik *et al*, 2011 has been discussed.

Key Words: *Shear Wall, Curtailment, Response Spectrum, RC Buildings, Dual System*

I. INTRODUCTION

In India, reinforced concrete structures are designed and detailed as per IS:456-2002. However, structures located in high seismic regions require ductile design and detailing. Provisions for the ductile detailing of monolithic reinforced concrete frame and shear wall structures are specified in IS:13920-1993. After the 2001 Bhuj earthquake, this code has been made mandatory for all structures in zones III and above. Reinforced concrete (RC) buildings often have vertical plate-like RC walls called Shear Walls in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150 mm, or as high as 400 mm in high rise buildings. Shear walls are usually provided along both length and width of buildings. These walls act like vertically-oriented wide beams that carry earthquake loads downwards to the foundation [1].

When a dual system is loaded laterally, the free deflected forms of the wall and frame cause them to interact horizontally through the floor slabs. The upper part of the shear walls actually takes a negative role in resisting the lateral loads because of the difference in the free deflected forms of shear walls and MRF. The discontinuity of shear walls may prove an effective technique in reducing this negative effect at the top. In the words of B.M. Atik, "The optimum level of curtailment always lies between the point of inflection and zero wall shear in the corresponding full height wall structures" [2]. The principle objective of this project is to analyze different models with Shear walls curtailed at different heights and compare

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them using ETABS, to understand the effect of curtailment of shear walls on the response of the structure. G+9 storied buildings are modeled using conventional beams, columns & slabs. These buildings were given square geometry with plan dimensions of 25m x 25m. They are loaded with dead loads, live loads and seismic forces (according to IS:1893:2002). These models are then analyzed using response spectrum method for earthquake zone V of India (Zone Factor = 0.36). The details of the modeled building are listed below. Modal damping of 5% is considered with OMRF having Shear Walls (Response Reduction Factor, R=5) and Importance Factor (I) =1.

Above the point of inflection i.e. where the bending moment curve changes direction, the wall moment is opposite to the external load moment, while the moment in the frame is actually greater than the moments due to external loads. Thus if we curtail the shear walls above this point of inflection, the moments in the frame will become equal to the moments due to the external loads. A similar trend is observed in the case of shear forces and hence if the walls are curtailed near the top, the shear in the frames will become equal to the shears due to the external loads [2]. Atik *et al*, 2011 studied this effect using continuum analysis and proposed a corrected curve for the prediction of shear wall curtailment, originally proposed by Nollet & Smith, 1993. Nollet & Smith, 1993 proposed that the curtailment of shear walls in a dual system is not necessarily detrimental to the performance of the structure as far as its lateral load carrying capacity is considered. If the curtailment is done at any level above the point of contra-flexure in the wall, the changes in the maximum roof displacement is minimum [3].

In order to further investigate the effects of curtailment on the efficiency of dual system, Atik *et al*, 2011 prepared a mathematical model for the solution of a continuum model of curtailed shear wall. They proposed that- "The level of curtailment which leads to delete the negative shear is the same that leads to delete the negative momentum." This means the discontinuity of shear walls at this particular level will eliminate the reverse force applied by the walls on the frame, leading to minimum top deflection [2]. The studies done by Atik *et al*, 2011 supported the finding of Nollet & Smith, 1993 leading us to confirm that the optimum level of shear wall curtailment indeed lies in between point of inflection and point of zero wall shear in the corresponding full height structure [2].

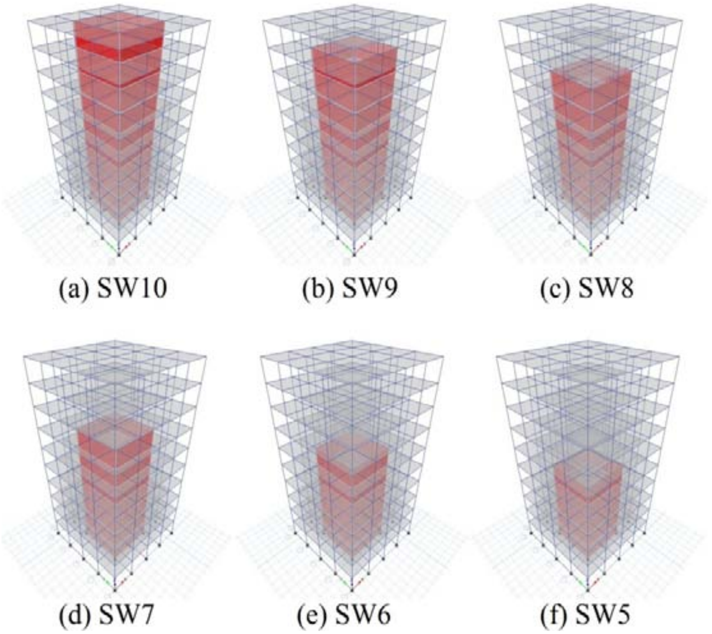
II. MODELLING & ANALYSIS

The following assumptions were made before the start of the modeling procedure so as to maintain similar conditions for all the four models:

- Only the main block of the building is considered. The staircases are not considered in the design procedure.
- The building is resting directly on the ground. Also infill walls are not provided as the study focuses only on the response of frame configuration with shear walls.
- For all structural elements, M30 & Fe415 are used.
- The footings are not designed. Supports are assigned in the form of fixed supports.
- Sizes of the members are as follows: (All dimensions are in mm)

Table 1 - Design Specification

SN	Specifications			Size
1	Plan dimensions			25m x 25m
2	Total height of Building (G+9)			35 m
3	Slab Thickness			200 mm
4	Beam Size			0.4 m x 0.3 m
5	Column Size			0.5 m x 0.3 m
6	Loads Applied	DL	Dead Load	as per Self Weight
			Floor Finish	1 kN/m^2
		LL	Live Load	2.5 kN/m^2
		EQX	Seismic Load (X direction)	as per IS:1893-2002


(a) SW10 (b) SW9 (c) SW8

(d) SW7 (e) SW6 (f) SW5

Fig. 1 - Generated models in ETABS

In this study, RSA is adopted for the analysis of prepared models. Models are represented by SW followed by a number showing the floor level at which curtailment is done. For instance SW8 indicates the model with shear wall running up to the 8th storey. The six models thus used were labelled as shown above in Fig. 1. In order to perform the seismic analysis of a structure at any location, the actual records of time history are needed. But it is not practically possible to prepare such records for all the are as and hence in many cases, these records are unavailable. In such cases, response spectrum analysis is carried out.

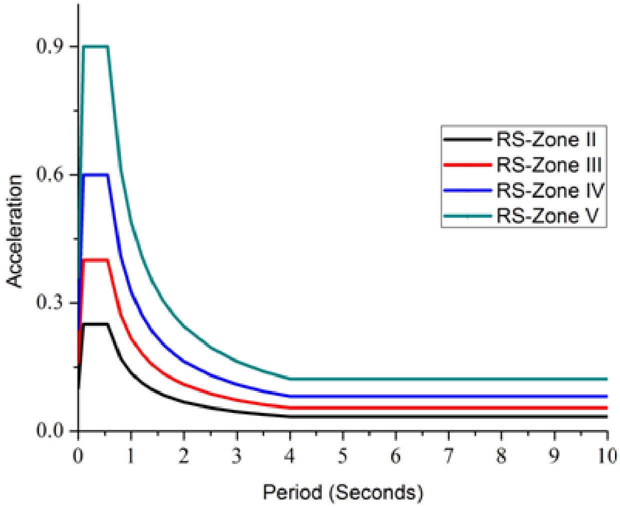


Fig. 2 - Response Spectra for different Seismic Zones as per IS:1893(Part-1)-2002 [4]

This method involves the calculation of only the maximum or peak values of member forces and displacements in each of the considered mode using prescribed design spectra. This spectra is the average of several past earthquakes and can be used as an effective method of employing earthquake ground motions [5]. As per IS:1893(Part-1)-2002, the response spectra shown in Fig. 2 is recommended for design of structures subjected to seismic forces. The spectra is shown for all four seismic zones in India as per IS:1893(Part-1)-2002. A response spectrum is basically a plot of the peak steady-state response in terms of displacement, velocity or acceleration, for of a series of varying natural frequencies. The main limitation of RSA if that they are universally acceptable only for linear systems. For nonlinear analysis, Time-History Analysis is adopted.

III. RESULTS

Exact seismic analysis of the structure is highly complex and to tackle this complexity, numbers of researches have been done with an aim to counter the complex dynamic effect of seismic induced forces in structures, for the design of earthquake resistant structures in a refined and easy manner [3]. After performing the RSA for the modelled structures, the following basic parameters were found. They are tabulated below:

Table 2 - Basic Earthquake parameters using RSA

Parameter	SW10	SW9	SW8	SW7	SW6	SW5
Base Shear (in kN)	2352.2904	2301.0737	2288.9468	2091.8959	1827.5218	1592.8472
Roof Disp. (mm)	15.162	14.993	15.888	16.782	17.349	17.574
Time Period - Mode 1 (sec)	0.748	0.739	0.744	0.772	0.871	1.025
Time Period - Mode 2 (sec)	0.717	0.708	0.704	0.71	0.757	0.855

Storey Drifts increase tremendously at the level of curtailment for all the models. Possible explanation for this is the reduction of lateral stiffness of the structure at curtailment level, leading to larger drifts [6], [7]. Among all the models, SW5 showed the maximum drift at 7th floor. These drifts values, after suddenly increasing, tend to get reduced in the top floors. It can be seen in Fig. 3 that initially, for structures with curtailed shear walls, the relative drift gets reduced. After the point of curtailment, the sudden increase was seen.

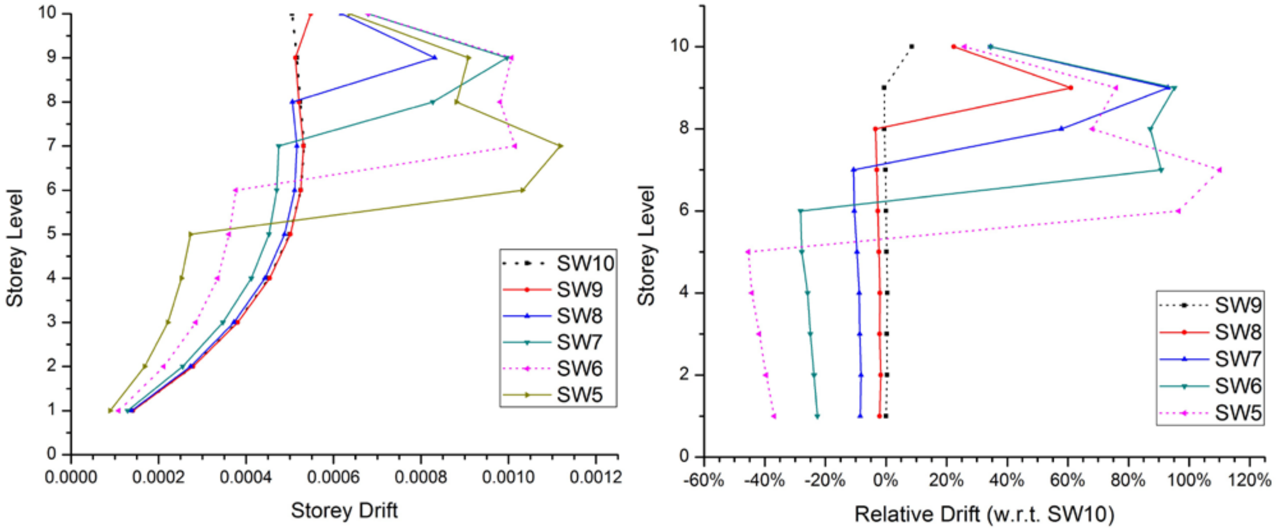


Fig. 3 - Storey Drifts

Roof displacements were not affected much. The top storey displacement increased by a mere 2 mm even for SW5. However, at curtailment level, the removal or discontinuity of shear wall led to a slightly decreased slope for the floor displacement curve as shown in Fig. 4 below. The relative displacement, like relative drifts, were reduced in models with curtailed shear walls. However after the point of curtailment, this trend got reversed.

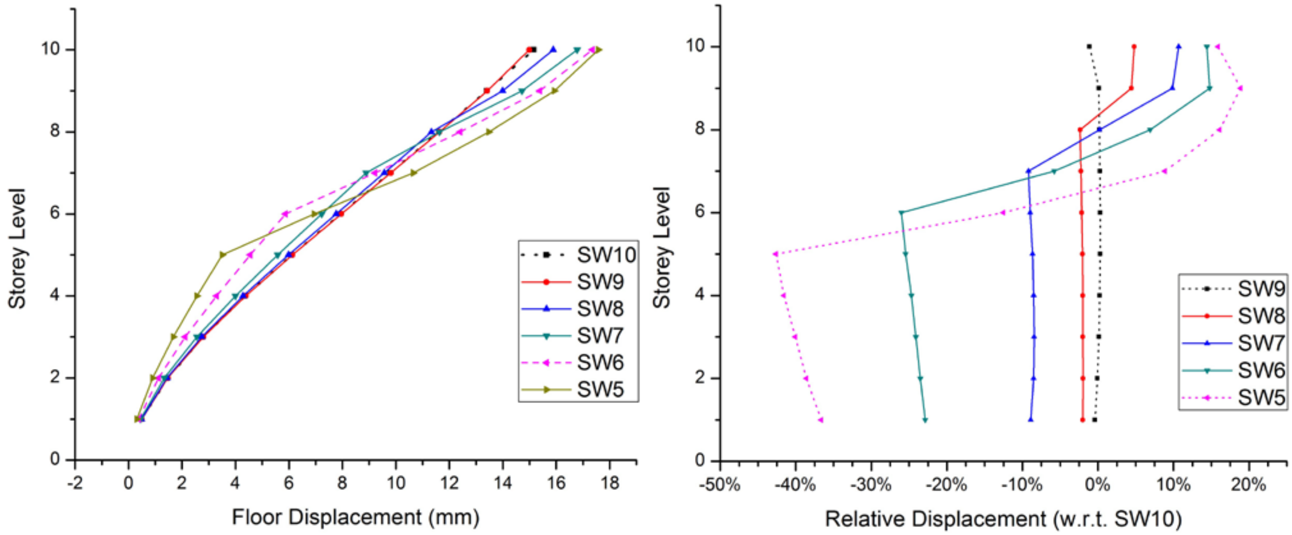


Fig. 4 - Storey Displacements

The storey forces vary hugely in all the six models. Maximum forces were observed in SW10 while SW5 displayed the minimum forces. This is again because of the higher stiffness of SW10 model, enabling it to withstand higher lateral forces as compared to the others. In SW5, there is a decrease of almost 33% in the storey forces when compared to SW10. However, compared to the lower stories, the forces at the higher

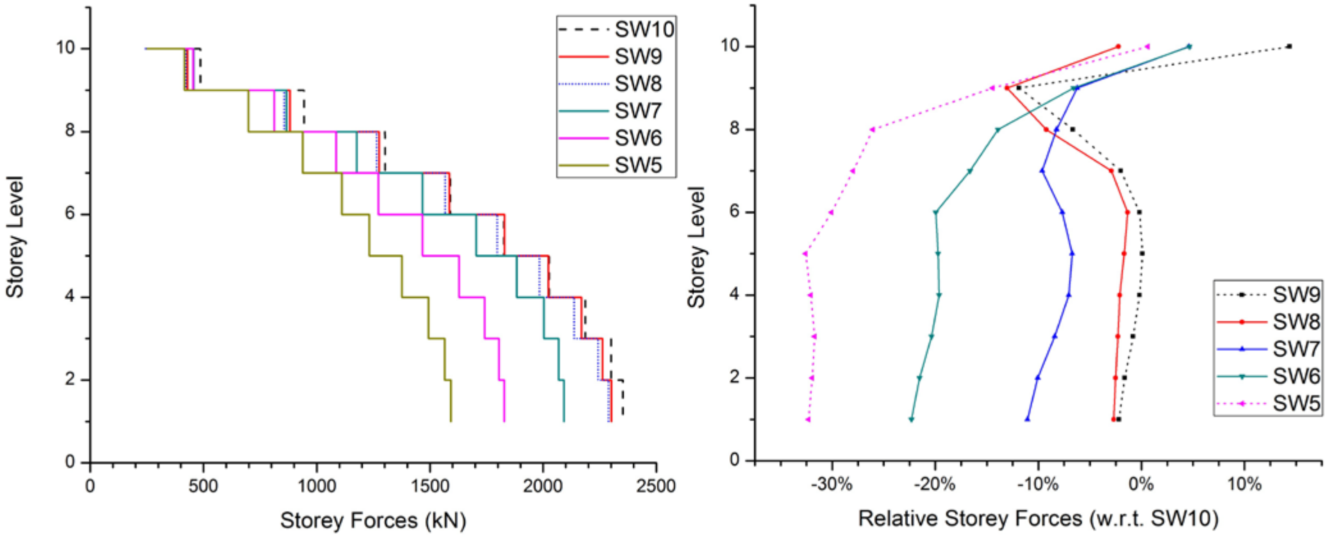


Fig. 5 - Storey Forces

levels varied with a smaller margin and the forces at the top floor were more or less the same. This can be seen in Fig. 5 below.

As soon as the shear walls were terminated at a particular floor, the storey stiffness reduced drastically in that storey (almost 90%). This invited lesser forces and slightly increased displacements. The stiffness of the lower floors remained almost same with a negligible change. The gradual slope for the stiffness curve turns almost horizontal at the curtailment level. It can be seen below in Fig. 6. This sudden decrease in the stiffness is because of the shifting of center of stiffness of the entire structure. When the shear walls get curtailed at the top stories, the center of stiffness moves downwards, providing higher stiffness values near the base and lower values at the top of the structure.

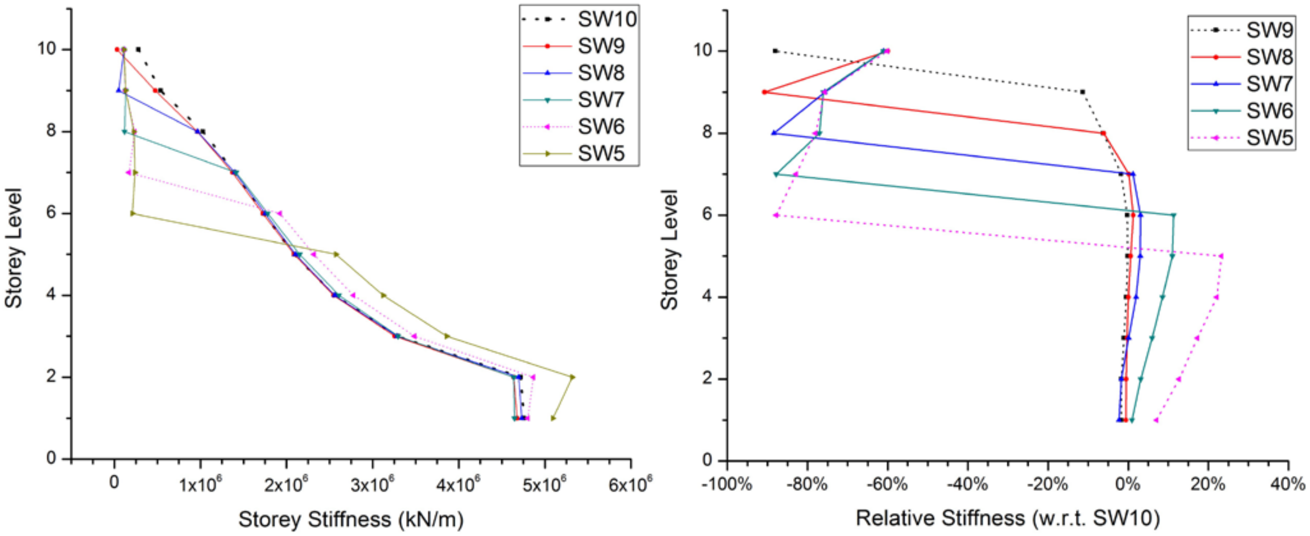


Fig. 6 - Storey Stiffness

IV. SUMMARY & CONCLUSIONS

This paper presented an analytical study of the effects of shear wall curtailment on the structural efficiencies and behaviour of medium rise buildings. Six models were prepared by terminating the shear walls at intermediate stories and then analyzed using RSA. The models displaced acceptable performance in terms if drift and displacements, even when the shear walls were curtailed up to half the height of the original structure. At the level of curtailment, storey drift was increased by almost 40%, floor displacement was increased by 15%, storey forces near the bottom floors got decreased by almost 25% and stiffness was reduced by almost 90%. The method of determining the optimum level of shear wall curtailment, as suggested by Nollet & Smith, 1993 and then later modified by Atik *et al*, 2011 was also discussed. Their findings supported our initial hypothesis that the curtailment of shear walls at some intermediate levels, instead of being detrimental, will prove to be a positive design technique for medium rise and high rise structures. This work can be further expanded by making a comparative evaluation with respect to the findings of Atik *et al*, 2011. For this, the optimum level of curtailment need to be found out using continuum mechanics and then, the same needs to be verified by software modelling using RSA.

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