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Seismic Evaluation with Shear Walls and Braces for Buildings

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Abstract**—**R.C.C. buildings with dual structural system consisting of shear walls (or braces) and moment resisting frames have been widely used to resist lateral forces during earthquakes. The dual systems are designed to resist the total design lateral force in proportion to their lateral stiffness. The response of combination of braces and shear walls has not yet been studied. The combination may prove to be more effective to resist lateral forces during earthquakes. This concept has been applied to regular R.C.C. buildings provided with shear walls, braces and their combinations.

Keywords**—**Dynamic analysis, Displacement, Dual structural system, Storey drift.

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I. Introduction

DUAL structural systems, i.e. systems combining frames and shear walls (or braces) that jointly carry seismic loading, are mostly used for reinforced concrete (R.C.C.) buildings. Shear walls provide excellent control of horizontal displacements both in the lower and in the upper part of the building [1]. Reference [2] analysed framed shear wall panels and concluded that the manner of arrangement of shear walls remarkably affected the maximum base shear caused by earthquakes. The zigzag arrangement of shear wall panels was found to be most effective arrangement in that case. Reference [3] carried out a study to determine optimum configuration in location of shear walls (lift core) in multistory buildings and concluded that shear walls should be placed at locations by coinciding centre of mass with centre of rigidity of the building. As per study conducted by [4] the zigzag shear walls yield better results with respect to lateral deflection and inter-storey drift when compared with conventional shear wall panels. Reference [5] studied seismic behaviour, modes of failure and the factors influencing the structural response of shear walls and proposed some design provisions for shear-walls in terms of general requirement, shear strength requirement, flexural strength, boundary element, coupled shear wall, openings in walls, discontinuous walls etc. Reference [6] investigated the redundancies of special moment resisting frames and dual systems. The factors considered were structural configuration (number of bays and shear walls), interaction between walls and moment frames.

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Reference [7] reported some advantage in using reinforced concrete braced frame over shear wall frame as the former resulted in lesser member forces and floor displacements. Reference [8] studied nonlinear response of braced reinforced concrete frames and concluded that braces raise lateral stiffness and dissipate considerable amount of energy during earthquake loading. The shear is primarily absorbed by the diagonal braces as axial load, thereby creating an efficient structural system.

Reference [9] studied the inelastic seismic response of reinforced concrete frames with concrete bracing members arranged in X and K patterns. They observed that the concept of using bracing members of intermediate slenderness ratio of the order of 80 in reinforced concrete frames was promising. Reference [10] investigated use of steel bracing in concrete-framed structures and found that a substantial increase in the shear resisting capacity of concrete frames could be achieved using diagonal steel X-bracing. It was assessed at four times more than the un braced frame. Reference [11] conducted non-linear dynamic analysis on 5, 10 and 15 storey concentrically braced frames and proposed a simplified analytical model for seismic response prediction.

II Objectives of Study

The structure should have adequate lateral strength, lateral stiffness and sufficient ductility to meet the requirements of safety and minimum damage to non-structural elements, on occurrence of an earthquake. Among the various structural systems, shear wall-concrete frame or brace-concrete frame system is preferred by the designers. It was common in high rise structures to provide either the shear walls or the braces in the outer frames of the building. The combination of shear walls and braces may perform better than provision of the either system in isolation. Therefore this study has been undertaken to compare the seismic response of reinforced concrete frames with shear walls, braces and their combinations.

II. Geometry of the Building Models Studied

Regular R.C.C. buildings consisting of different combinations of shear walls and R.C. braces for 10, 15 and 20 storeyed frames were considered in the study. The plan and isometric view of the buildings is shown in Fig. 1 and the side elevation for different arrangements is shown in Fig 2. The shear walls and braces were provided in the outermost frames of the buildings. Depending upon the provision of combinations, various models of the buildings were designated as shown in the Fig. 2. Size of the columns is

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shown in Table I. All beams and braces were of 350 x 600 mm section and the thickness of shear walls was 250 mm. The columns are assumed to be fixed at base.

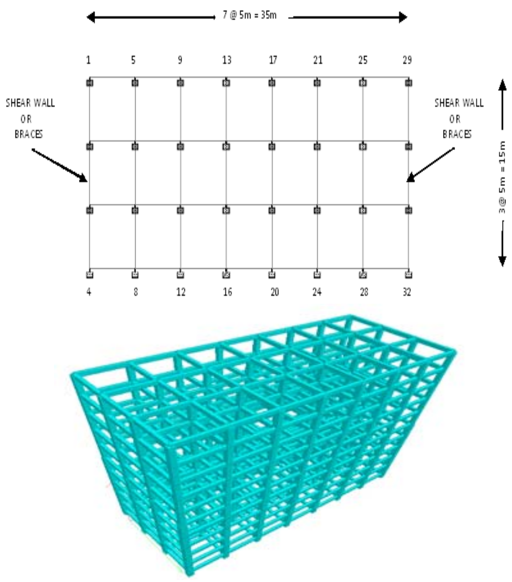

Fig. 1 Plan and isometric view of buildings

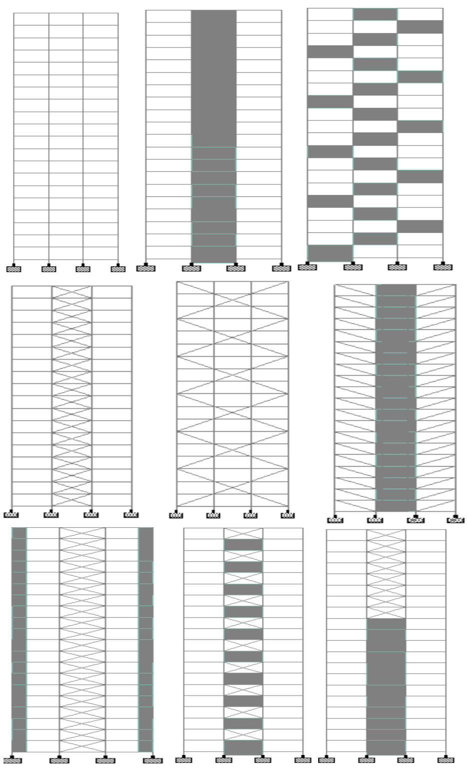

Fig. 2 Side view of buildings (Base, S-100, SZ, B-100, BM, SB-A, SB-B, *SB-C. SB-D)*

TABLE I
SIZE OF COLUMNS AT DIFFERENT LEVELS

Frame	Storey level	Column size (mm)
10-Storey	1 to 5	700 x 700
	6 to 10	550 x 550
15-Storey	1 to 5	700 x 700
	6 to 10	550 x 550
	11 to 15	400 x 400
20-Storey	1 to 7	750 x 750
	8 to 14	600 x 600
	15 to 20	450 x 450

III. METHOD OF ANALYSIS

The dynamic analysis of the buildings was carried out by using three-dimensional modelling in STAAD-Pro. Software and earthquake loads as per IS – 1893: 2002 (Part-I) [12]. Floors were assumed to act as rigid diaphragms. For distribution of earthquake forces, the contribution of six interior frames without shear walls or braces was grouped together and remaining forces were assumed to be taken by the two exterior frames with shear walls or braces. Related factors taken were; Zone factor 0.24, Response reduction factor 5, Importance factor 1.5, Structure type- concrete, Damping 0.05 and Foundation Soil type as medium. Dead load intensity at all floor levels was taken as 6 kN/m^2 and live load as 1.5 kN/m^2 for roof and 3 kN/m^2 for other floors. For calculation of seismic weight no live load was considered at roof level.

IV. RESULTS AND DISCUSSION

The dynamic analysis of 10, 15 and 20 storey frames with and without lateral load resisting elements in different configurations showed that the fundamental time period was not much affected with the change of configuration of lateral load resisting elements, Table II.

TABLE II A
FUNDAMENTAL TIME PERIOD OF DIFFERENT BUILDING MODELS, SECONDS

Models	**Base**	**S-100**	**B-100**	**SZ**	**BM**
20 storey	2.88	2.6	2.6	2.61	2.63
15 storey	2.27	2.02	2.01	2.02	2.02
10 storey	1.35	1.27	1.26	1.27	1.28

TABLE II B
FUNDAMENTAL TIME PERIOD OF DIFFERENT BUILDING MODELS, SECONDS

Models	**Base**	**SB-A**	**SB-B**	**SB-C**	**SB-D**
20 storey	2.88	2.61	2.6	2.59	2.59
15 storey	2.27	2.02	2.01	2.01	2
10 storey	*1.35*	*1.27*	*1.26*	*1.26*	*1.26*

The lateral load resisting capacity of each system of shear walls, braces or combinations could be gauged by the percentage of storey shear shared by the two outer frames containing those elements, reduction of lateral displacement and inter storey drift.

The introduction of shear walls in the exterior frames of a building added to its lateral stiffness and relieved the interior frames of the lateral shear force. In the base frame the share of

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two exterior frames in storey shear was 20 to 24% for 20 storey building, 21 to 24% for 15 storey building and 19 to 23% for 10 storey building, at different storey levels, whereas it increased to 25 to 45%, 26 to 49% and 26 to 40% respectively in the frames with conventional shear walls (S-100). Similarly, introduction of braces also increased the stiffness of frames. In the building with conventional X-braces (B-100) the share went up from 24 to 45%, 26 to 45% and 24 to 37% for 20, 15 and 10 storey buildings respectively, at various storey levels for the two exterior frames.

It was observed that the two outer frames with SB-A combination of shear wall and braces increased the stiffness considerably and contributed the maximum storey shear at different storey levels i.e. to the extent of 36 to 77% in 20 storey frame, 35 to 64% in 15 storey frame and 29 to 46% in the 10 storey frames. However in the 20 and 15 storey frames SZ pattern of shear walls and mega braces had a marginal edge over this combination in a few upper storeys, Figs. 4-6.

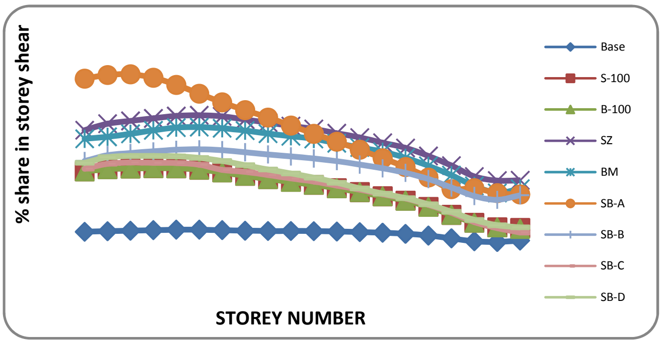

Fig. 4 Share of two exterior frames in storey shear in 20 storey buildings

The lateral displacements of the frames are shown in Figs. 7-9. It was observed that the SB-A combination reduced the maximum lateral displacement over base frame by 73.8%, 72.6% and 80.6% for 20, 15 and 10 storey buildings respectively. It was the highest reduction among all the considered frame configurations. The maximum inter storey drift was also reduced over the base frame from 5.82 mm to 1.86 mm, 5.91 mm to 1.57 mm and 4.63 mm to 0.73 mm in the 20, 15 and 10 storey buildings respectively.

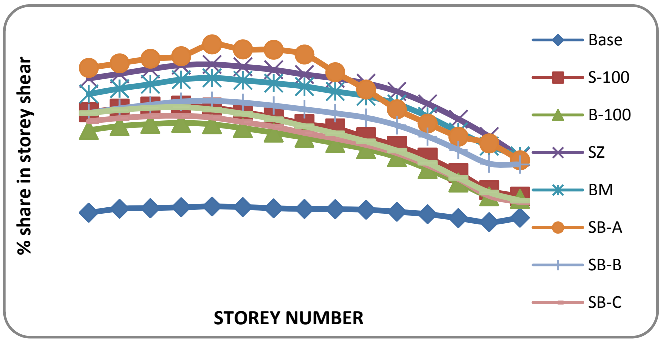

Fig. 5 Share of two exterior frames in storey shear in 15 storey buildings

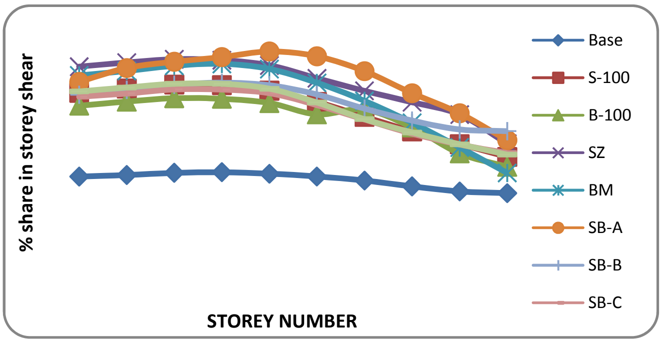

Fig. 6 Share of two exterior frames in storey shear in 10 storey buildings

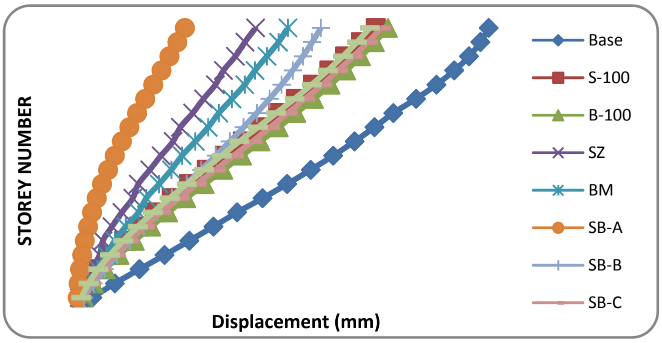

Fig. 7 Lateral displacement of end frames of 20 storey buildings

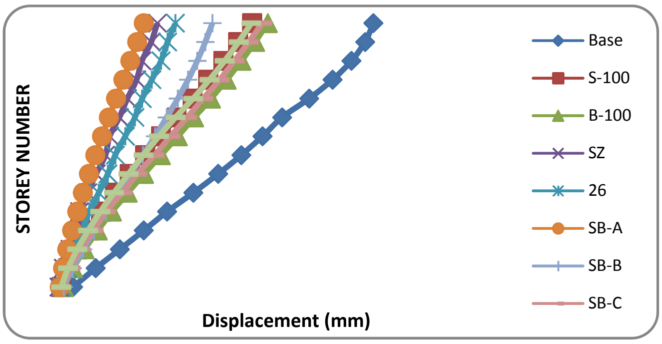

Fig. 8 Lateral displacement of end frames of 15 storey buildings

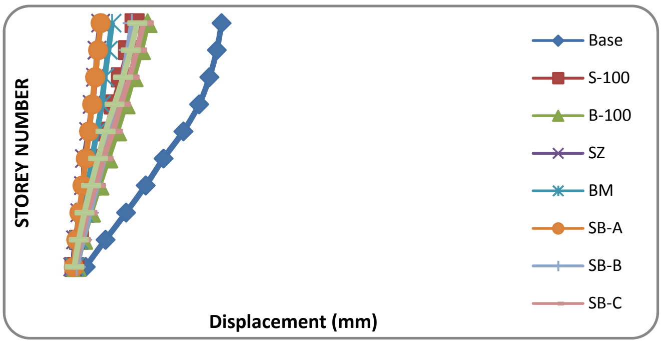

Fig. 9 Lateral displacement of end frames of 10 storey buildings

For comparing the performance of frames in the linear range of deformation Displacement reduction factor (DRF) has been introduced. It has been defined as the ratio of the maximum lateral displacement in the *Base frame* (D_{bf}) minus maximum lateral displacement in a frame with lateral load resisting elements (Shear wall, Braces or combinations, D_{tf}) divided by the maximum lateral displacement in the *Base frame* (D_{bf}).

$$DRF = \frac{Dbf - Dtf}{Dbf}$$

The larger value of the factor indicated more reduction in lateral displacement and more strength of the elements or the system. From the values of DRF and the corresponding graph between total storey number and DRF (Fig. 10) it can be seen that the SB-A combination of shear walls and braces was better choice for buildings of all heights.

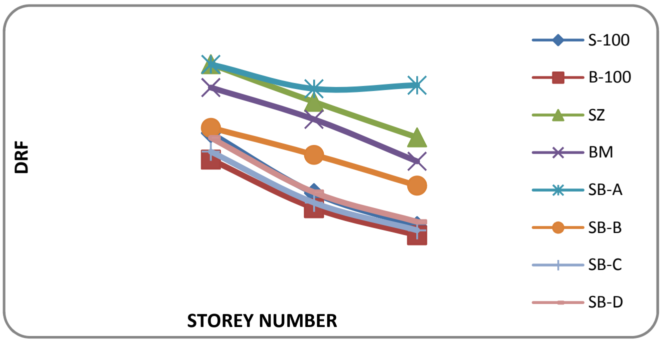

Fig. 10 Displacement Reduction Factors (DRF) of end frames of buildings

V. Conclusions

1. Shear walls and braces improved the seismic performance of frames. The shear walls reduced the maximum lateral displacement at the top of 20, 15 and 10 storey the frames by 27%, 38% and 58% respectively as compared to base frame. The braces reduced the maximum displacement in the same frames by 24%, 33% and 49% respectively.
2. In the present study SZ configuration of shear walls reduced the maximum lateral displacement in 20, 15 and 10 storey frames by 57%, 68% and 81% respectively as compared to base frame. The mega braces (BM) reduced the maximum displacement in the same frames by 49%, 63% and 73% respectively.
3. Combination of braces and shear walls in a specific arrangement (SB-A) containing shear walls in middle bay and braces in the outer bays was the most effective arrangement for lateral load resistance in the elastic range.

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