Seismic Analysis of Precast and Reinforced Concrete Structures

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Abstract

The rapid acceptance of precast structures in construction industry triggers the demand of feasibility analysis of precast structure as earthquake resistant structures across seismic zones. A comparative analysis of three genres of structures, namely, conventional reinforced concrete structure, braced reinforced concrete structure and precast structure for their earthquake resistance was performed. Linear analysis method which includes response spectrum and equivalent lateral force methods was carried out in seismic zones II to V using ETABS 2016 Ultimate 16.2.0. For all the three structures studied, the estimated parameters, namely, storey drift, storey displacement and base shear were within the design limits as per codal recommendations for earthquake resistant design of structures IS 1893. Precast structures showed reduced storey drift and storey displacement by 70% when compared with that of reinforced concrete and braced reinforced concrete structures. Precast structures showed greater base shear than that of reinforced concrete structures by 48%. Overall analysis confirmed the suitability of precast structure as earthquake resistant structures across all seismic zones.

Keywords: *Base shear; Braced structure; Dynamic Analysis; Precast walls; Response spectrum*

1.0 Introduction

"It takes an earthquake to remind us that we walk on the crust of an unfinished planet."

It is a quite natural and genuine need of human to have a dwelling unit that withstands disasters such as cyclones, hurricanes, tornadoes and severe thunderstorms. Earthquake analysis can be performed either linear or non-linear manner. Equivalent Lateral Force (ELF) analysis and Response Spectrum (RS) analysis are examples of linear elastic analysis, while time history method is an example of non-linear analysis.

ELF approach is a static analysis method that defines a series of forces

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acting on a building to represent the effect of earthquake ground motion. This analysis is applicable to buildings which are symmetric, with minimal torsion, less irregularities and no discontinuities. The storey force is generated according to the height at which the storey is located from the seismic base. RS method is a dynamic analysis approach permits the multiple modes of response of a building to be taken into account in the frequency domain. RS method is considered as a best alternative seismic analysis mechanism when time history data is insufficient. The magnitudes of forces in all directions i.e. X, Y & Z are calculated to estimate effects on the structure. It includes combination methods such absolute, square root of sum of squares and complete quadratic combination for combining modal responses. It is applied when structures are either too irregular, too tall or of significance to a community in disaster response. The proposed work is to analyze 3 genres of structures such as conventional Reinforced Concrete structure (RC), reinforced concrete structure with Bracing (BRC) and Precast Structure (PC) in-terms of its earthquake resistant capabilities.

In literature, there is information on linear and non-linear analysis on precast and reinforced concrete structures. Bindurani et.al [1] carried out analysis of a precast multi-storey structure located at Boiwada, Mumbai using ETABS. The structure was modelled in two ways such as integrated model that considers joint behave monolithically and discrete model that with 20mm gap between wall panels. The conclusions drawn are that monolith model is sufficient for moderate seismiccondition and discrete model provides conservative design. Surekha et al. [2] carried outanalysis of load bearing precast wall structure due to lateral loads by using ETABS in different earthquake zones and has observed non-linearity in out of plane moment andshear force. Rao et al. [3] carried out study on G+13 residential building subjected to seismic loads using ETABS software. Non-linear analysis was carried out by considering critical seismic zones and type II soil conditions as defined in IS 1893:2002. Results for various parameters like displacement, storey drift and base shear are plotted and compared.

Alghuff et al. [4] conducted a comparative study of static and response spectrum methods for seismic analysis of regular reinforced concrete buildings using ETABS software. The results show that shear forces obtained using the response spectrum analysis in the X directions are less than those obtained using the equivalent static analysis by 35-60% and by 40-65% in the Y direction for the high-rise building, while for the low-rise building is less by 25% in X direction and 22% in Y direction. Sallal [5] carried out design and analysis of G+8 storey building under seismic and wind load using ETABS software. Various results are obtained like shear forces, bending moment and deflection and are compared with manual design value. Jogdand et al. [6] carried out analysis of three-storeyed pre-fabricated building modelled in SAP2000. In this work, a semi rigid connections wasconsidered at the joints in order to overcome incorrect results obtained due to hinged connections.

Kumar et al. [7] performed an analysis of G+11 storeyed residential buildingwith precast load bearing wall. Various wall forces, displacements and moments have been worked out for different load combinations, and identified lateral load as worst loadcombination. Effect of lateral load on out-of-plane moments, axial forces, shear force, base shear, maximum storey drift and tensile forces on shear wall are plotted. The effect of seismic zone and wind zone are also tabulated. Patil et al. [8] carried out seismic analysis of high-rise building using Response Spectrum Method and STAAD Pro range in a better way. Test results includes base shear, storey drift and storey deflections are presented and suggested effective lateral load resisting system. Jose et al [9] carried out an analysisand design of G+3 commercial building using ETABS software using static method and compared with manual design. It observed that ETABS software provides similar design values for beams and columns as that of manual design. The aim of the work is to compare the suitability of precast structure as earthquake resistant structures.

2.0 Methodology

The analysis using ETABS 2016 Ultimate 16.2.0 is carried out on RC, braced reinforced concrete and precast structures with respect to storey drift, storey displacement and base shear in zone II, zone III, zone IV and zone V using response spectrum and equivalent static lateral force method. Response spectrum method is used to find storey drift, storey displacement and base shear. Equivalent static Lateral Force (ELF) analysis is used to estimate base shear. Structure and precast structure in-terms of its earthquake resistant capabilities. The activities involved in the workare as follows:

2.1.1 To model a G+9 storeyed reinforced concrete structure, braced reinforced concrete structure and precast structure in ETABS 2016 Ultimate 16.2.0.

2.1.2 To perform seismic analysis in terms of seismic parameters such as storey drift, storey displacement and base shear using response spectrum method.

2.1.3 To perform seismic analysis also in terms of base shear using ELF method.

2.1.4 To compare performance of reinforced concrete structure, braced reinforced concrete structure and precast wall panel structure in zone II, zone III, zone IV andzone V seismic zones.

2.2 Building Specifications

Reinforced concrete structure, braced reinforced concrete structure and precast structure are modelled using ETABS 2016 Ultimate 16.2.0. This section provides specifications for each of these buildings.

2.2.1 Reinforced Concrete Building

The plan and position of columns of reinforced concrete structure chosen for analysis areas shown in Fig. 1 and 2. The general building details are given in Table 1. The components details are mentioned in Table 2.

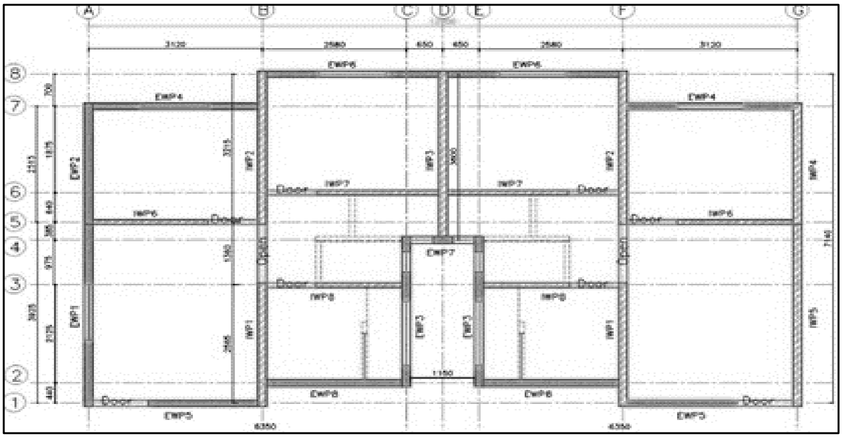

Fig. 1. Plan

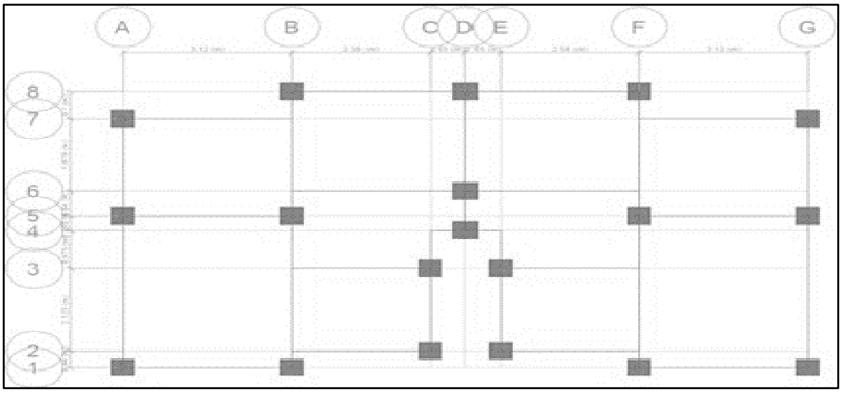

Fig. 2. Position of columns in reinforced concrete structure

Table 1 Building Details

Parameter	Unit / Dimensions
No. of storeys	9
Storey height	3m
Foundation to plinth height	1.5m
Category	Residential

Table 2 Components Specifications

Components	Dimensions
Beam Size	300 x 450mm
Column Size	450 x 450mm
Slab Thickness	150mm
Bracing	ISHB,ISJB,ISLB,ISMB,ISWB
Material type	M40 grade
Rebar	Fe 500 grade

2.2.2 Braced Reinforced Concrete Structure

Braced reinforced concrete structure is designed to resist both vertical and horizontal forces such as wind loads and earthquake forces. The beams and columns carry vertical loads whereas bracing, composed of structural steel members, reduce lateral displacements and bending moments according to IS 808:1964 [10] and SP-6 [11]. Providing bracing is an alternative mechanism to suppress twisting effects in building. 3D view of reinforced concrete structure with X-shaped bracing is as shown in Fig. 3.

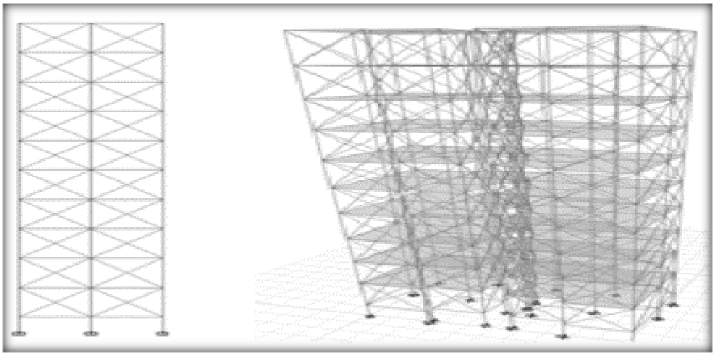

Fig. 3. Braced Reinforced Concrete Structure

2.2.3 Precast Structure

The precast structure consists of precast wall panels and slabs having 150mm thicknessare considered. The plan and 3D view of precast structure as shown in Fig. 4.

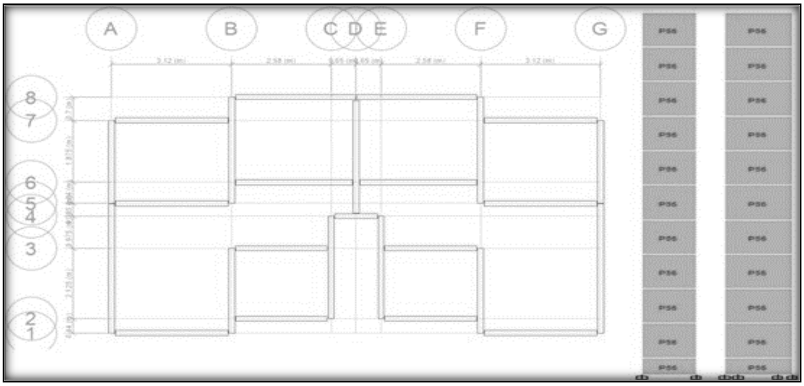

Fig. 4. Precast structure

The ETABS specifications are tabulated in Table 3. The wall panels are modelled using shell element, designated as shear walls and slabs are modelled using membrane elements, designated as rigid diaphragms. The meshing sizes of models are assigned by ETABS software automatically.

Table 3. Specifications of PC Structure

Parameters	**Wall**	**Slab**
Material	Concrete	Concrete
Grade	M40	M40
Element	Shell Thin	Membrane
Thickness	150	150

2.3 Loading Cases

The gravity loading as per IS 875 Part I & II [12, 13] and seismic loading as per IS 1893[14] are considered for the analysis. Fourteen load combinations are adopted as per IS codes of practice. The seismic zones II, III, IV and V are considered for evaluation and corresponding seismic load parameters are shown in Table 4.

Table 4. Seismic Load Parameters

Parameters	Zone			
	II	III	IV	V
Zone factor	0.1	0.16	0.24	0.36
Importance Factor, I	1	1	1	1
Response reduction factor, I	5	5	5	5
Height of structure, h	31.5	31.5	31.5	31.5
Type of soil	II	II	II	II

2.4 Parametric Study in Seismic Zone II

This section provides the behaviour of structure in terms of parameters such as storeydrift, storey displacement and base shear in zone II.

2.5 Storey drift

The storey drift is relative horizontal deflection within the structure and it is an importantparameter to measure with respect to lateral forces as shown in Figure 5. The dimensionsH_b indicates height of the structure, h_i indicates storey height, Δ_i indicates storey drift and Δ_{roof} indicates storey displacement at roof level. With the increased lateral forces, ‘P–delta’ effects also increases which may lead to the failure of structures. In addition, functioning of non- structural elements such as cladding, partitions and pipework should work even after seismic impact. Accordingto IS 1893-2016 [14], the allowable maximum storey drift of the structure measured by response spectrum analysis should not exceed $0.015H_b$ where H_b is the average roof height of structure with respect to the base.

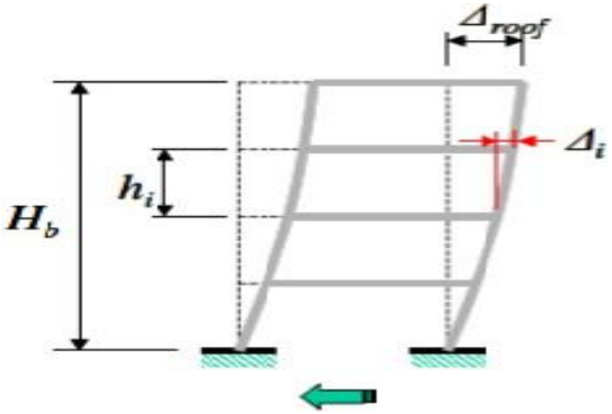

Fig. 5. Storey Drift

The inter storey drift under design base shear V_b, should not exceed 0.004 times storey height, h*i*. The design limitation value of inter storey drift for the structure with floor height of 3m should be ≤12mm.

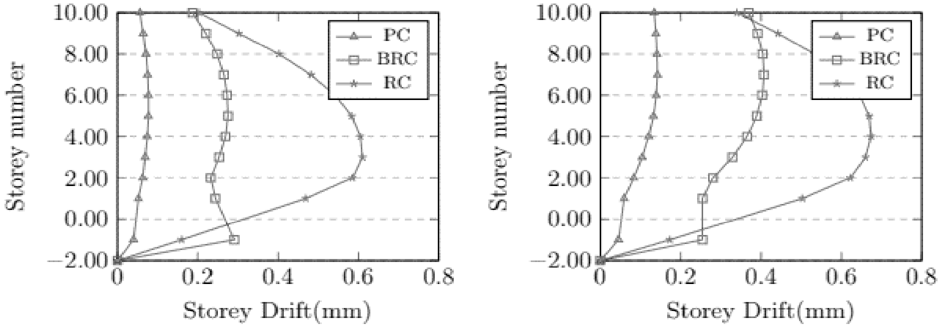

Fig. 6. Variation of Storey Drift w.r.t Storey level (a) X-Direction (b) Y-Direction

It is observed from Figure 6(a) that precast structure is having 86.67% and 70.3% reduction of storey drift in X-direction as compared to reinforced concrete and braced reinforced concrete structures respectively. Also, it is observed from Figure 6(b) that precast structure is having 79.1% and 65% reduction of storey drift in Y-direction as compared to reinforced concrete and braced reinforced concrete structures respectively.

2.6 Storey Displacement

The storey displacement is the relative horizontal deflection of structure with respect to ground level as shown in Figure 7. The dimension H indicates height of the structurefrom base and Δ_1, Δ_2, Δ_3 and Δ_4 are displacements at respective storey levels. According to IS 1893-2016 [14], the allowable maximum storey displacement of the structure measured by response spectrum analysis should be limited to H/500. Where, His total height of structure. The design limitation value of maximum storey displacement for the structure considered with height, H of 31.5m should be ≤ 63mm.

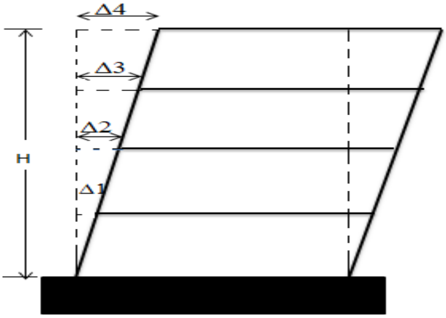

Fig. 7. Storey Displacement

It is observed from Fig. 8a that precast structure is having 86.67% and 73.68% reduction of storey drift in X-direction as compared to reinforced concrete and braced reinforced concrete structures respectively. Also, it is observed from Fig. 8b that pre-cast structure is having 77% and 61% reduction of storey drift in Y-direction as compared to reinforced concrete and braced reinforced concrete structures respectively.

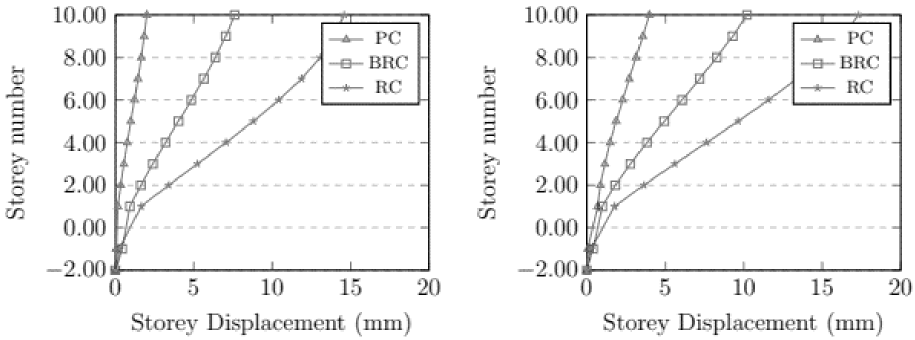

Fig. 8. Variation of Storey Displacement w.r.t Storey level (a) X-Direction and (b)Y-Direction

2.7 Base Shear

The parameter base shear is an estimate of the maximum expected lateral force on thebase of the structure due to seismic activity. It is estimated based on seismic zone, soil material and lateral force equations. The total base shear depends on the total external lateral load on structure due to wind and earthquake. The base shear estimation in this work is carried out by two mechanisms, equivalent static lateral force method and response spectrum method. Both methods are performed as per IS 1893:2016 [14].

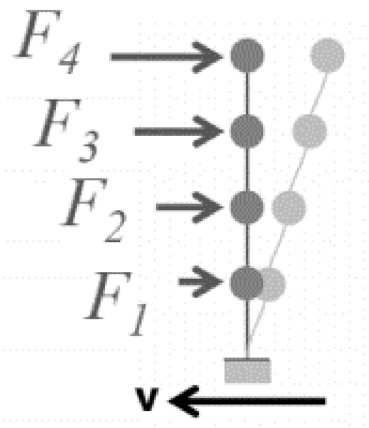

Fig. 9. Base Shear

In ELF method, the algebraic sum of the shear forces from all storeys should be equalto applied lateral load as shown in Figure 9 and it can be represented as in Eq.1. Where V is the seismic base shear and F1, F2, F3 and F4 are storey shear forces at respectivefloor levels.

$$V = F1 + F2 + F3 + F4 \qquad (1)$$

The base shears in X-direction and Y-direction are plotted in Figure 10(a) and Figure 10(b) respectively. It is observed that precast structures are showing increased base shear of 44.8% and 47% with respect to reinforced concrete structures using ELF method and response spectrum method respectively. It is also observed that due to the increased self-weight of braced reinforced concrete structure, it shows an increased base shear of around 24% compared to precast structures during the seismic analysis. The base shear obtained in ELF and response spectrum analysis methods are well within 45kN difference in all 3 genres of structures, precast, reinforced concrete and braced reinforced concrete structures.

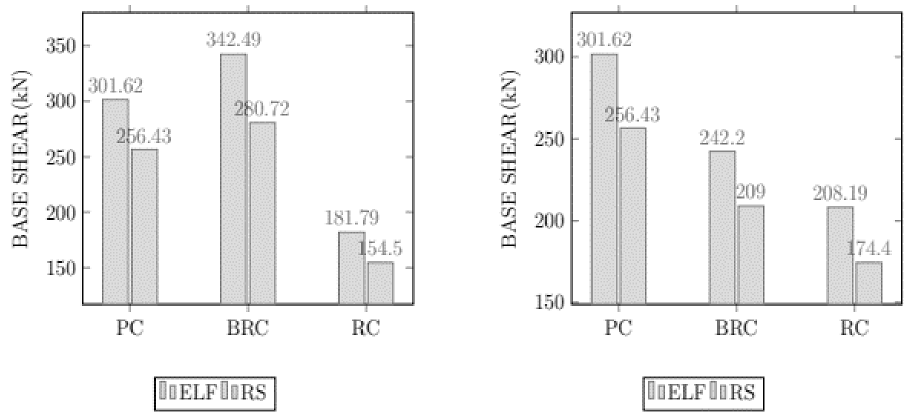

Fig. 10. Base Shear (a) X-Direction (b) Y-Direction

2.8 Zone II Analysis Summary

The behaviour of reinforced concrete structure, braced reinforced concrete structure and precast structures in terms of parameters such as storey drift, storey displacement andbase shear at zone II are shown in Table 5.

Table 5. Zone II

Parameters	Direction	PC	BRC	RC
Storey Drift (mm)	X	0.08	0.27	0.60
	Y	0.14	0.40	0.67
Storey Displacement (mm)	X	2.00	7.60	14.57
	Y	3.98	10.21	17.32
ELF Base Shear (kN)	X	301.62	342.29	181.79
	Y	301.62	242.19	208.19
RS Base Shear (kN)	X	256.43	280.72	154.50
	Y	256.43	209.00	174.40

The major observations are precast structures having lesser storey drift and storeydisplacement compared to reinforced concrete structures and braced reinforced structures. In case of base shear, it was observed that precast structures were having higher valuethan reinforced concrete in both ELF and response spectrum analysis. However, in case of braced structure, it was observed that higher base shear values are obtained by static ELF method, due to the increased self-weight of structure contributed by steel braces. The linear parametric analysis on storey drift, storey displacement and base shear confirm the suitability of precast structure as an earthquake resistant structure for building construction in zone II.

3.0 Parametric Study in Varying Seismic Zones

3.1 Parametric Analysis in Zone III

The parametric estimation on reinforced concrete structure, braced reinforced concrete structure and precast structure in zone III are tabulated in Table 6.

Table 6. Zone III

Parameters	Direction	PC	BRC	RC
Storey Drift (mm)	X	0.12	0.44	0.90
	Y	0.22	0.63	1.04
Storey Displacement (mm)	X	3.19	12.13	23.28
	Y	5.92	15.73	26.58
ELF Base Shear (kN)	X	482.59	666.00	290.87
	Y	482.59	550.98	328.30
RS Base Shear (kN)	X	410.21	556.24	247.20
	Y	410.21	472.98	279.00

The analysis of mentioned structures in Zone III provides the following insights aboutprecast structures. In comparison with reinforced concrete structure, precast structure is showing reduced storey drift of 86.6% in X-direction and 78.8% Y-direction. With respect to braced reinforced concrete structures, they are showing reduced storey drift of 72.7% in X-direction and 65% in Y-direction respectively. The analysis on storey displacement also indicates reduced values compared to both reinforced concrete and braced reinforced concrete structures. Compared to reinforced concrete structure, precast structures are showing reduced storey displacement of 86.29% in X direction and 77.7% in Y-direction. With respect to braced reinforced concrete structures, they are showing a reduction of 73.7% in in X-direction and 62.3% in Y-direction. Precast structures are showing increased base shear by around 65.9% in X-direction and 46.9% in Y-direction with respect to reinforced concrete structures for both ELF and response spectrum analysis. Due to increased self-weight of braced reinforced concrete structure,it shows increased base shear in X-direction and Y-direction of around 27.5% and 12.4% respectively compared to precast structures.

3.2 Parametric Analysis in Zone IV

The parametric estimation on reinforced concrete structure, braced reinforced concrete structure and precast structures in zone IV are tabulated in Table 7.

Table 7. Zone IV

Parameters	Direction	PC	BRC	RC
Storey Drift (mm)	X	0.18	0.65	1.40
	Y	0.33	0.94	1.50
Storey Displacement (mm)	X	4.79	18.07	34.89
	Y	8.50	23.06	38.93
ELF Base Shear (kN)	X	723.39	1009.2	436.30
	Y	723.39	848.78	493.45
RS Base Shear (kN)	X	615.26	857.84	370.80
	Y	615.26	721.44	418.60

The analysis of mentioned structures in Zone IV provides similar insights about precast structures. In comparison with reinforced concrete structures, precast structures are showing reduced storey drift of 87.1% in X-direction and 78.0% Y-direction. With respect to braced reinforced concrete structures, they are showing reduced storey drift of 72.0% in X-direction and 64.8% in Y-direction respectively. Similarly, compared to reinforced concrete structure, precast structures are showing reduced storey displacement of 86.2% in X direction and 78.1% in Y-direction. With respect to braced reinforced concrete structures, they are showing a reduction of 73.4% in in X-direction and 63.1% in Y-direction. Precast structures are showing increased base shear by around 65.8% in X-direction and 46.7% in Y-direction with respect to reinforced concrete structures forboth ELF and response spectrum analysis. Due to increased self- weight of braced rein- forced concrete structure, it shows increased base shear in X-direction and Y-direction of around 28.3% and 14.7% respectively compared to precast structures.

3.3 Parametric Analysis in Zone V

It was observed that the parametric analysis results obtained in seismic zone V also indicates similar trends in results as that of other seismic zones II, III and IV. The parametric estimation on reinforced concrete structure, braced RC structure and precaststructures in zone V are tabulated in Table 8.

Table 8. Zone V

Parameters	**Direction**	**PC**	**BRC**	**RC**
Storey Drift (mm)	X	0.27	0.98	2.20
	Y	0.49	1.40	2.30
Storey Displacement (mm)	X	7.18	26.29	52.32
	Y	12.51	33.08	57.46
ELF Base Shear (kN)	X	1085.80	1598.10	654.45
	Y	1085.80	1326.70	738.68
RS Base Shear (kN)	X	992.95	1430.69	556.30
	Y	992.95	1149.78	627.90

In comparison with reinforced concrete structures, precast structures are showing reduced storey drift of 87.7% in X-direction and 78.6% Y-direction. With respect to braced reinforced concrete structures, they are showing reduced storey drift of 72.4% in X-direction and 65.0% in Y-direction respectively. Similarly, compared to reinforced concrete structure, precast structures are showing reduced storey displacement of 86.2%in X direction and 78.2% in Y-direction. With respect to braced reinforced concrete structures, they are showing a reduction of 72.6% in in X-direction and 62.1% in Y- direction. Precast structures are showing increased base shear by around 65.9% in X- direction and 46.9% in Y-direction with respect to reinforced concrete structures for bothELF and response spectrum analysis. Due to increased self-weight of braced reinforced concrete structure, it shows increased base shear in X-direction and Y-direction of around32.0% and 18.1% respectively compared to precast structures.

4.0 Conclusion

The major observations from the comparative seismic analysis of precast structures with respect to reinforced concrete structures and braced reinforced concrete structures are:

a. Precast structures are having reduced storey drift and storey displacement compared to reinforced concrete and braced reinforced concrete structures in all seismic zones.

b. With respect to braced reinforced concrete structures, precast structures shows

- A reduced storey drifts of around 72% in X-direction and 65% in Y-direction.
- A reduced storey displacement of around 73% in X-direction and 62% in Y-direction.
- A reduced base shear approximate 32% in X-direction and 18% in Y-direction

c. With respect to reinforced concrete structures, precast structures shows

- A reduced storey drifts of around 87% in X-direction and 79% in Y-direction.
- A reduced storey displacement of around 86% in X-direction and 78% in Y-direction.

d. Precast structures possess large lateral stiffness and does not require any additional bracing, so it is economicallyviable than braced structures.

e. It was also observed both equivalent static lateral force method and response spectrum method yields comparable base shear estimations.

The work confirms the suitability of precast structure as earthquake resistant structures across all seismic zones.

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