

# Comparative Study on Low-, Medium- and High-Rise RC Framed Buildings Using Force-Based Design Method and Direct Displacement-Based Design Method



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## 1 Introduction

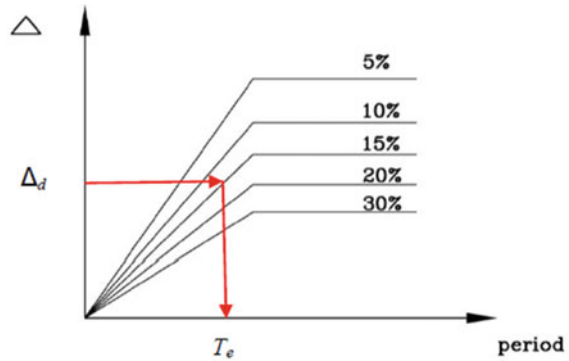
Earthquake is the most destructive of all hazards that kills people, destroys nature leaving behind a huge damage. In India, reinforced concrete moment frame structures have been developed and designed using seismic design and IS 13920: 1993, IS 1893 (Part 1): 2002 [6, 7] for several decades. These Indian standard codes are based on force-based design (FBD). Based on computations from elastic analysis of internal forces, every component of the structure is designed for strength so that the structure can survive low intensities without damage, can survive intermediate intensities without structural damage and can survive higher intensities without full collapse of the structure. In the recent years, studies have shown a progressive trend away from this stance, with researchers acknowledging that increase in strength may not enhance safety, or prevent damage. A four-storey RC structure was modelled and designed as per IS 456:2000 and analysed in SAP2000 v17 for life safety performance level, storey drift, pushover curve, capacity spectrum curve, performance point and plastic hinges as per FEMA 273 were discovered [4]. Base shear, storey drift, steel and concrete consumption at the performance point for 8-, 10-, 12-, 14- and 16-storey buildings were evaluated utilizing FBD and Direct displacement-based design (DDBD) approaches, with the DDBD technique proving to be the most cost-effective [9]. With hysteretic parameters and the high-mode effect, performance-based seismic design of self-centring steel frames with smart memory alloy bracing was investigated [3]. Seismic resistance design has undergone a major reassessment recently that focuses on shifting from ‘strength’ to ‘performance’ [1]. It was discovered that if plastic hinges are installed in beams rather than columns, the building

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**Fig. 1** Displacement response spectrums for various effective damping ratios [8]

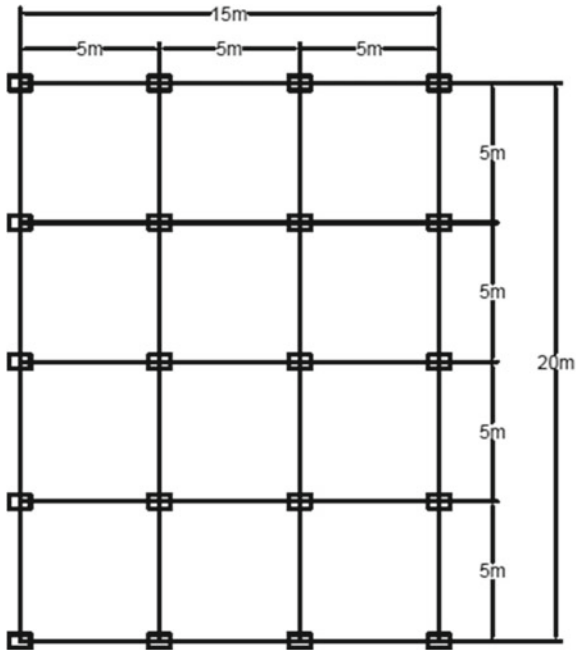


frame would perform better during a seismic event. This can be seen as the beginning of performance-based seismic design, where the structure performance is used as a function of the design process [2].

In this investigation, the considered approaches to compare the building models are first the force-based approach, which is based on calculating the base shear force from the dynamic effect of earthquakes utilizing the acceleration response spectrum and the building's elastic period. Static lateral force actions, which are equivalent to most design symbols are used to model these effects by applying a force to each floor level, which is directly proportional to height [8] (Fig. 1). Second, the DDBD method which makes use of displacement response spectrum for computing the base shear force. It is the simplest design technique to analyse a structure with multiple degrees of freedom. The design technique is based on obtaining a specified displacement limit condition at the design level, which is established by either material strain limits or non-structural drift restrictions from design standards under seismic intensity [10, 11]. This procedure eliminates problems in strength-based design (FBD), in which it uses initial stiffness to define the elasticity period which is a fault seen in most of the building codes [5].

## 2 Modelling and Analysis

For comparing the considered approaches, a typical plan is considered which is shown in (Fig. 2). The number of storeys considered for low-, medium- and high-rise buildings is 4, 8 and 12, respectively, with a typical storey height of 3 m. There are three spans in the X direction and four spans in the Y-direction, each measuring 5 m in length. The detail of member sizes of the buildings under study is shown in (Table 1).



**Fig. 2** Typical plan view

**Table 1** Member sizes of all building models

Type of Building	Structural Elements	Width (mm)	Depth (mm)	
4 storey	Beam	250	400	
	Column	350	350	
	Slab thickness	120 mm		
8 storey	Beam size in X-direction	300	500	
	Beam size in Y-direction	300	600	
	Column	4–8 storey	400	400
		1–3 storey	450	450
Slab thickness	120 mm			
12 storey	Beam size in X-direction	300	500	
	Beam size in Y-direction	300	600	
	Column	6–12 storey	450	450
		1–5 storey	550	550
Slab thickness	120 mm			

**Table 2** Maximum storey drift values

Building model	Storey drift		
	FBD method	DDBD method	Difference in %
Low rise	0.001331	0.000917	18
Medium rise	0.000805	0.000484	25
High rise	0.000838	0.000457	29

### 3 Loading Data

The wall load on all beams and live load is taken to be as 13.8 kN/m and 3 kN/m<sup>2</sup>, respectively. The three building models are considered to be at Zone V with a zone factor of 0.36. The soil is taken to be as medium soil. The importance factor and response reduction factor are 1 and 3, respectively, according to IS 1893: 2016.

### 4 Results and Discussion

In this section, the considered methods are used to analyse and create the three building models.

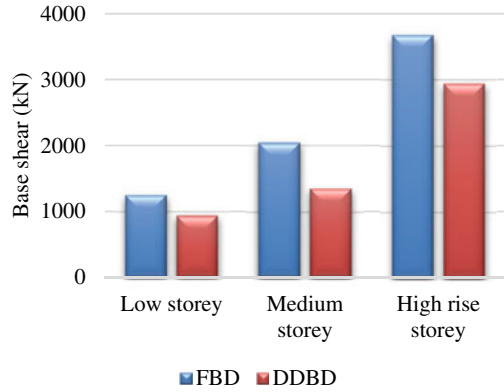
#### 4.1 Comparison of Base Shear of All Building Models by Both Methods

The base shear calculated for all the three building models using FBD method as per IS 1893:2016 and base shear calculated by DDBD method is shown in (Fig. 3). It is observed that the total base shear shown by DDBD for 4, 8, and 12 storeys are 14%, 20% and 11%, respectively, lesser than that compared to FBD. The reduction in the base shear demand of the building models as per DDBD confirms the possibility of economical sizes of the members.

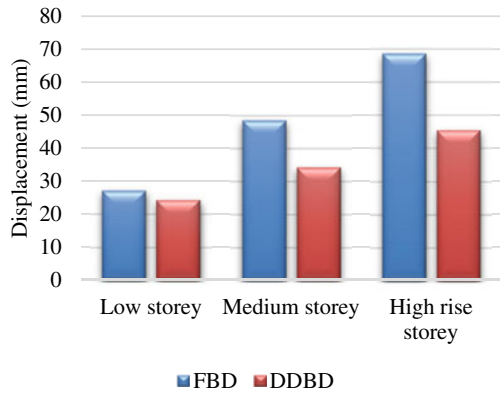
#### 4.2 Comparison of Storey Displacement of All Building Models by FBD and DDBD Methods

The storey displacement for all the three structure models using FBD approach as per IS 1893:2016 compared with storey displacement by DDBD method is shown in (Fig. 4). It is observed that the maximum storey displacement shown by DDBD

**Fig. 3** Maximum base shear



**Fig. 4** Maximum storey displacement



for 8, 10, and 12 storeys are 13%, 17.2% and 20.3% less than when compared to FBD, respectively. The results showed significant reduction of displacement by using DDBD method which may be directly related to the reduced damage level in the framed buildings.

### 4.3 Comparison of Storey Drift of All Building Models by FBD and DDBD Methods

From (Fig. 5), it is observed that highest storey drift values for DDBD are less than the FBD approach in all the building models. The table infers that the drift of the building models are appreciably reduced when DDBD method is used (ref. Table 1). It is also observed that for all the building models, the maximum drift value did not exceed the drift limit (0.004) as given in IS 1893:2016, which means that the structure is within the permissible limit. From (Fig. 6a-c), the maximum storey drift

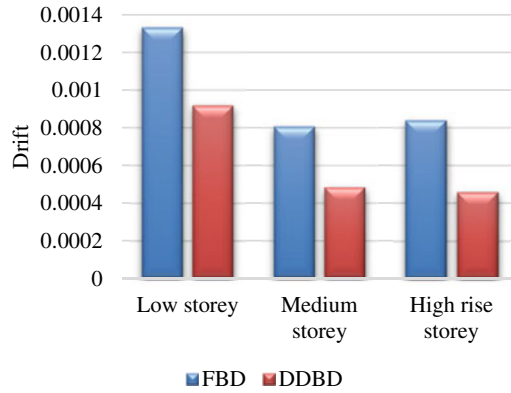


Fig. 5 Maximum storey drift

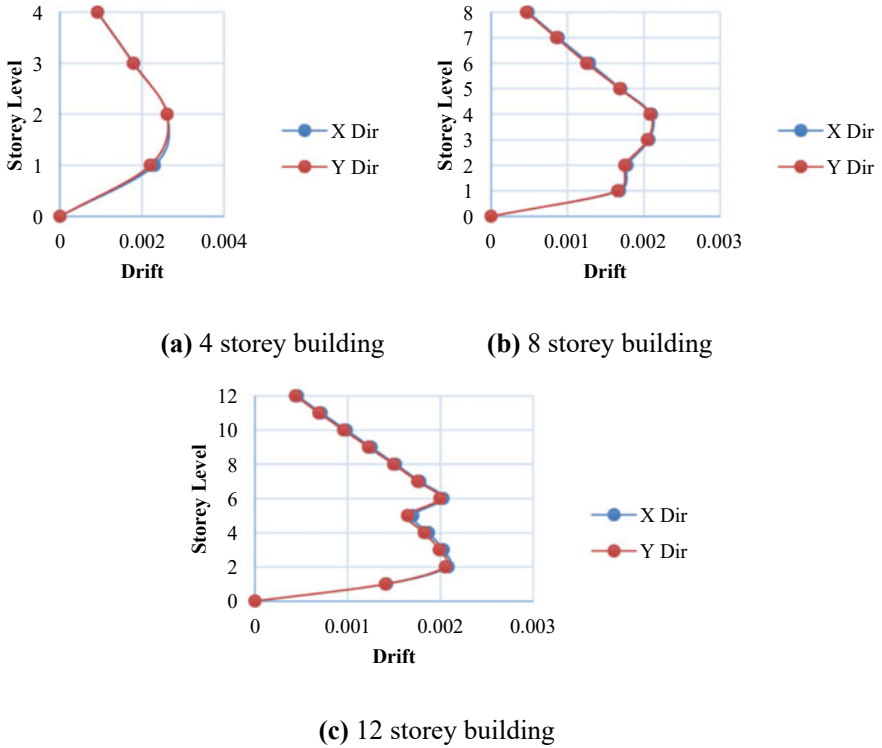


Fig. 6 Storey drift of building models

**Table 3** Comparison between reinforcement requirements of all building models

Building type and design method	Beam Rebar %	Column Rebar %	Beam Req. area (mm <sup>2</sup> )	Difference in %	Column Req. area (mm <sup>2</sup> )	Difference in %
Low-rise FBD	1.5	3.75	1497	16.3	4600	22.84
Low-rise DDBD	1	2.11	1077		2889	
Medium-rise FBD	1.52	2.25	1744	22.47	4549	24.64
Medium-rise DDBD	1.1	1.36	1104		2750	
High-rise FBD	1.6	2.24	3093	35.95	6770	31.2
High-rise DDBD	1	1.17	1457		3545	

value for 4-storey building occurs at its second storey level, for 8-storey building the maximum drift value is at its fourth storey level and for 12-storey building the maximum drift value is at its sixth storey level. The maximum drift is found at the mid-height of the respective structure model (Table 2).

#### 4.4 Comparison of Reinforcement Requirements

The reinforcement percentage and rebar area for all the three building models using FBD method and DDBD method is shown in (Table 3). It is observed that in buildings designed with direct displacement-based method requires reinforcement area for beam 16.3%, 22.47% and 35.95% less for 4, 8, and 12 storeys, respectively, than the building models designed with force-based method. The reinforcement area for column for building designed with DDBD requires 22.84%, 24.64% and 31.2% less for 4, 8, and 12 storeys, respectively, than the building models designed with FBD as per IS 1893:2016. It is found that as the floor level rises, the variation in percentage of reinforcement area also increases, from which is understood that at lower rise building models it is sufficient to follow FBD method.

#### 4.5 Responses at Performance Point

The response of all the building models at performance point is shown in (Table 4). The load factor and material safety force in FBD building models are meant to provide actual steel for increased force. The building models are not designed using load

**Table 4** Response of all the three structure models at performance point

Building model	Applied base shear V (kN)		Base shear at performance point (kN)		Displacement (mm)		Effective damping (%)		No. of hinges			
									IO		LS	
Direction	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Low-rise FBD	1245	1261	5471	5631	27	26.4	0.051	0.052	71	34	–	–
Low-rise DDBD	1006	1032	1363	1429	24.24	24.6	0.06	0.068	156	133	–	–
Medium-rise FBD	2042	2087	7289	7311	44.4	43.5	0.05	0.05	97	81	62	67
Medium-rise DDBD	1851	1913	1402	1564	34.2	33.6	0.062	0.064	212	190	120	129
High-rise FBD	3675	3760	8752	8512	68.5	67.88	0.051	0.051	149	162	92	63
High-rise DDBD	2942	3006	2174	2263	45.4	44.7	0.064	0.066	282	276	146	135

factor and material factor because DDBD is a performance-based design. Therefore, base shear values at performance point are greater in FBD building model than in DDBD building model. The hinge formation in all the building models under study is shown in (Fig. 7). It is found that all the hinges remain at immediate occupancy state for low-rise building. There are hinges formed at immediate occupancy state and life safety state for medium-rise and high-rise building models.

## 5 Conclusion

From the comparison of parameters like base shear, storey drift, storey displacement, reinforcement requirement and hinges, the following conclusions are found:

- DDBD approach showed lower base shear value than FBD approach (as per IS 1893:2016). Base shear from DDBD is 14%, 20% and 11% for 4, 8 and 12 storeys, respectively, less than that of FBD. As medium-rise building has the higher difference, DDBD is more suitable for medium-rise building.
- It is found that the structures designed with DDBD approach are cost-effective than those by FBD approach. It is observed that as the storey level increases, the differences in percentage of reinforcement area also increases, from which it can be concluded that for low-rise building models, it is sufficient to follow FBD method.

Lots of improvements in the DDBD are being researched in terms of economy and seismic performance of buildings and other infrastructure. The current study can be extended to the existing buildings for the purpose of retrofitting or strengthening if required.



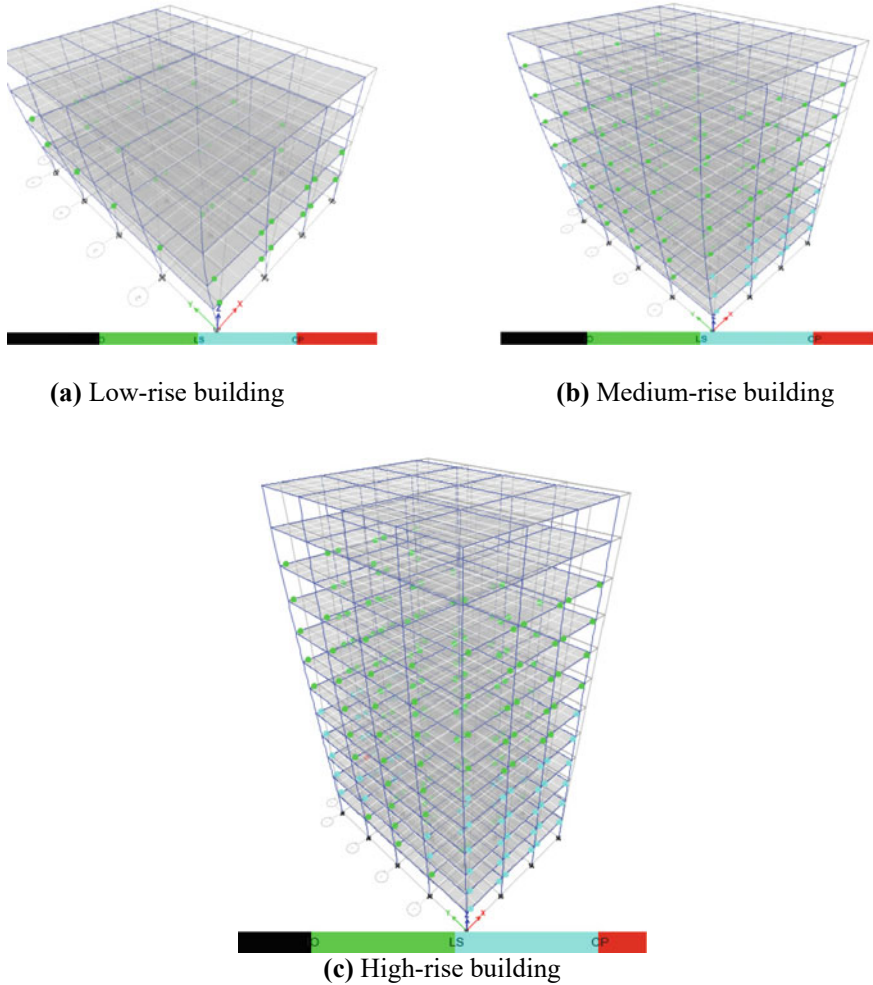


Fig. 7 Hinge formation of building models

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