

A Comparative Study of FBD and DDBD of Two-Dimensional Steel Frames with Concentric Bracings



U. Sadhana and S. Karthiga

1 Introduction

Earthquake is one of the natural catastrophes that are random and uncertain. As these earthquake forces cause damage to the structures, the engineering tools need to be enhanced for the analysis of structures constructed in seismically active regions. The Direct Displacement-Based Design (DDBD) is based on Force-Based Design (FBD), the ideal difference between both the methods are based on the displacement of the structure. In FBD, displacement of the structure is the final outcome to access the design performance level of the building, whereas the DDBD procedure applies designed target displacement. The main objective of DDBD procedure is to manage the structural deformations in order to control the structural damage [1]. The displacement profile is determined based on two criteria such as limit material strain and code specified drift limits [2, 3]. In this study, the drift limit of 0.020 was considered and the design procedure was carried out. Various methods were considered for the design procedure of DDBD.

2 Modelling and Analysis

The modelling and analysis of the concentrically braced steel frames were prepared using Structural Analysis Program SAP 2000 (version 14). Totally, 21 two-dimensional (2D) steel frames with concentric bracings [4] of height 15 m (5 storey), 30 m (10 storey), and 45 m (15 storey). The steel frames were modelled with 3 m constant storey height and 6 m bay width of 6 m. The gravity loads (dead load and

U. Sadhana · S. Karthiga (✉)

Department of Civil Engineering, College of Engineering and Technology, SRM Institute of Science and Technology, SRM Nagar, Kattankulathur 603203, Tamil Nadu, India
e-mail: karthigs@srmist.edu.in

Table 1 Sectional properties of beams, columns and bracings

No. of storey	Beam elements (mm)	Column elements (mm)	Bracing elements (mm)
5	ISWB 300	ISWB 225	ISA 200 × 200X12
10	ISWB 350	ISHB 300	ISA 200 × 200X12
15	ISWB 300	ISHB 350	ISA 200 × 200X12

imposed load) on each storey were distributed as its own structure weight and the live load according to commercial buildings as per code [5]. ASTM A992Fy50 steel materials were used and the steel sections including the bracings were assigned as per code [6] after a series of iteration. The steel frames were sketched for the most actively seismic zone V [7] with a peak ground acceleration of 0.48 g and analysed for seven different ground movements [8]. The dimensions of beams, columns and bracings used in the study are shown in Table 1.

The elements of the steel frames were designed for flexural hinges as per code [9] and the ends are assigned with rigid support. The 2D steel frames modelled and designed by FBD were analysed by non-linear time history analysis. The concentrically braced steel frames at different levels are shown in Fig. 1. Further, design steps were carried out for DDBD procedure based on Priestly method.

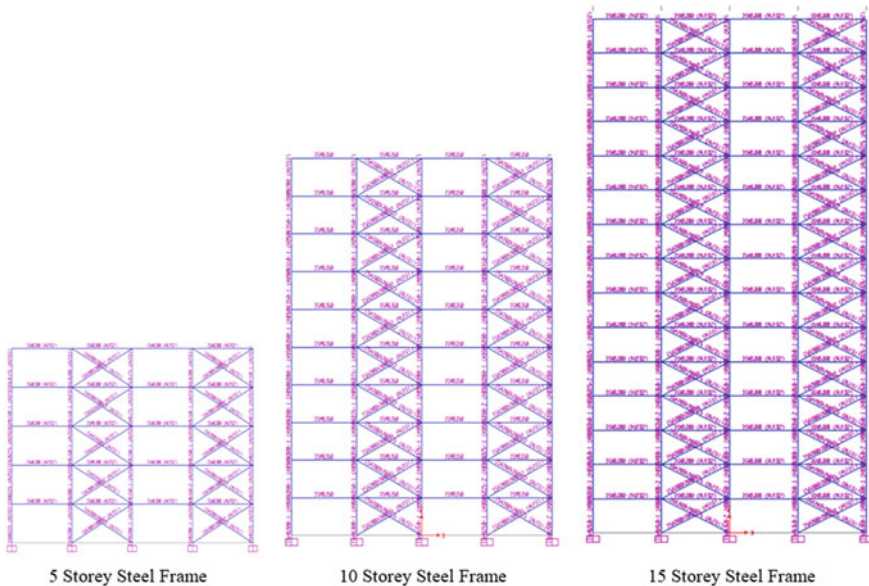


Fig. 1 Modelling of steel frames with concentric bracing

3 Results and Discussion

This paper elaborated the modelling, design and analysis of 2D concentrically braced steel frames (5S, 10S and 15S) of 5, 10 and 15 stories. The performances of the concentrically braced steel frames are evaluated by comparing their interstorey drift and base shear values. The results are shown below.

3.1 Interstorey Drift

Interstorey drift is defined as the relative displacement between one storey to the other storey, which is used as the parameter to examine the performance of the structure. The drift values are calculated from (Eq. 1) for FBDesign procedure.

$$\text{Interstorey drift} = \frac{(\Delta_{n+1} - \Delta_n)}{h} \tag{1}$$

- Δ_{n+1} = Displacement at n+1th storey.
- Δ_n = Displacement at nth storey.
- h = height of storey.

The drift values of 5-, 10- and 15-storey 2D steel frames with concentric bracings for different ground motions by FBD and DDBD method are plotted below in Figs. 2, 4 and 6 and Figs. 3, 5 and 7, respectively.

Fig. 2 Drift values by FBD (5S)

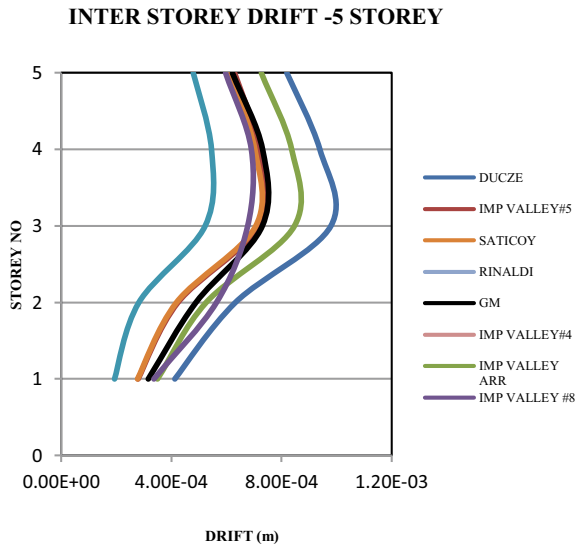


Fig. 3 Drift values by DDBD (5S)

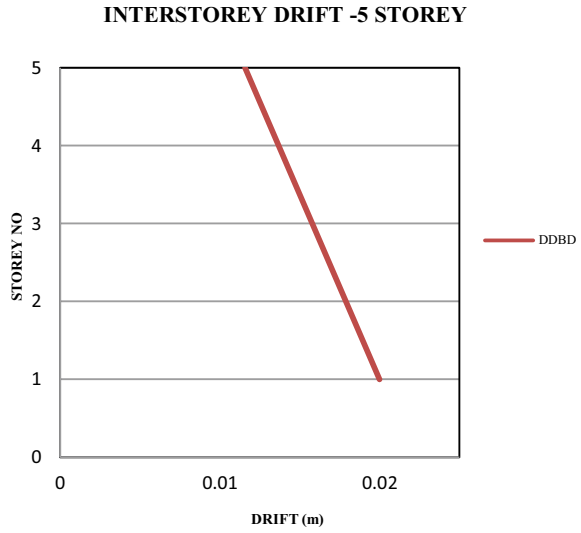
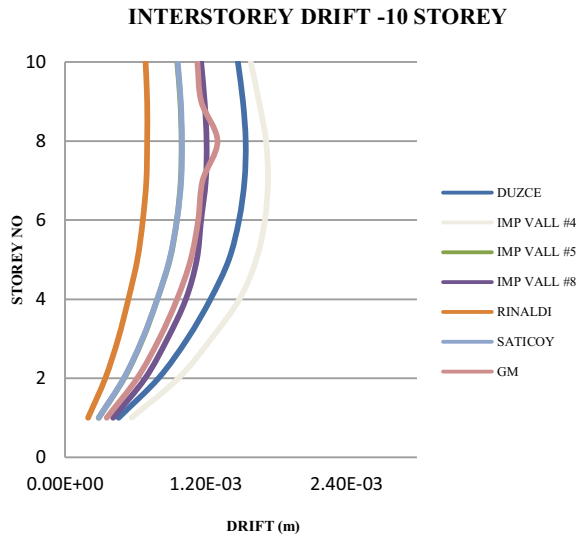


Fig. 4 Drift values by FBD (10S)



From the figures, it's clear that the interstorey drift value initially increases as the storey increases and then reduces as it reaches upper stories. The interstorey drift value gets increased by 56%, 66.8% and 79.5% at the intermediate stories for 5S, 10S and 15S frames, respectively, and then decreases by 15.1%, 5.15% and 6.83% for 5S, 10S and 15S frames, respectively, as the storey height increases. Generally, intermediate stories experiences higher interstorey drift values compared to lower and upper stories because of the elastic behaviour of lower and upper stories.

Fig. 5 Drift values by DDBD (10S)

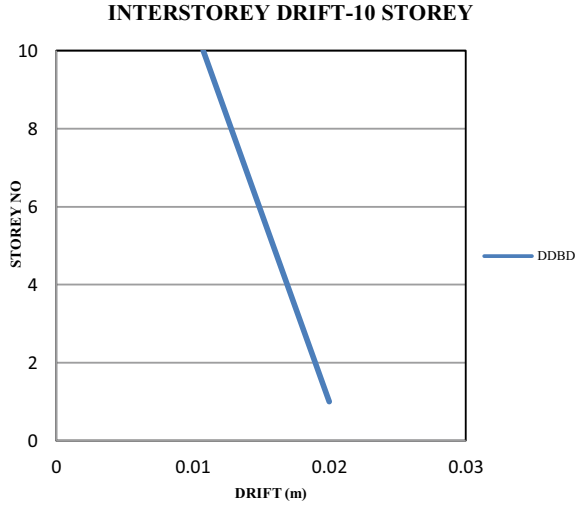
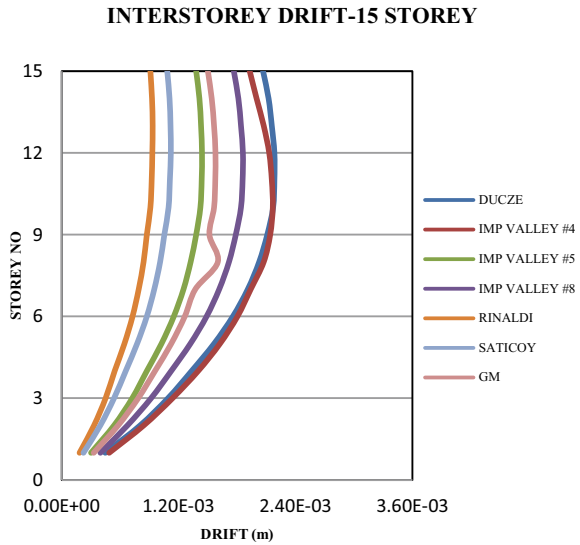


Fig. 6 Drift values by FBD (15S)



The design storey displacement (Δ_i) values for DDBD procedure was calculated manually by (Eq. 2) then the drift values are calculated from (Eq. 1), [10, 11].

$$\Delta_i = W_{\Theta} \Theta_c H_i \frac{4H - H_i}{4H - H1} \tag{2}$$

H_i = Storey Level at i Storey.
 H = Total Height of the frame.

Fig. 7 Drift values by DDBD (15S)

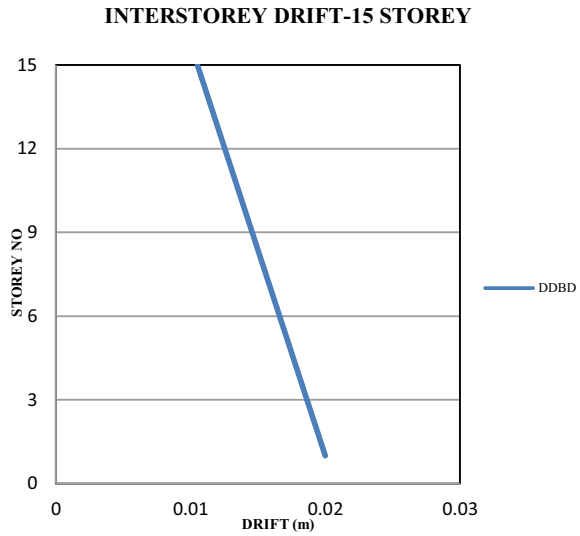


Table 2 Comparison of interstorey drift values

No. of storey	FBD	DDBD
5	0.00073	0.015
10	0.0013	0.015
15	0.0016	0.015

H1 = Height of first storey.

$W_o = 1.15 - 0.0034 H \leq 1.0$ is a reduction factor.

θ_c = Code drift limit.

The interstorey drift values are compared between FBD and DDBD of 2D steel concentrically braced frames are compared for their geomean values and are shown below in Table 2.

The interstorey drift values of DDBD is 95.4, 91.3 and 89.2% higher than the FBD for 5S, 10S and 15S frames, respectively, because of the rigid behaviour of the FBD, while the DDBD is more flexible in nature which helps in achieving higher drift values.

3.2 Base Shear

Base Shear is the measure of the expected lateral forces that occur at base of the structures during the earthquake. Typically, earthquake damage occurs at the base of the building and then the cracks develop due to the shear force. Hence, base shear is used as the parameter to define the performance of the structures. For FBD method,

Fig. 8 Comparison of base shear values

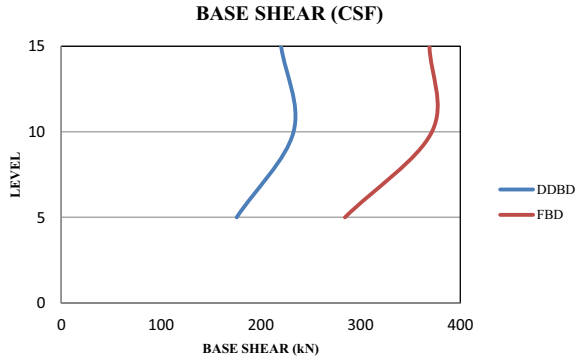


Table 3 Base shear values of concentrically braced steel frames

No. of storey	FBD (kN)	DDBD (kN)
5	285	176
10	371	288
15	370	220

time history analysis of 5S, 10S and 15S steel frames were carried out and their geomean for base shear was calculated. In DDBD procedure, base shear (V_{base}) is calculated from (Eq. 3) [12]

$$V_{base} = K_e \Delta_d \tag{3}$$

K_e = Effective Stiffness (kN/m); Δ_d = Design Displacement (m).

The comparison of base shear values for 5, 10 and 15 stories of concentrically braced steel frames (CSF) is plotted in Fig. 8.

The base shear values of FBD and the DDBD are compared in Table 3.

On comparing the base shear of steel frames with concentric bracings shows that the values of FBD are greater than DDBD procedure. Table 3 indicates that the base shear values of FBD are greater than the DDBD by 61.7%, 29.3% and 67.43% for 5S, 10S and 15S, respectively, frames are indicated in Table 3.

4 Conclusion

This paper has explained the comparative study of DDBD and FBD, the methodology has been applied to 2D steel frames with concentric bracings.

- (a) The above experiment shows that the interstorey drift values of DDBD is 95.4%, 91.3% and 89.2% higher than the FBD for 5S, 10S and 15S frames, respectively.

- (b) The higher drift values explain the rigid behaviour of the FBD, while the DDBD is more flexible in nature which helps in achieving higher drift values.
- (c) On comparing the base shear of steel frames with concentric bracings shows that the values of FBD are greater than the DDBD.
- (d) The base shear values of FBD are 61.7%, 29.3% and 67.43% higher than the DDBD procedure for 5S, 10S and 15S frames, respectively, which explains better stability of the structure.
- (e) From the results, it proves that the new methodology for the design and analysis of high-rise building gives better results, i.e. the DDBD is better when compared to FBD.

References

1. Priestly MJN, Calvi GM, Kowalsky MJ (2007) Displacement based seismic design of structures. IUSS PRESS, Pavia, Italy
2. Pirmoz A, (Max) Liu M (2017) Direct displacement based seismic design of semi-rigid steel frames. *J Construct Steel Res* 201–209
3. Priestly MJN, Kowalsky MJ (2000) Direct displacement based seismic design of concrete buildings. *Bulletin New Zealand Soc Earthq Eng*
4. Al Mashaykhi M, Rajeev P, Wijesundara KK (2019) Displacement profile for displacement based seismic design of concentric braced frames. *J Constr Steel Res* 155(2019):233–248
5. IS 1893 (Part-1)-2002 Indian standard code of practice for criteria for earthquake resistant design of structures. Bureau of Indian Standards, (New Delhi)
6. IS 800–2007 Indian standard code of practice for general construction in steel. Bureau of Indian Standards, (New Delhi)
7. Sil A, Das G, Hait P (2019) Characteristics of FBD and DDBD techniques for SMRF buildings designed for seismic zone-V in India. *J Build Pathol Rehabil* 4:1
8. Moehle JP (1996) Displacement based seismic design criteria. Eleventh world conference on Earthquake Engineering
9. FEMA 356 (2000) (Federal Emergency and Management Agency)
10. Timothy John Sullivan (2013) Direct displacement based seismic design of steel eccentrically braced frame structures. *Bull Earthq Eng* 2013(11):2197–2231
11. Abhyuday T (2017) Fundamentals of direct displacement based design procedure-A brief introduction. *Disaster Adv* 10 (6)
12. Dohadwala AT, Sheth RK, Dr. Patel IN (2014) Comparison of base shear for forced based design method and direct displacement based design method. *Int J Adv Eng*