Comparison of Base Shear for Forced-Based Design Method and Direct Displacement-Based Design Method

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Abstract – An alternative design other than Forced-Based Design method for seismic design of structures has been proposed, that is, Direct Displacement-Based Design method. A four storey building has been taken for three different zones, that is, Zone III, Zone IV and Zone V and is designed with both the methods and their respective base shear has been found. The design procedure has been elaborated and comparison of base shear for both the procedure has been plotted. Finally concluding remarks has been highlighted.

Keywords – Base Shear, Forced-Based Design, Frame Structures, Direct Displacement-Based Design, Displacement

I. INTRODUCTION

Amongst all the natural hazards, earthquakes have the potential for causing the greatest damages. The Buildings, which appeared to be strong enough, may crumble like houses of cards during an earthquake and deficiencies are exposed. For, earthquake forces are random in nature and unpredictable, the engineering tools need to be sharpened for analyzing structures under the action of these forces. There is no other alternative than to make seismic earthquake resistant.

Designing process for making structure seismic resistance has been undergoing a critical reappraisal in recent years, with the emphasis changing from **strength** to **performance**. During the mid of the 20th century, an era when designing structures seismic resistance were actually taken into consideration by codes, strength and performance criteria were considered to be parallel and compatible to each other. However, over the past 25 years there has been a gradual shift from this position with the realization that increasing strength may not actually increase safety, neither necessarily reduce damage. This lead to an approach towards a new design concept called "Performance-Based Seismic Design (PBSD)". PBSD is a modern designing concept of seismic resistant structure. Performance-based design is a more general design philosophy in which the design criteria are expressed in terms of achieving stated performance objectives when the structure is subjected to stated levels of seismic hazard. During the last decade, seismic design of structures has matured with revaluation due to the evolution of PBSD methodologies and the encouraging analytical results.

Current seismic codes are based on Forced Based Design (FBD). Current force-based design (spectral acceleration-based design) is considerably improved compared with procedures used in earlier years; there are many fundamental problems with the procedure, particularly when applied to reinforced concrete structures. Although the structure is designed to yield during the design earthquake, only the elastic part of the response, up to yield, is examined. The analysis is based on the corresponding secant stiffness. To overcome the problems with FBD a newly design concept has been developed known as Direct Displacement Based Design (DDBD) which promise a more rational design philosophy compared to the conventional Force-Based Design (FBD).

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1.1 Forced-Based Design

Current seismic design in the India and even in most countries in the world is carried out in accordance with force-based design methodology. Although current force-based design (spectral acceleration-based design) has appreciably improved compared with procedures used in the beginning of this century, there are many fundamental problems with the procedure, particularly when applied to reinforced concrete or reinforced masonry structures. In order to examine these problems, it is first necessary to briefly review the force-based design procedure, as currently specified by IS 1893 (Part 1): 2002.

1.2 Direct Displacement Based Design (DDBD)

Performance-based seismic design criteria, intended to produce structures that satisfy specific performance objectives. Performance levels, indeed, are described in terms of displacements, as damage is better correlated to displacements rather than forces. As a consequence, new design approaches, based on displacements, have been recently implemented. One of such approach is the Direct Displacement-Based Design (DDBD), firstly proposed by Priestley (1993). DDBD is based on the observation, that damage is directly related to strain (structural effects) or drift (non-structural effects), and both can be integrated to obtain displacements. The fundamental philosophy behind the design approach is to design a structure which would achieve, rather than bonded by, a given performance limit state under a given seismic intensity. The fundamental difference between FBD and DDBD characterizes the structure to be designed by as a single degree of freedom, representation of performance at peak displacement response, rather than by its initial elastic characteristics.

II. Design Procedure for Direct Displacement-Based Design

The design method is illustrated with reference to Figure 1.

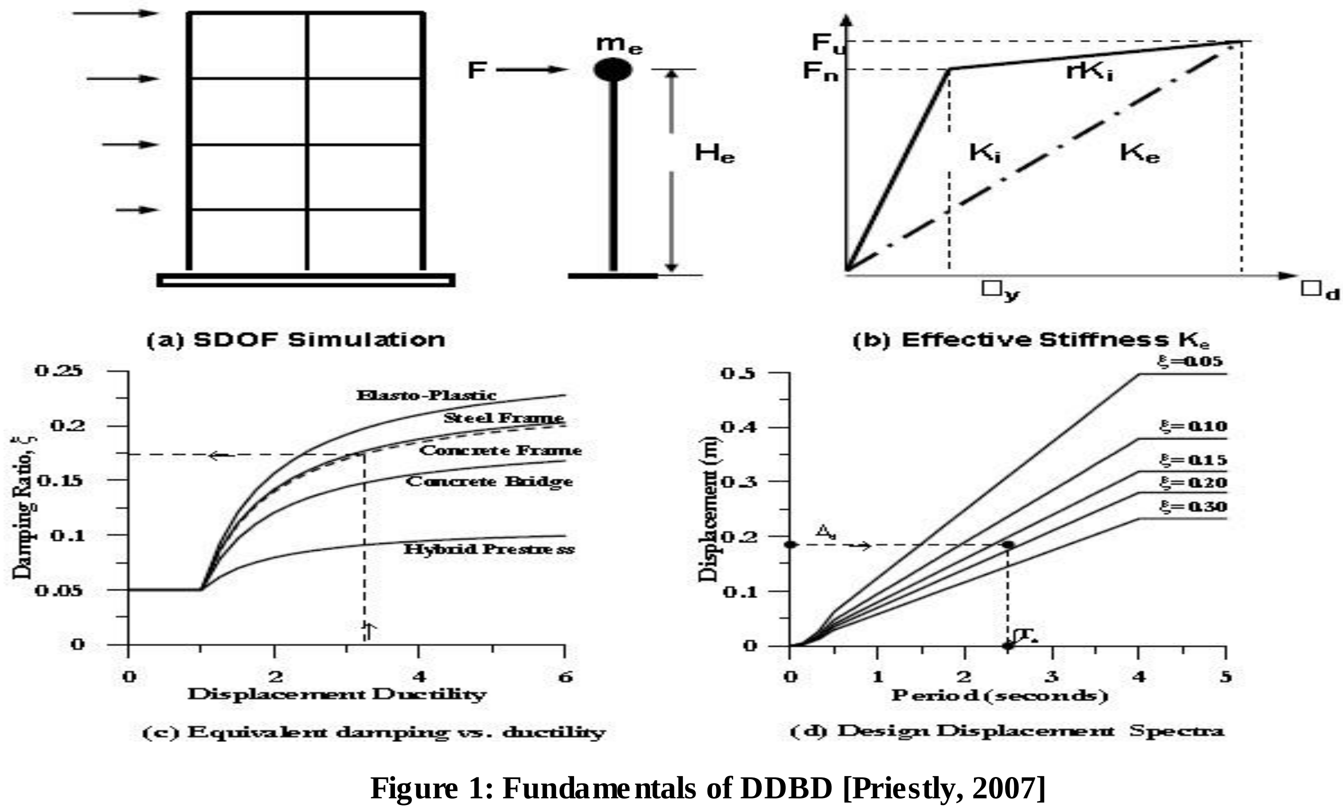

Figure 1: Fundamentals of DDBD [Priestly, 2007]

A SDOF representation of a frame building is shown (Fig.1 (a)), though the basic fundamentals apply to all structural types. The bilinear envelope of the lateral force-displacement response of the SDOF representation is shown in (Fig. 1 (b)) and a level of equivalent viscous damping ɪ, representative of the combined elastic damping and the hysteretic energy absorbed during inelastic response. Thus, as shown in (Fig.1(c)), for a given level of ductility demand, a structural steel frame building with compact members will be assigned a higher level of equivalent viscous damping than a reinforced concrete bridge designed for the same level of ductility demand, as a consequence of "fatter" hysteresis loops.

Design Displacement Profile

- Design profiles are defined in the Model Code for regular structures by Priestley et.al. 2007, based on the results of Non-linear Time History Analysis.
  For regular frame structures, the design displacement profile is given by,

$$\Delta_i = \omega\theta.\theta c.H_i.\frac{4Hn - H_i}{4Hn - H_1} \quad (1)$$

Where,

$\omega_\theta = 1.15 - 0.0034Hn \leq 1$ is a reduction factor for higher mode amplification of drift

θc = Drift limit (0.02 for life safety perspective) [FEMA 356 (2002)]

The properties for single degree of freedom system is determined by,

- Design displacement of the equivalent SDOF structure is related to the storey displacements. It is given by,

$$\Delta d = \frac{\Sigma\,(m_i\Delta_i{}^2)}{\Sigma\,(m_i\Delta_i)} \quad (2)$$

$$me = \frac{\Sigma\,(m_i\Delta_i)}{\Delta d} \quad (3)$$

$$He = \frac{\Sigma\,(m_i\Delta_i H_i)}{\Sigma\,(m_i\Delta_i)} \quad (4)$$

Where,

m*i*, h*i* and Δ*i* are respectively the mass, height from base and displacement for *ith* storey. *Δd* is target (spectral) displacement, *me* is equivalent mass, *He* is the effective height of the ESDOF system.

The design displacement ductility factor is a relation between design displacement and yield displacement.

For reinforced concrete frames, yield drift can be developed from the yield curvature as,

$$\theta y = 0.5\varepsilon y.\frac{Ld}{Hb} \quad (5)$$

- Yield displacement will be,

$$\Delta y = \theta y.He \quad (6)$$

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Hence,

$$\mu = \frac{\Delta d}{\Delta y} \tag{7}$$

Equivalent damping for Concrete Frame building is dependent on design displacement ductility. It is given by:

$$\xi eq = 0.05 + 0.565.\frac{\mu-1}{\mu\pi} \tag{8}$$

The effective period Te corresponding to Δd and ξeq is to be obtained from the design displacement spectra.

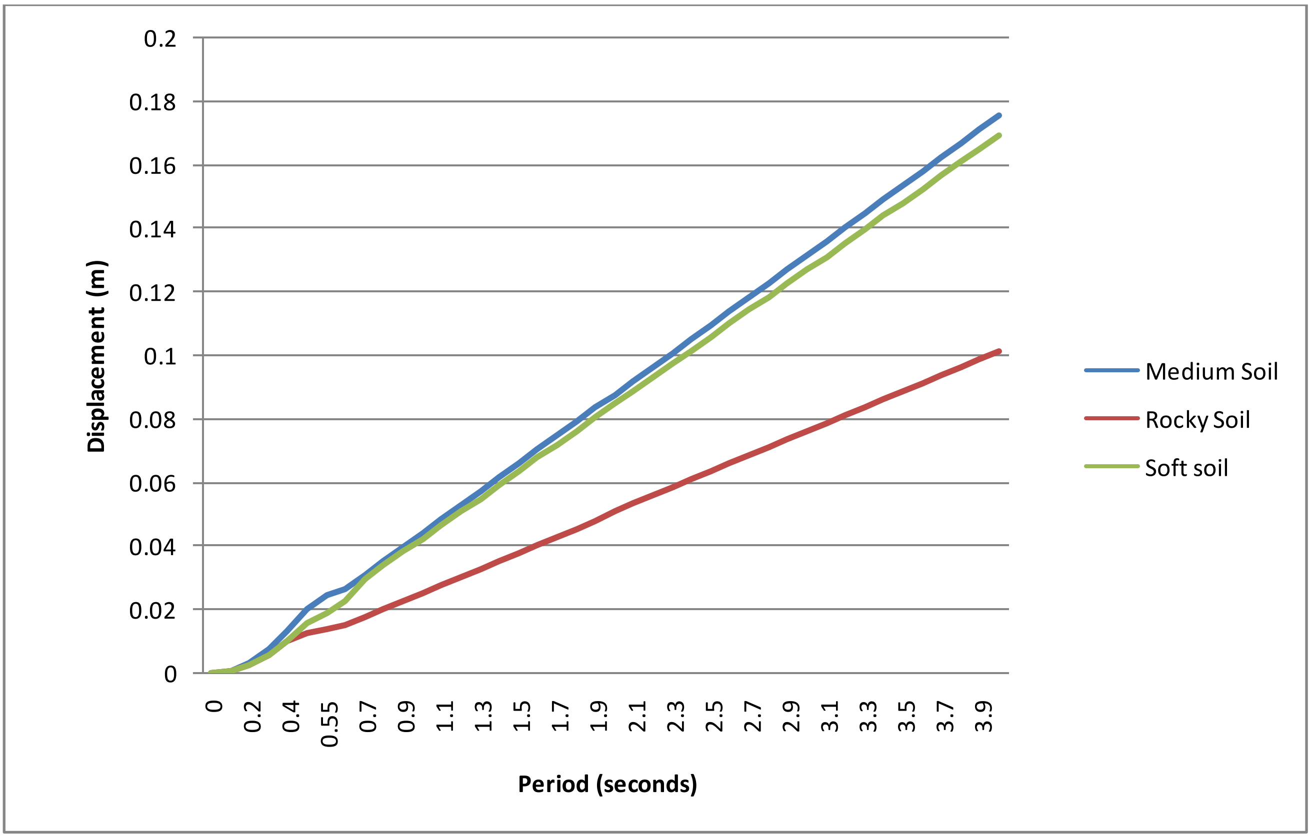

Figure 2: Response Spectra for 5% damping [IS 1893 (Part 1) 2002]

The effective stiffness Ke, of the substitute SDOF structure, derived from its effective mass me and effective period Te and hence the base shear is obtained

$$Ke = \frac{4\pi^2 me}{Te^2} \tag{9}$$

$$F = Vbase = Ke.\Delta d \tag{10 a}$$

Then the base shear force is distributed to the floor levels in proportion to the product of mass and displacement as,

$$Fi = Ft + Vb.\frac{mi\,\Delta i}{\Sigma\,(mi\Delta i)} \tag{10 b}$$

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Where,

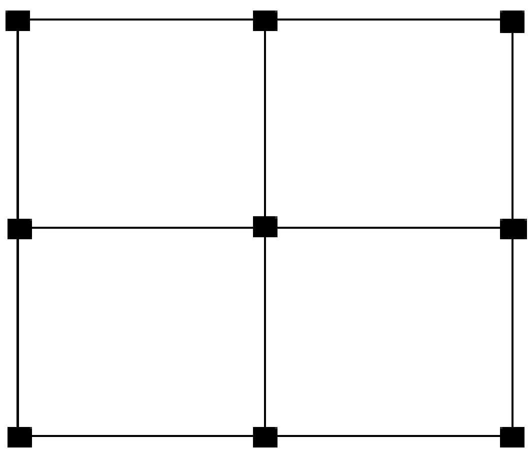
$$Ft = 0.1Vb \text{ (at roof) and 0 (at all floors)}$$

III. Problem Statement

The example illustrated consists of designing a **4-storeyed** Moment Resisting RC frame as shown in figure 4.1 using Force Based Design and Direct Displacement Based Design method. The frame has equal bay width of 5.0m and storey heights of 3.20m. The ground storey columns have a height of 4.00m. It is located in **Zone-III**, **Zone-IV** and **Zone-V**. The building is assumed to be constructed in medium soil condition.

Table 1 Building Specification

Beam Size	300mm x 450mm all
Column Size	400mm x 400mm all
Slab Thickness	120mm all
Imposed Load	1.50 kN/ m² (roof) and 4.00 kN/ m² (all other floors)
Floor Finish	1.00 kN/m²
Wall Thickness	230 mm (external) and 115 mm (internal)
Concrete Grade	M25



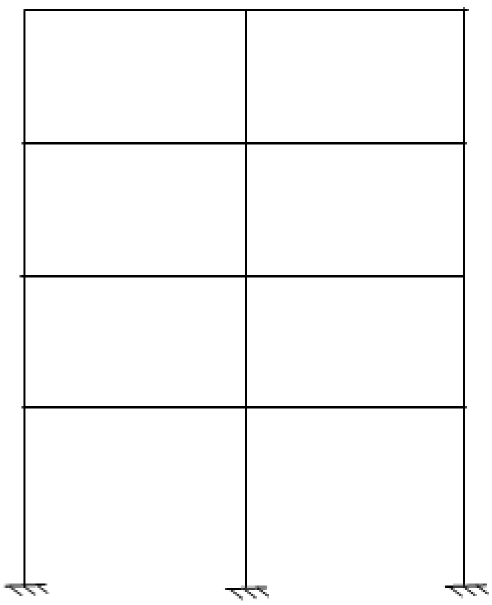


Figure 3: 4-Storey Building

Table 2 Seismic Load Calculation

Storey No.	Wi (kN)	Hi (m)	WiHi² (kN.m²)	C=WiHi²/ΣWiHi²

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Roof	790.1	13.6	146136.9	0.36205972
3	1461.7	10.4	158097.5	0.391692502
2	1461.7	7.2	75774.53	0.187734276
1	1476.1	4	23617.6	0.058513503
Ground	72	0	0	0
Total	**5261.6**		**403626.5**	

Table 3 Base Shear Calculation by FBD

Parameters	ZONE III	ZONE IV	ZONE V
Seismic Weight (kN)	5261.6	5261.6	5261.6
Time Period (seconds)	0.3871	0.3871	0.3871
Sa/g	2.5	2.5	2.5
Ah	0.04	0.06	0.09
Vbase (kN)	210.46	315.70	473.54

Table 4 Base Shear Distribution by FBD

Storey No.	Vbase (kN)		
	Zone III	Zone IV	Zone V
4	76.201	114.301	171.451
3	82.437	123.656	185.484
2	39.511	59.267	88.901
1	12.315	18.472	27.709
0	0	0	0

Table 5 Displacement Profile for equation 1

Storey No.	mi (tonnes)	Δi (m)	Hi (m)
roof	80.54026504	0.22019	13.6
3	149.0010194	0.181587	10.4

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2	149.0010194	0.134857	7.2
1	150.4689093	0.08	4
Ground	7.339449541	0	0

Different DDBD parameters as required in design has been calculated by Eq. 2- Eq. 10. The base shear found by equation 10 for Zone III, Zone IV and Zone V are distributed as given in Table 6 below.

As per IS 1893 (Part 1): 2002, Cl. 6.4.2

Rξ = 0.776

Building is located in Zone III,

So design PGA = 0.16/2 = 0.08

Building is located in Zone IV, PGA = 0.24/2 = 0.12

Building is located in Zone V, PGA = 0.36/2 = 0.18

Table 6 Base Shear Distribution by DDBD

Storey No.	Vbase (kN)		
	Zone III	**Zone IV**	**Zone V**
4	45.57	61.56	86.23
3	46.91	69.82	92.66
2	34.84	53.96	74.24
1	20.87	29.72	32.75
0	0	0	0

IV. Differences between the two design methods

The difference between FBD and DDBD method are stated as follows. The first is a force based design where characteristic material strength is used. Here, it uses variable load combination: (1) 1.5(DL+LL), (2) 1.2(DL+LL±SL), (3) 1.5(DL±SL), (4) 0.9DL±1.5SL, where DL stands for dead load, LL for imposed load and SL for seismic load along the frame; the number of modes depends on the sum total of their modal mass to make up at least 90% of the total seismic mass; lateral load distribution does not accounts for higher mode effect; missing mass correction beyond 33% for higher mode effect.

The latter is a displacement based design which uses expected material strength in the design stage. It also uses constant beam section for a particular frame; load combination as (1) DL+LL, (2) DL+LL±SLx (3) DL+LL±SLy inelastic 1st mode displacement profile by Eq.1; lateral load distribution accounts for higher mode effect as in Eq. 10a- 10b.

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Force-based design methods for other codes are more or less similar regarding the basic assumptions mentioned above. However, some assumptions like factor of safety for loading apart from the basic limit state design may vary. So, they are expected to behave similarly specially in inelastic time history analysis for similar conditions and also their structural cost.

V. Comparison

For base shear comparison between the three seismic zones of a building having same plan as shown in figure 3 have been considered. The height of buildings considered is given in problem statement. The nomenclature of the buildings has been listed in Table 1. Symbols **FBD** and **DDBD** represents buildings designed by Forced-Based Design method and Direct Displacement-Based Design Method respectively.

The comparison Graphs are given below.

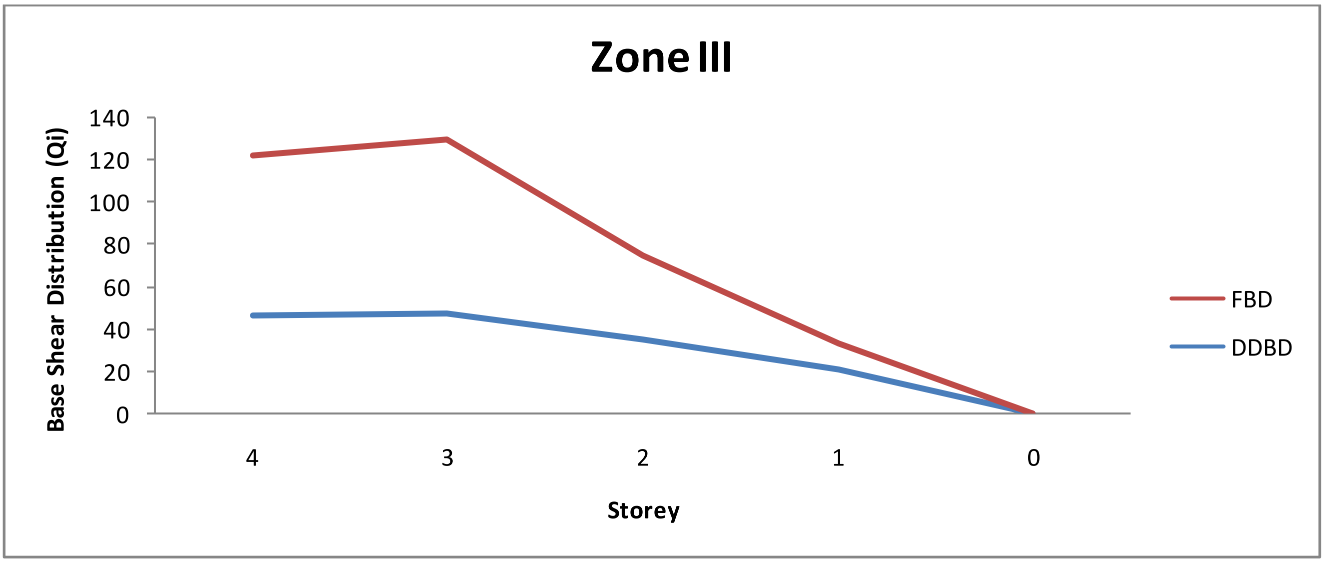

Figure 4 Graph of Base Shear Distribution for Zone III

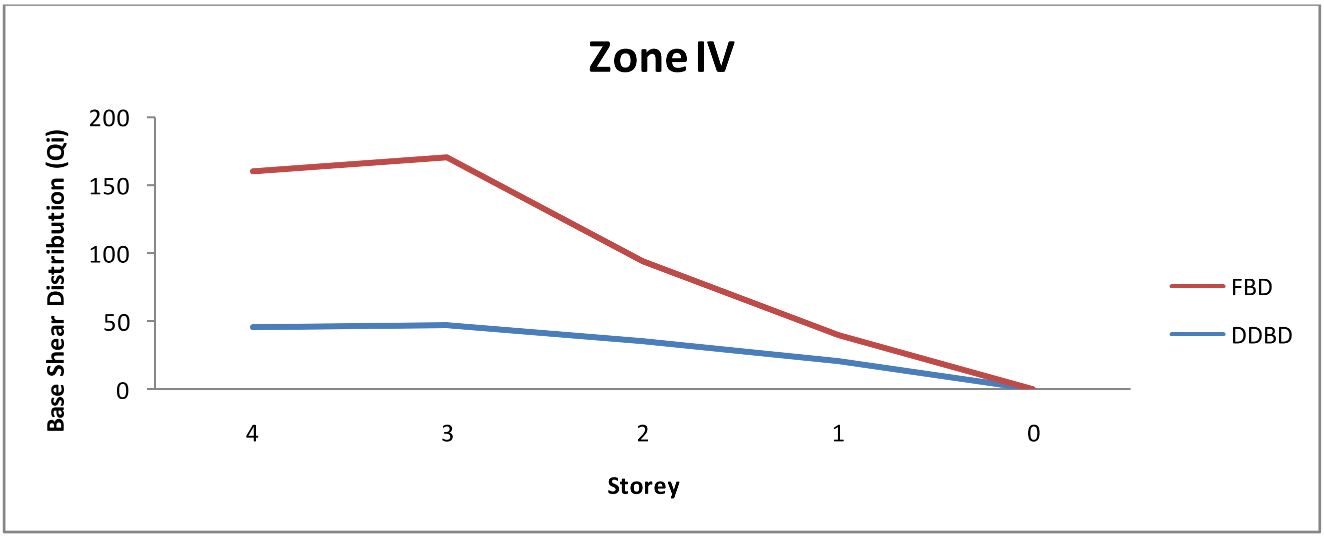

Figure 5 Graph of Base Shear Distribution for Zone IV

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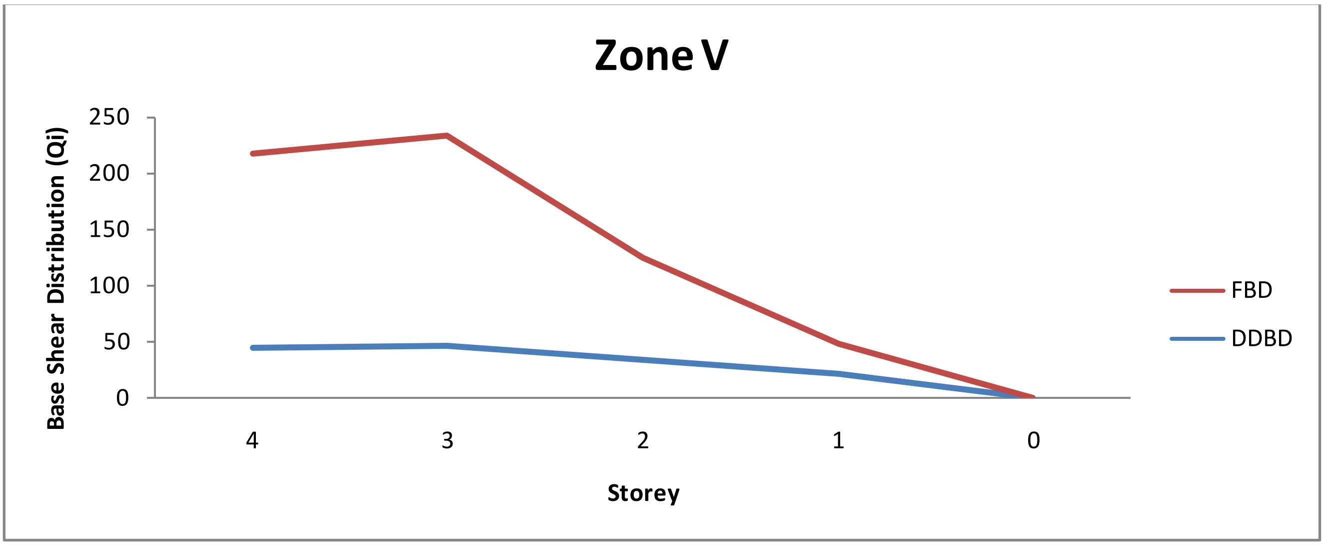

Figure 6 Graph of Base Shear Distribution for Zone V

VI. Concluding Remarks

The base shear of R.C frame buildings designed with Direct Displacement-Based Design has been compared with those designed with Forced-Based Design method. Frame buildings for three different zones have been designed with Forced-Based Design method. The same category of buildings has been designed with Direct Displacement-Based Design for the criteria specified given by those designed with Forced-Based Design method. Results have been presented for various zones. The base shear for all the three zones has been evaluated. It has been found that buildings designed with Forced-Based Design method are having more base shear than those designed with the Direct Displacement-Based Design method.

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