ISSN : 2454-9150 Vol-08, Issue-06, Sep 2022

Assessment of the Capability of Moment Resisting Frames using Force-based and Displacement-based Approaches

Adnan Amin Thara, PG student, MGM's College of engineering, Nanded, Maharashtra, India, adnanthara.75@gmail.com

Mohd. Zameeruddin, Associate Professor, MGM's College of engineering, Nanded, Maharashtra, India, md_zameeruddin@mgmcen.ac.in

Abstract - **Experience learnt from damages occurring to the building during past-earthquakes showed the inadequacy of forced based methods. With increase in knowledge of seismology and the soft computing tool availability leads towards the development of displacement-based methods. Displacement based design techniques proved to be the best alternative device for performance-based seismic design. Of the various available displacement-based design methods had not guided about the appropriate standards for usage in design practices in cognizance to the recent trends of building configurations. Present study focuses on the use of the direct displacement-based for design of Moment Resisting frame subjected to gravity loads. Example frames consist of 4, 8 and 12 stories design as per BIS 1893:2002 using force-based and displacement-based design approaches. The performance evaluation of example moment resist frames is done using nonlinear static pushover analysis. The obtained results are compared with force-based and displacement-based approaches in terms of base shear, story drift, and number of hinge formation for achieving the structural performance level.**

Keywords — Performance based design, force-based design, direct displacement-based design, push over analysis, parametric studies

I. INTRODUCTION

Recent years, more importance has been given to "performance" instead of "strength" for structures prone to seismic hazards. This has demanded alternative design methodology based on deformation rather than force. These are named as Performance-based seismic design (PBSD) philosophies. These philosophies show the attainment of inelastic displacement for every incremental increase in applied lateral loads.

Force-based design (FBD) procedure adopted in most of the seismic design codes allows the design of building structures using elastic design spectra. A fundamental problem with the FBD method is the selection of the appropriate member stiffness. In preliminary design member sizes are designed for gravity loads before the evaluation of design lateral forces. These lateral forces are calculated on the basis of seismic weight distribution over the height of building, if member size is varying from the initial assumption, then the calculated force is no longer valid, and recalculation required, thus making it an iterative process.

Researchers have pointed out that force is a poor indicator of the damage and that there is no clear relationship between the strength and the damage [Priestley, 1993, 2000 and 2003]. Hence, the force cannot be a good criterion for design. Further, assuming a rational value of the response reduction factor for a class of buildings is not realistic, because ductility depends on so many factors, such as degree of redundancy, axial force, steel ratio, structural geometry etc. To overcome this limitation of the FBD, an alternative design philosophy named "Displacement-Based Design (DBD)" has been put forth [Qi and Moehle, 1991], The proposed DBD includes the use of the translational displacement, rotation, strain etc., in the basic design criteria. Later improvements in DBD were suggested in Direct Displacement Based Design (DDBD) [M.J.N. Priestley, 1993]. The DDBD is based on Performance- based Design (PBD). PBD involves the design of structure on the basis of damages sustained by

 DOI : 10.35291/2454-9150.2022.0435

structural and structural components. These damages are traced with the help of rooftop displacement, inter-storey displacement, member rotations and strains. PBD is a very promising design tool that enables a designer to design a structure with predictable performance.

Direct displacement-based design

DDBD was first introduced in New Zealand, in 1993. The concept was further developed and improved for real time application by the USA and Europe. It has been used as a viable and logical alternative to the current FBD approaches. DDBD characterizes the structure by secant stiffness at maximum displacement associated with a level of equivalent viscous damping. It is a representation of the combined elastic damping and the hysteretic energy absorbed during inelastic response (as shown in figure 1). The DDBD design process includes;

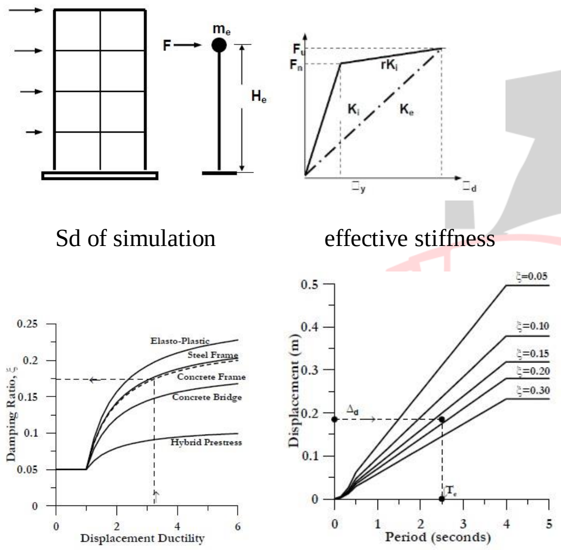

Fig.1: DDBD design process

Step 1: Evaluate the design displacement of SDOF system

The design story displacements (Δ_i) of the individual masses are obtained from:

$$\Delta_i = \omega_\theta \theta_d h_i \frac{(4H_n - H_i)}{(4H_n - H_i)} \quad (1)$$

where, ω_θ equals to{1.15 - 0.0034 H_n} ≤ 1.0 is a reduction factor for higher mode amplification of drift, θ_c is the code drift limit, H_n represents building height, H_1 and H_i are the heights of floor level 1 and i respectively, Equivalent Mass of the SDOF structure & Equivalent Height of the SDOF structure are calculated using Eqs: 2-4.

$$\Delta_d = \frac{(\sum_{i=1}^{n} m_i \Delta^2{}_i)}{(\sum_{i=1}^{n} m_i \Delta_i)} \quad (2)$$

$$m_e = \frac{\sum_{i=1}^{n}(m_i \Delta_i)}{\Delta_d} \quad (3)$$

$$H_e = \frac{\sum_{i=1}^{n}(m_i \Delta_i H_i)}{\sum_{i=1}^{n} m_i \Delta_i} \quad (4)$$

Step 2: Estimation of equivalent viscous damping (ξ)

The equivalent viscous damping equation is given below [Priestley, Calvi, & M.J.Kowalsky, 2007].

For frame building

$$\xi_{eq} = 0.05 + 0.565\left[\frac{\mu - 1}{\mu\pi}\right] \quad (5)$$

Displacement ductility of the SDOF structure

$$\mu = \frac{\Delta_d}{\Delta_y} \quad (6)$$

Where μ is displacement ductility, Δd is design displacement and Δy is yield displacement

$$\Delta y = \theta_y \times H_e \quad (7)$$

Where He is effective height, θy is yield rotation

$$\theta y = 0.5 \times \xi_y \times \left[\frac{L_d}{H_b}\right] \quad (8)$$

Step 3: Determination of the effective period (T_e) of structure

$$S_{De} = S_a \left[\frac{T}{2\pi}\right]^2 \quad (9)$$

Where; S_a is elastic response spectrum, displacement spectrum other than 5% damping can be found out from the formulation in EC8

Step 4: Effective stiffness K_e of the substitute SDOF structure

$$K_e = 4\pi m_e^2 / T_e^2 \quad (10)$$

Where; M_e is effective mass and T_e is time period that can be calculated from response spectra

The design base shear

$V_{base} = K_e x \Delta_d$ (11)

Distribution of base shear carried out using following formula

$$F_i = V_{base} \frac{(m_i \Delta_i)}{\sum_{i=1}^{n}(m_i \Delta_i)} \quad (12)$$

$$F_i = F_t + 0.9 V_{base} \frac{(m_i \Delta_i)}{\sum_{i=1}^{n}(m_i \Delta_i)} \quad (13)$$

 DOI : 10.35291/2454-9150.2022.0435

For $n < 10$ use equation (12) and for n>10 use equation (13)

Force-based Design Method

The Force Based Design is based on calculating the base shear force resulting from the earthquake dynamic motion using the acceleration response spectrum and the expected elastic period of the building. In this procedure the static loads are applied on a structure with magnitudes and directions that closely approximate the effects of dynamic loading caused by earthquakes. Concentrated lateral forces due to dynamic loading tend to occur at each floor in buildings, where concentration of mass exists. It also tends to follow the fundamental mode shape of the building where it is larger at higher elevations in structure. Thus, the greatest lateral displacements and the largest lateral forces often occur at the top level of a structure. These effects are modelled in equivalent static lateral force procedures of most design codes by placing a force at each storey level in the structure, which is directly proportional with the height.

In force-based design procedure, seismic base shear force is calculated by multiplying the seismic weight of the structures with design horizontal spectral acceleration at fundamental natural period of the structure derived from the design spectrum at design basic earthquake. Then calculated lateral seismic shear is distributed along the height of the structures based on the lumped mass at story level. Typically, in FBD approach, it is assuming that the fundamental mode of the vibration is the most dominant and mass and stiffness are evenly distributed. This assumption may be right for regular low rise structures but in irregular and tall structures, the contribution of the higher modes may be important. The steps to evaluate the seismic shear using FBD procedure is summarized as follows

Firstly lumped mass at the story level are calculated and the corresponding seismic weight (W_h) are determined. The design base shear is obtained as;

$$V_{base} = \frac{Z \times I \times S_a}{2 \times R \times g} W_h \quad (14)$$

Where; Z is a seismic zone factor, R is assumed response reduction factor, Sa/g is a spectral acceleration coefficient corresponding to natural time period and type of soil, I is importance factor of the structure, and W_h is the total seismic weight of structure

$$Q_i = V_b \times \frac{W_i \times H_i^2}{\Sigma_{j=1}^{n} W_i H_i^2} \quad (15)$$

Where Q_i is design lateral force at floor I, H_i is height of floor i , W_i is seismic weight of floor i , n is number of storey

Pushover analysis

Pushover analysis is a static procedure. In this process the structure is subjected to incremental lateral loads to reached rooftop displacement in equivalence to targeted displacement values. The inelastic excursion of structure is obtained in terms of capacity curve. The collapse mechanism resulting from pushover analysis shows the yielding of members and their corresponding performance levels. These performance levels are defined in terms of damages to structural and non-structural components up to targeted drift values.

II. MODELLING

Building Geometry

Regular moment resisting frames with storey height 3m and bay width 3m in X direction and 3m in Y direction are considered (refer figure 2). Frames with four, eight, and twelve stories are studied. The design of all the frames were in accordance to the Indian standards IS 456, IS 1893 and ductile detailing was done following the recommendation of IS 13920. Table 1 provides modelling parameters of example MRF. The 2-D MRF with 4, 8, and 12, storey were modelled in ETABS. The beam and column dimensions, are illustrated in Table 2. Analysis has been performed for both FBD and DDBD.

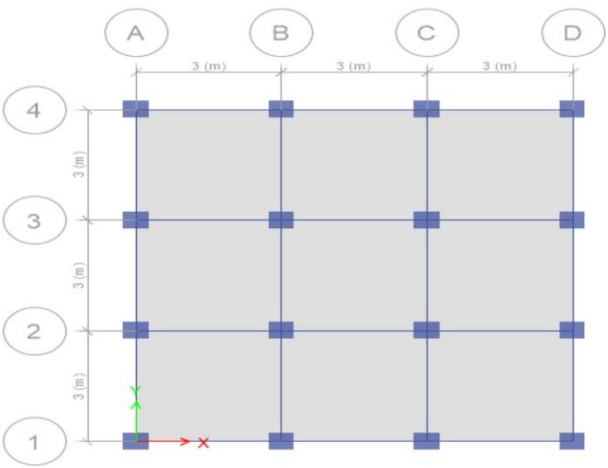

Fig 2: typical plan of building for 4,8,& 12 storey for both FBD And DDBD analysis

Table 1: Material Properties and design constants

Particulars	Values
Grade of Concrete	M 25
Grade of rebar's	Fe 500
Wall load (UDL) on beam	13.8 kN/m²
Live load on floor	3 kN/m²
Seismic Zone	IV (0.24)

 DOI : 10.35291/2454-9150.2022.0435

ISSN : 2454-9150 Vol-08, Issue-06, Sep 2022

Soil type	Medium soil
Response reduction factor (R)	5
Importance factor (I)	1

From the design result we can conclude that, for FBD method the structural member sizes required are larger as compare to that of DDBD. Higher the cross-sectional demand higher will be the reinforcement percentage which raises the question about the economical design of structure.

Table 2: Structural component design

Structural Comp. / Type of building	Size of column	Size of beam
FBD (4 storey)	300 x 450	300 x 380
DDBD (4 storey)	230 x 380	230 x 380
FBD (8 storey)	300 x 530	300 x 450
DDBD (8 storey)	300 x 450	300 x 380
FBD (12 storey)	450 x 600	380 x 450
DDBD (12 storey)	450 x 530	300 x 380

III. RESULTS AND DISCUSSION

The analysis and design has been done accordance to the recommendation of the Indian codes of practice. No unique computing tool has been available for DDBD we performed manual operation to obtain the base shear values at each storey levels and applied them at respective nodes. The design combinations were taken as per IS 1893 for both methods, for DDBD the partial safety factor for all loads are taken as 1 as it is performance based and force for building for specified performance as evaluated.

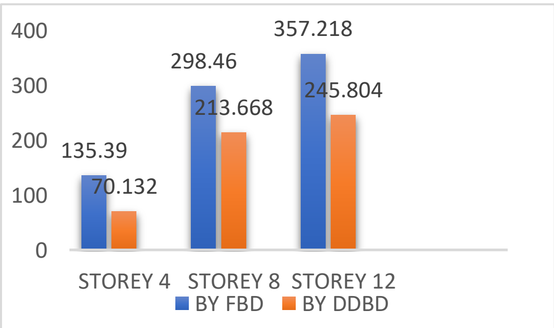

Fig. 3: Computed design results of base shear of FBD and DDBD

Figure 3 shows the comparison of base shear of example MRFs. The base shear of FBD MRFs was found to be higher than that of DDBD method. The stiffness posses by the DDBD MRFs possess less stiffness and lighter cross-sections are needed thereby making it economical design process. Figure 4-6 shows the stiffness values of example MRFs. Figure 7-9 represents the storey drift of example MRFs. It is observed that DDBD designed frames attains more storey drift as compared to FBD designed frames. Figure 10-15 shows the attainment of various performance levels of example MRFs. The structural components of DDBD MRFs possess higher rotation capability compared to FBD frames.

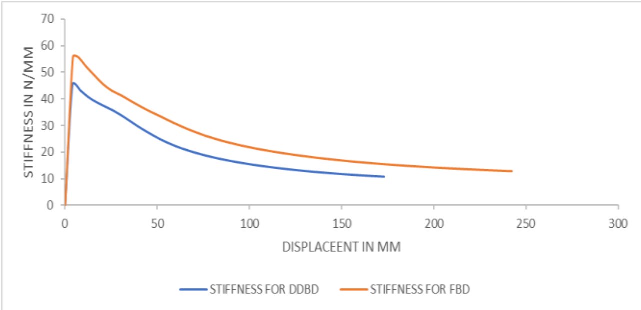

Fig 4: Stiffness values of example 4-storey MRF

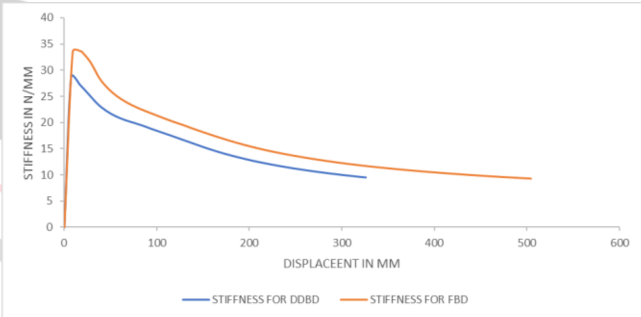

Fig 5: Stiffness values of example 8-storey MRF

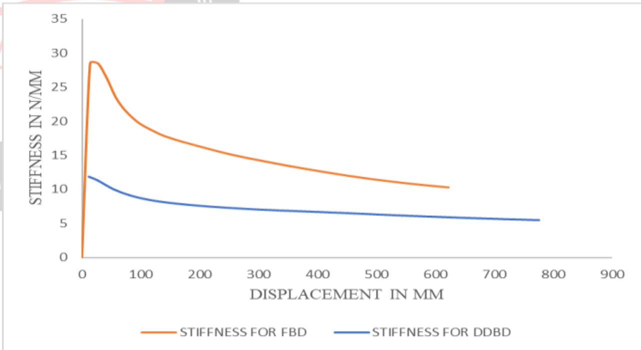

Fig 6: Stiffness values of example 12-storey MRF

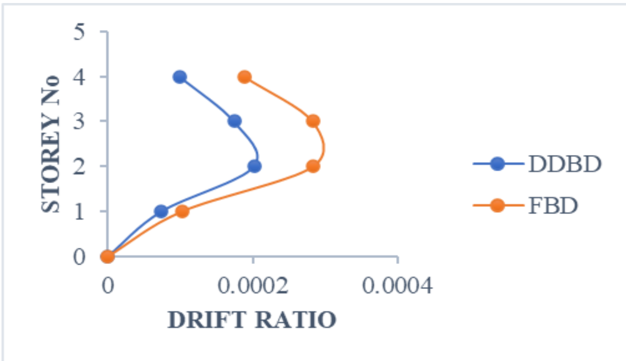

Fig 7: Storey drift of example 4-storey MRF

 DOI : 10.35291/2454-9150.2022.0435

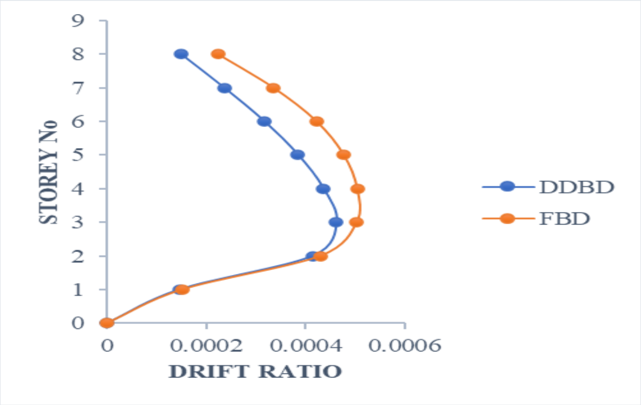

Fig 8: Storey drift of example 8-storey MRF

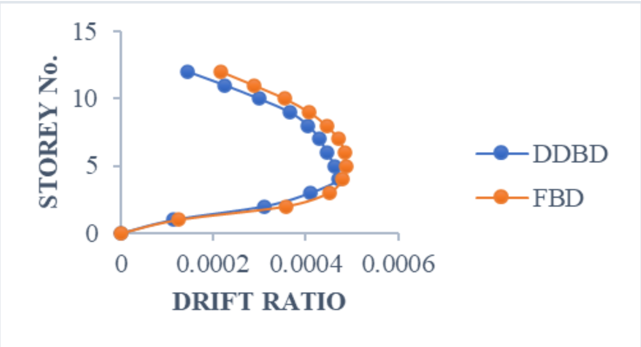

Fig 9: Storey drift of example 12-storey MRF

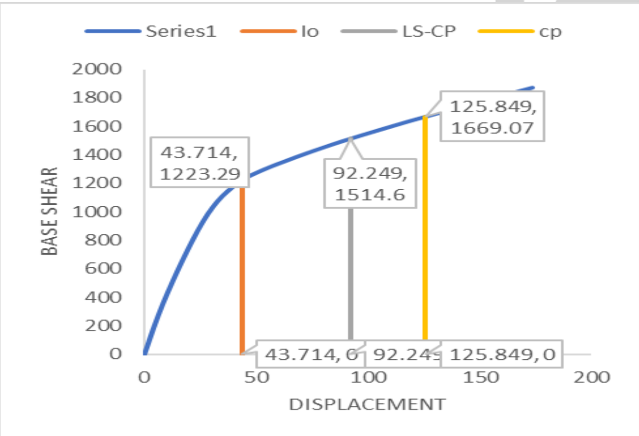

Fig 10: Performance levels for 4-storey DDBD MRF

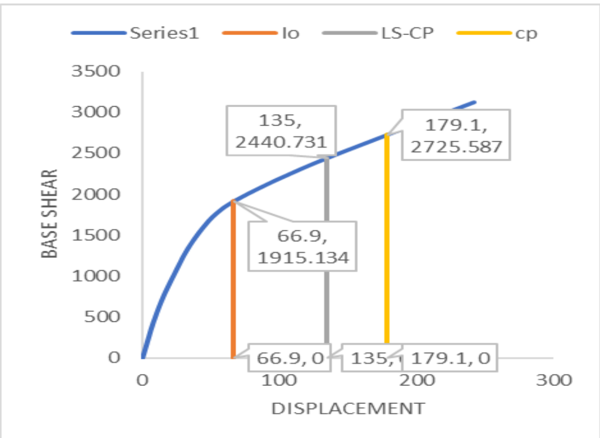

Fig 11: Performance levels for 4-storey FBD MRF

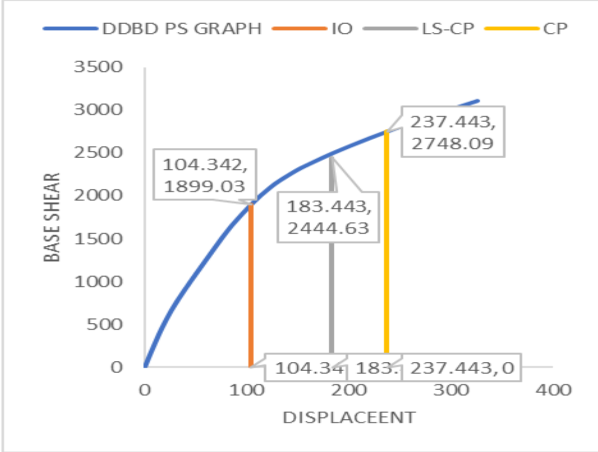

Fig 12: Performance levels for 8-storey DDBD MRF

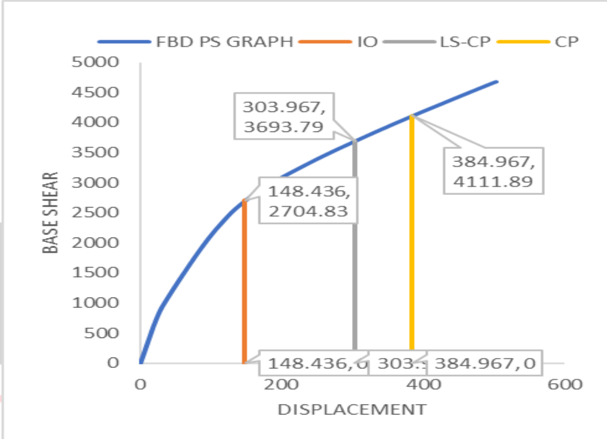

Fig 13: Performance levels for 8-storey FBD MRF

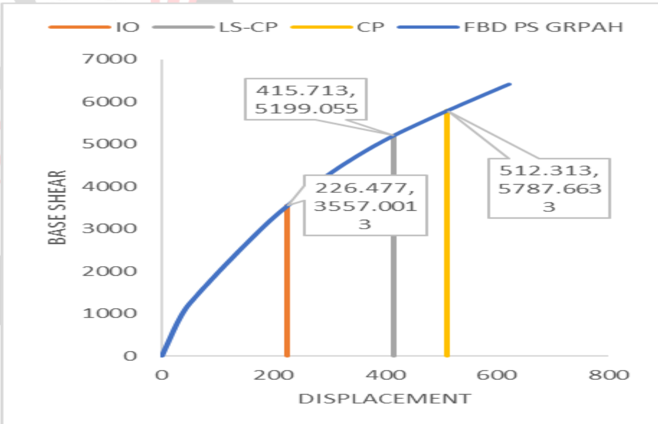

Fig 14: Performance levels for 12-storey FBD MRF

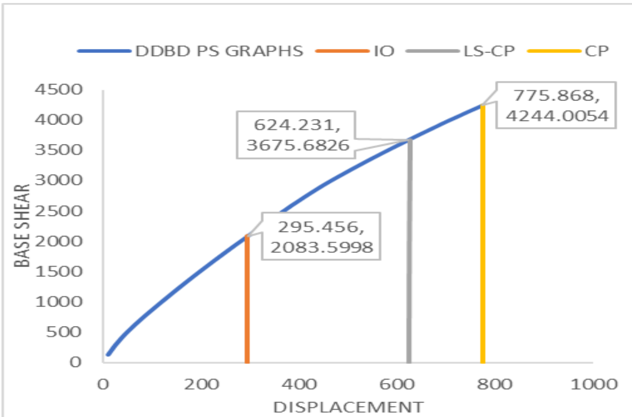

Fig 15: Performance levels for 12-storey DDBD MRF

 DOI : 10.35291/2454-9150.2022.0435

IV. CONCLUSION

From parametric studies on FBD and DDBD models following conclusions are drawn:

- The base shear attracted by FBD designed structures are more compared to the DDBD design structure for same height, loading and seismic zone characteristics. This may be attributed towards the introduced ductility in DDBD structure. FBD structure response may be attributed towards the stringent conversion factor that has been used in lateral load distribution along the height of the structure and modeling of nonlinear characteristics of reinforced concrete members.

- When overall performance of DDBD structures is observed at operational level, immediate occupancy level and life safety range shows that enough ductility level is maintained with fewer damages as compared to FBD design structure. This may be traced from the fall of stiffness at incremental pushover load step.

- DDBD design results in structure with slender member cross-section, less percentage of rebar's compared to FBD demands, thus make approach to be more economical that FBD structures with assured safety to life and structure

ACKNOWLEDGMENT

The author of this paper acknowledges the research contribution of all the citation under reference and the support of faculty member and by the chairman, MGM college of engineering, Nanded, India.

REFERENCES

[1] M.J.N. Preistley, G.M. Calvi, M.J. Kowalsky, "Displacement Based Seismic Design of Structures", IUSS Press, Pavia, Italy

[2] Mehmet Inel, Hayri Baytan Ozmen, "Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings", Engineering Structures (ELSEVIER) 28 (2006), P. 1494-1502.

[3] B.Massena, R. Bento, H. Degee, "Direct Displacement Based Design of a RC Frame – Case of Study" (2010), ISSN: 0871-7869, Relatorio ICIST.

[4] T.J. Sullivan, G.M. Calvi , M J N Priestley, Direct Displacement Based Design of Frame-Wall Structures , Volume 10 No.spec01 , Journal of Eartquake Engineering 2006.

[5] IS 456:2000 "Plain and Reinforced Concrete Code of Practice", BIS, New Delhi.

[6] IS-1893(Part 1):2002. "*Criteria for Earthquake Resistant Design of Structures*, Part-I, General Provisions and Buildings", BIS, New Delhi.

[7] IS 13920:1993 (Reaffirmed 1998) "*Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces"* BIS, New Delhi.

[8] FEMA-440 (June 2005), "Improvement of Nonlinear Static Seismic Analysis Procedures", Department of Homeland Security, Federal Emergency Management Agency, Washington, D.C.

[9] J. P. Moehle, "Displacement-Based Design of Building Structures Subjected to Earthquakes," Earthquake Spectra, Vol. 8, no. 3, pp. 403-428, 1992.

[10] A. Kadid and A. Boumrkik, "Pushover Analysis of Reinforced Concrete Frame Structures," Asian Journal of Civil Engineering (Building and Housing),Vol. 9, no. 1, pp. 75-83, 2008.

 DOI : 10.35291/2454-9150.2022.0435