ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

Comparison of Various Direct Displacement Based Approaches for Seismic Design

[1] Sourabh Kriplani, [2] Onkar G. Kumbhar [3] Ratnesh Kumar
[1] PG Student (MTech. SDE), [2] Research Scholar, [3]Assistant Professor
[1][2][3] Visvesvaraya National Institute of Technology Nagpur

***Abstract:*— Contemporary seismic design procedure proposed in various national codes follow the force-based design approach. Force based method holds good for building behavior in elastic domain, whereas the precise inelastic behavior of same building during severe seismic event is unpredictable. Some performance assessment guidelines like FEMA 445 provide cumbersome iterative procedure to ascertain the seismic performance of buildings. The iterative procedure of FEMA 445 is difficult to be performed in design offices for regular buildings. Therefore, a design methodology based on anticipated nonlinear performance is desired. Moreover, the design method should be robust and shall involve few or no design revisions. Relative displacement or drift of different levels of building under seismic event is one of the primary reasons of structural damage. Structural damage can be evaluated on the basis of cracking or deformations or in terms of dimensional changes i.e. strains. Indirectly by controlling displacement/drift of structure, damage can be controlled. Therefore, a relatively new technique of performance based seismic design i.e. Direct Displacement Based Design (DDBD) has evolved in last two decades. The approach of Direct Displacement Based Design method (DDBD) proposed by many researchers differ from each other in terms of effective viscous damping equation, displacement profiles and consideration of mode shapes. The study presents the variation in magnitude of seismic base shear and storey shear amongst various DDBD approaches and compares with the currently prescribed force based approach in Indian seismic code. The study also evaluates the advantages as well as disadvantages of these methods.**

***Index Terms* :-- Base shear, Direct displacement based design (DDBD), Performance based design, Target drifts.**

I. INTRODUCTION

The Force-based design (FBD) procedures for earthquake resistant structure are common design practice proposed in various national codes for seismic design including India. Force based method holds good for buildings behavior in elastic domain and inelastic behavior of same building during seismic event is unpredictable. Relative displacement of structure is one of the reasons of structural as well as nonstructural damage occurred during past earthquakes. Therefore, Moehle [1] proposed a method which estimates the inelastic displacement of structures based on estimated strength and stiffness of structure using displacement spectra. Proposed method calculates the displacement demand and capacity of structure using iterative procedure. Further Kowalsky et al. [2] proposed a Direct Displacement Based Design (DDBD) method in which a "single degree of freedom system" (bridge pier) is designed for some pre decided target drift. Instead being variables, the strength and stiffness are the outcome of design procedure. Later same approach has been adopted by Priestley and Kowalsky [3] for multi degree of freedom system. The aforementioned method uses pseudo elastic displacement spectra for estimated equivalent viscous damping. However, Chopra and Goel [4] emphasized that the use of elastic displacement spectra for predicting the inelastic response is inappropriate, therefore proposed a method demonstrating use of inelastic displacement spectra in direct displacement based design method. Xue [5] proposed a method based on the formulation derived from the capacity spectrum method using Newmark-Hall reduction factors for the in-elastic spectrum. For the given target displacement and the elastic design spectrum, the required stiffness and strength of a structure can be evaluated numerically with the assumption of ductility ratio and post-yield stiffness ratio. Generally several researchers [6]-[14] made use of elastic displacement spectra for assessed value of equivalent elastic viscous damping. From preliminary time history analysis, Pettinga and Priestley [6] observed that the existing approach of DDBD [3], gave inadequate control over the inter-storey drift demands, particularly for taller structures. Hence modifications were made in the existing DDBD procedure for better performance. Moghim and Saadatpour [7] investigated the applicability of DDBD method proposed by Priestley et al. [8] for near fault areas. The approach adopted by Massena et al. [9], Dzakic et al [10], Muljati et al. [11] and Bezabeh et al. [12] is similar to Priestley et al [8]. Fakhraddini and Salajegheh [13] proposed a design algorithm that uses DDBD design procedure given in [8] which minimizes the material and construction cost of reinforced Concrete structure and satisfying the limitations and specifications of ACI code. Kappos et al. [14] followed similar procedure as in [8] except the displacement profile has

ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 2, Issue 3, March 2017

been evaluated using Multi Modal Superposition (MMS). The design steps for DDBD as suggested by several researchers are similar yet they differ in terms of treatment provided to various governing parameters in the design process. There are variations in the considered target displacement profile, equivalent viscous damping equation and the base shear distribution pattern. From the design steps of DDBD as proposed by many researchers, it is implicit that the seismic base shear acting on the building is dependent on the aforementioned parameters. Hence, the study presents the variation in magnitude of seismic base shear from the DDBD approaches along with its distribution pattern and compares with the currently prescribed force based approach in Indian seismic code. The Acceleration Response Spectra proposed in IS 1893:2002 [15] has been used to evaluate the base shear.

II. SPECIFICATION OF BUILDING

A regular five storey building with plan shown in Fig. 1 has been selected for the study. Seven equi-spaced (at 4 m) bays are present along the longitudinal direction. In transverse direction, three bays, i.e. two exterior bays of 5 m and a middle bay of 2.6 m are considered. The plan is symmetric along both the longitudinal and transverse direction. A constant storey height of 3 m is considered for all floors. The building is assumed to be situated on medium soil strata and located in the seismic zone V with Peak ground acceleration (PGA) as 0.36g under maximum considered earthquake. Special moment resisting frame (SMRF) is considered with response reduction factor (R) as 5. The reinforced concrete slab thickness at each floor level is assumed as 150 mm. The reinforced concrete frames are made with concrete M25 and the reinforcement steel is Fe415. In addition, a distributed dead load of 1 KN/m2 due to floor finish as well as an imposed live load with nominal value of 3 KN/m2 is considered.

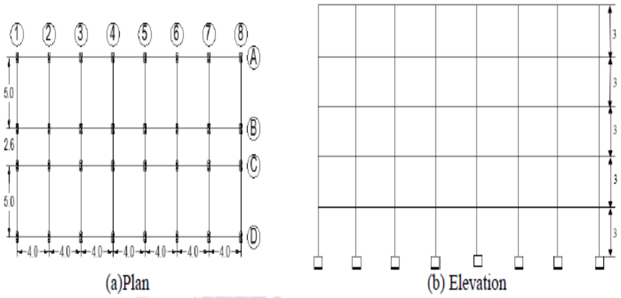

Fig. 1: General Layout of Building under study, (all dimension are in meters)

III. TARGET DISPLACEMENT PROFILE

The target displacement profile of the structure can either be generated using pre-determined inelastic first-mode displacement profile or Eigen value mode shapes from MMS. Equations for pre-determined target displacement as proposed in [3] are based on the number of stories considering first mode as predominant mode of vibration. Same displacement profiles are used in [7] and [13]. Pettinga and Priestley [6] proposed revised equations for the target displacement profile independent of number of stories and are used in [8]-[12]. MMS approach for calculating displacement profile is used in [5] and [14]. Three distinct displacement profiles as proposed in literature are plotted for 2 percent drift limit (θd) for the considered building and shown in Fig. 2.

For the considered building, all DDBD approaches predict similar displacement profile (i.e. linear) up to the first floor level. However, for higher stories the predicted displacement profile differs significantly. The MMS predicts different displacement in longitudinal and transverse directions, whereas, the displacement profiles according to [3] and [6] are same in both directions, since it depends on the height and independent of plan dimensions of the building. The MMS predicts maximum displacement values in both the directions.

IV. EQUIVALENT VISCOUS DAMPING

The substitute structure considered in DDBD, has an effective viscous damping equal to the sum of elastic and hysteretic damping. The magnitude of hysteretic damping and damping modifiers assessed by the various researchers are different, hence the period estimated by each method is different for same design drift values. For a design drift limit (θd) equal to 2 percent, the reduced design displacement spectra are plotted in Fig. 3.

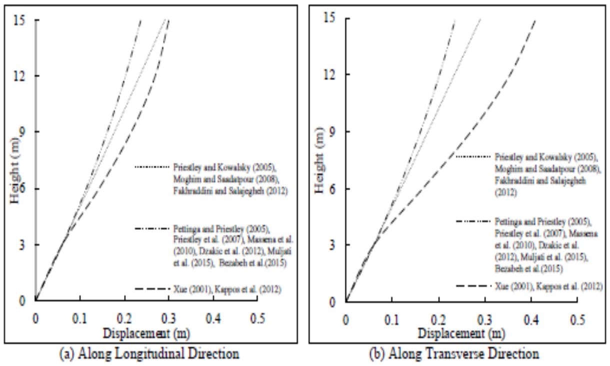

Fig. 2: Target Displacement Profile of the building

All Rights Reserved © 2017 IJERMCE

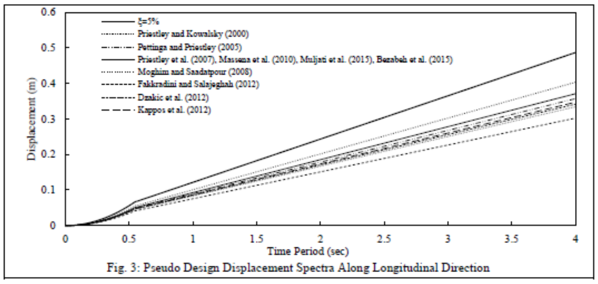

Fig. 3: Pseudo Design Displacement Spectra Along Longitudinal Direction

Effective stiffness is determined from the effective period of the system and consequently the base shear acting on the frame is estimated. Since the period predicted by Fakhradini and Salajeghah [13] is maximum (Fig. 3), the corresponding base shear is minimum. Base shear values calculated from various methods is shown in Fig. 4. The value of storey displacements and base shear (as shown in Fig. 2 and Fig. 4), indicate that for a given storey, the profile which predicts lesser displacement will demand a lower value of equivalent viscous damping (i.e. smaller ductility requirement) which leads to lesser effective period and hence provides higher magnitude of base shear. In most of the cases, the design base shear from DDBD is more than FBD.

V. BASE SHEAR DISTRIBUTION

Base shear evaluated from DDBD is distributed to all floors of the building according to the pre-determined inelastic storey displacement profile. For a constant design drift limit of 2 percent, the base shear distribution from the DDBD approaches and FBD is plotted in the form of storey shear vs height of building and is shown Fig. 5. For lower stories, FBD predict lesser magnitude of storey shear as compared to DDBD. It is to be observed that the distribution of base shear varies linearly with respect to storey displacements, however displacement profile of structure is parabolic in nature for the considered building that results in parabolic distribution of base shear.

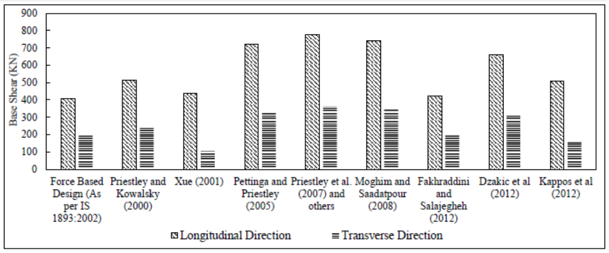

Fig. 4: Seismic Design Base Shear

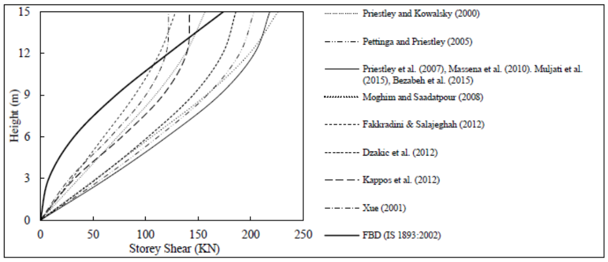

Fig. 5: Base Shear Distribution along Longitudinal Direction

VI. EFFECT OF DESIGN DRIFT LIMIT ON BASE SHEAR

The design seismic base shear acting on the building depends on the target displacement profile which consequently depends on the design drift limit. Five design drift limit (θd) values between 1.5 percent and 3.5 percent (with increment of 0.5 percent) have been considered and the corresponding design base shear coefficient VB/W (where W is total seismic weight of the building) is obtained and plotted in Fig. 6.

With the increase in design drift limit, the ductility demand of structure increases resulting in reduction of design base shear. For low level drift limit, i.e. 1.5 percent, the base shear estimated by DDBD is greater than the base shear estimated from IS 1893:2002 code procedure for SMRF. However, for drift value more than 3.5 percent, base shear estimated by IS 1893:2002 is higher than the DDBD procedures considered in this study.

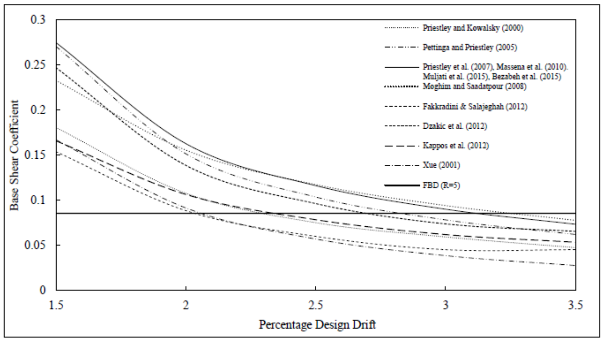

Fig. 6: Base Shear Coefficient Along Longitudinal Direction

REFERENCES

[1] J. P. Moehle, “Displacement-based design of RC structures subjected to earthquakes”, Earthquake spectra, vol. 8(3), pp. 403-428, August 1992.

[2] M. J. Kowalsky, M. J. Priestley, and G. A. Macrae, “Displacement-based design of RC Bridge columns in seismic regions”, Earthquake engineering & structural dynamics, vol. 24, pp.1623-1643, December 1995.

[3] M. J. N. Priestley, and M.J. Kowalsky, "Direct Displacement Based Seismic Design of Concrete Buildings", Bulletin of the New Zealand society for Earthquake Engineering, vol. 33(4), pp. 421-444, December 2000.

[4] A. K. Chopra, and R. K. Goel, "Direct Displacement-Based Design: Use of Inelastic vs. Elastic Design Spectra", Earthquake Spectra, vol. 17(1), pp. 47-64, February 2001.

[5] Q. Xue, "A direct displacement-based seismic design procedure of inelastic structures", Engineering Structures, vol. 23, pp. 1453–1460, September 2001.

[6] J. D. Pettinga, and M. J. N. Priestley, "Dynamic Behaviour of Reinforced Concrete Frames Designed With Direct Displacement-Based Design", J. Earth. Eng., vol. 9(2), pp.309-330, 2005.

[7] F. Moghim, and M. M. Saadatpour, "The applicability of Direct Displacement-Based Design in designing concrete buildings located in near-fault regions", The 14th World Conference on Earthquake Engineering, Beijing, China, October 2008.

[8] M.J.N. Priestley, M.C. Calvi, and M.J. Kowalsky, "Displacement-Based Seismic Design of Structures", IUSS Press, Pavia, pp. 670, 2007.

[9] B. Massena, R. Bento, and H. Degée, "Direct Displacement Based Design of a RC Frame – Case of Study", ISSN, 0871-7869, November 2010.

[10] D. Dzakic, I. Kraus, and D. Moric, "Direct Displacement Based Design of regular concrete frames in compliance with Eurocode 8", Technical Gazette, vol. 19(4), pp. 973-982, October 2012.

[11] I. Muljati, F. Asisi, and K. Willyanto, "Performance of force based design versus direct displacement based design in predicting seismic demands of regular concrete special moment resisting frames", Procedia Engineering, vol. 125, pp. 1050 – 1056, November 2015.

[12] M.A. Bezabeh, S. Tesfamariam, S.F. Stiemer, M. Popovski, and E. Karacabeyli, "Direct Displacement Based Design of a Novel Hybrid Structure: Steel Moment-Resisting Frames with Cross Laminated Timber Infill Walls", Earthquake Spectra, vol. 32(3), pp. 1565-1585, October 2015.

[13] A. Fakhraddini, and J. Salajegheh, "Optimum Automated Direct Displacement Based Design of Reinforced Concrete Frames", The 15th World Conference on Earthquake Engineering, Lisbon, Portugal, September 2012.

[14] A.J. Kappos, I.G. Gidaris, and K.I. Gkatzogias, "Problems associated with direct displacement based design of concrete bridges with single-column piers, and some suggested improvements", Bull Earthquake Eng., vol. 10, pp. 1237–1266, April 2012.

[15] IS 1893(Part 1)(2002): Criteria for earthquake resistant design of structures, Part 1 general provision and buildings (fifth revision), BIS, New Delhi, India, June 2002.

IFERP
connecting engineers... developing research