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Direct Displacement Based Design of RC Beams and Columns

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ABSTRACT

Structural displacement is now recognized as a key parameter for structural and non-structural damage to a building during earthquake. The direct displacement based design (DDBD) which considers displacement as the primary design input promises to be a more rational design philosophy than conventional force based design (FBD) procedures. The DDBD is a non-iterative approach that aims to design buildings which would achieve a predefined performance level under the design seismic action. World over the DDBD has attracted considerable research into its implementation, practical advantages and shortcomings. However, in the Indian scenario, research in the field of DDBD is still in a nascent stage of development. In this paper, the direct displacement based design was applied for design of typical RC moment resisting frames of 4, 8 and 12-storey located in seismic zone III and compared with FBD in accordance with the Indian seismic code. The performance of the two methods were assessed by nonlinear time history analysis using seven spectrum compatible ground motions and it was found that frames designed using both the methods satisfied the desired performance levels. The direct displacement based design provides a complete design procedure and gives economical designs for low to medium rise frames; but for taller structures in lower seismic zones, the DDBD results were conservative.

Keywords: Force Based Design (FBD), Direct Displacement Based Design (DDBD), Base Shear, RCC Frame, SAP 2000

I. INTRODUCTION

The major cause for building damage is due to seismic effect. As the ground shakes, building loses its stability and gets collapsed. So for any structure, seismic analysis is mandatory as it resists the structure against the seismic forces. In different parts of world, different methods of seismic analysis are practiced. we consider two different seismic approaches for our study:

i. Force Based Design Method (FBD).
ii. Direct Displacement Based Design Method (DDBD)

1.1 Force Based Design (FBD)

Force based design method practiced in India, which focus on the seismic force over the structure. In this method, the design procedure is carried out for the seismic force acting on the system where stiffness, time period and strength are the initial properties of the design. FBD method is performed based on IS1893 (Part 1):2002.The existing conventional code based procedures are normative in nature[2]. This code needs to cover a wide range of structures and this method usually cannot be considered as the expected performance level and seismic risk levels are not generalized. Linear elastic analysis of the structure is performed for the lateral forces calculated from the procedure.

1.2 Direct Displacement Based Design (DDBD)

Direct Displacement-Based Design (DDBD), first proposed by Priestley (1993) is a performance design approach in which Performance levels, indeed, are described in terms of displacements, as damage is better correlated to displacements rather than forces. The fundamental goal of DDBD is to obtain a structure which will reach a target displacement profile when subjected to earthquakes consistent with a given reference response spectrum. The performance levels of the structure are governed through the selection of suitable values of the maximum displacement (D_d) and maximum interstorey drift (θ_d). In our study, we follow nonlinear dynamic seismic analysis procedure. The Nonlinear dynamic analysis procedure utilizes a combination of ground motion records with a detailed structural model, and therefore is capable of producing results with relatively low uncertainty. The detailed structural model subjected to a ground motion record produces estimates of component deformations for each degree of freedom in the model and the model responses are combined using schemes such as square-root-sum of squares. The method captures the effect of amplification due to resonance, the variation of displacements at diverse levels of a frame, an increase of motion duration, and a tendency of regularization of movements.

II. METHODS AND MATERIAL

A. Building Geometry

Regular 2-D frames with storey height 3.3m and bay width 5m are considered. Frames with four, eight and twelve stories are studied. The design of all the frames was according to the Indian standards IS 456(2000), seismic code IS 1893(2002).

The two dimensional 4,8 & 12 storey frames were modelled by assigning the beam and column dimensions. A series of iteration was carried out for the structure to get apt section. Below table 1 shows the dimensions of beams and columns for 4, 8 & 12 stories.

Table 1 Dimensions of beams and columns

Building	Number of Stories	Column Dimension (mm)	Beam Dimension (mm)
FBD-4	4	400x400	300x450
FBD-8	8	450x450	300x450
FBD-12	12	500x500	400x450
DDBD-4	4	400x400	300x450
DDBD-8	8	450x450	300x450
DDBD-12	12	500x500	400x450

B. Structural Elements

In this study, all beams and columns were modelled as frame elements. The beam and column joints were modelled by giving end-offsets to the frame elements and assumed to be rigid. For slabs due to their in-plane stiffness, "diaphragm" action at each floor level was assigned. The load contribution of slab is modelled separately on the supporting beams and the loads were uniformly distributed the foundation was considered as fixed for all the models. All the frame elements are modelled with non linear properties at the possible yield locations.

C. Nonlinear Time History Analysis

Non-Linear Time history analysis is a step by step analysis of dynamic response of a structure subjected to a specified ground motion. Hilber-Hughes-Taylor alpha (HHT) method was used for performing direct integration time history analysis. The HHT method uses a single parameter (alpha) whose value is bounded by 0 and -1/3. These coefficients were computed by specifying equivalent fractions of critical modal damping at two different periods. The dynamic input has been given as a ground acceleration time-history which was applied uniformly at all points of the base of the structure and only one horizontal component of ground motion has been considered.

D. Design Displacement Profile

The displacement approach procedures as follows. For regular frames, the design displacement profile is given by

$$\Delta_i = \omega\theta.\theta c.H_i[(4Hn - H_i)/(4Hn - H_1)]$$

Where

$\omega\theta$ = 1 is a reduction factor

θc = Drift limit [FEMA 356(2002)]

Hn = roof height

H_i = height of ith storey

Design drift (Δd) is given by

$$\Delta d = \{[\Sigma (m_i \Delta_i 2)]/[\Sigma(m_i \Delta_i)]\}$$

m_i = mass of ith storey

For RC frames, yield drift (θy) is given by

$$\theta y = 0.5\varepsilon y(Ld/Hb)$$

Where

εy = yield strain

Ld = beam bay length
Hb = beam depth

Yield displacement, $\Delta y = \theta y.He$
Where, $He = [\Sigma (m_i \Delta_i H_i)]/[\Sigma (m_i \Delta_i)]$

Design Ductility(μ) is given by

$$\mu = (\Delta d / \Delta y)$$

Base shear is given by $F = Ke.\Delta d$
where $Ke = (4\pi^2 me)/Te^2$
Te = time period calculated from response spectra chart.

III. RESULTS AND DISCUSSION

A. Base Shear

The design comparison is done in terms of the design base shear estimate by both DDBD and FBD. The results of both the methods are given in the following section in tabular format as shown in table 2 to table 4.

Table 2 Design Base Shear - 4 Storey

Method	Base shear capacity, kN
DDBD	117.57
FBD	278.78

Table 3 Design Base Shear - 8 Storey

Method	Base shear capacity, kN
DDBD	117.57
FBD	278.78

Table 4 Design Base Shear– 12 Storey

Method	Base shear capacity, kN
DDBD	272.93
FBD	442.7

B. Hinge Pattern

The following are the buildings with varying number of stories viz, 4, 8 and 12 are analysed by defined spectrum function. It is observed that the buildings with real time demand curve are falling under immediate occupancy level where as the buildings with seismic co-efficient are falling under life safety level. The hinge pattern results are shown in figure 1 to figure 4. The pink and blue hinges on the figures indicate performance level within Immediate occupancy and within Life safety respectively. The frames designed using both the methods achieved the performance level within 'life safety' with the desired sway mechanism.

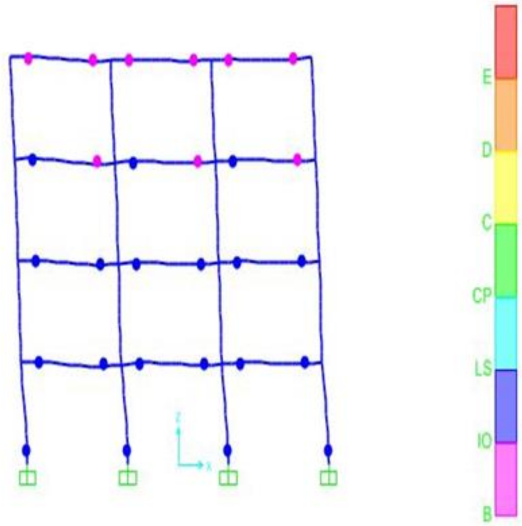

Figure 1: Hinge Pattern at end of NLTHA – 4-Storey DDBD

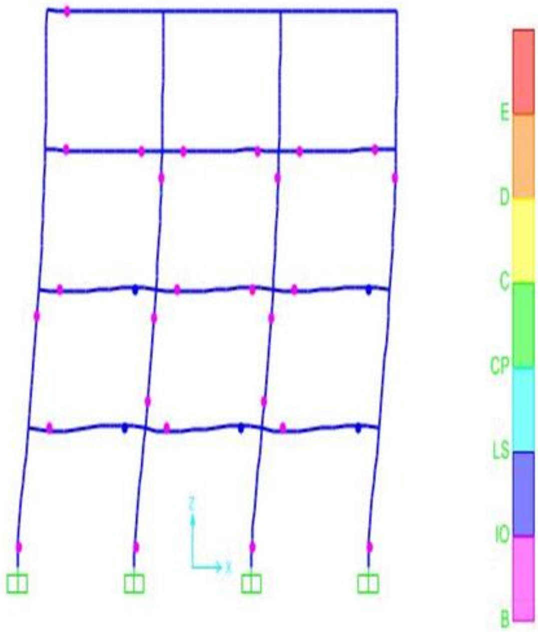

Figure 2: Hinge Pattern at end of NLTHA – 4-StoreyFBD

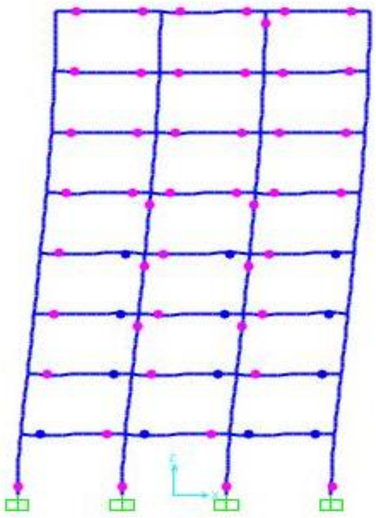

Figure 3: Hinge Pattern at end of NLTHA – 8-Storey DDBD

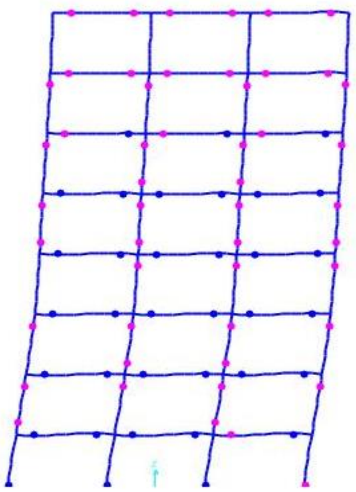

Figure 3: Hinge Pattern at end of NLTHA – 8-storey FBD

From the result, it can be seen that the number of hinges reaching the performance level is more for DDBD frames as compared to FBD frames. In case of FBD frames, the hinges reaching the performance level are concentrated in the lower floors of both four-storey and eight-storey frames. Whereas in the four-storey and eight-storey DDBD frames, the hinges reaching performance level are more and distributed throughout the height of the building indicating improved performance as compared to FBD frames. Although hinge formations can be seen at ends of some columns other than the ground storey columns, this do not raise much concern as the state of these hinges are well into the beginning of the inelastic stage. For the 12-storey frame, the DDBD gives a very conservative design with no plastic hinges forming anywhere.

IV CONCLUSION

I. The DDBD predicts values of Base shear lower than FBD for 4-storey ,8-storey and 12-storey frames.

II. The frames designed using DDBD method satisfied the performance objective of 'Life Safety'.

III. Response of both frames showed sway mechanism with plastic hinges forming at the beam ends and column ends columns.

IV. The beam hinges attaining performance level are distributed to higher stories in case of 4-storey and 8 storey.

V. For 12-storey DDBD gives a very conservative design with no Formation of plastic hinges

VI. For low and medium rise building DDBD is a safer , economic and alternative to FBD.

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