RESEARCH ARTICLE

PERFORMANCE BASED SEISMIC DESIGN OF RCC BUILDING IN NEPAL USING DIRECT DISPLACEMENT BASED DESIGN PRINCIPLES

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ABSTRACT

Direct Displacement Based Design (DDBD) is an alternative structure design methodology based on Performance Based Seismic Design (PBSD) Approach and is apart from current seismic design code based on Force Based Design. FBD design methodology has several drawbacks which led to rise of alternate design methodology like PBSD/DDBD. This method is the most effective way to implement PBSD theory recently developed. This paper explains the DDBD procedure in detail and show its advantage on code-based design practices in developing country like Nepal where cost matters a lot. It is observed that building designed by PBSD/DDBD approach is much economical than designed by NBC 105:1994 and IS 1893:2002 code which is current in practice in Nepal.

**Key Words:** Performance Based Seismic Design, Direct Displacement Based Design, IS 1893 and NBC 105, Interstory Drift Ratio, Roof Displacement Pushover Analysis.

INTRODUCTION

Nepal is the country with least economic growth rate and always in high risk of earthquake. In history various highly vulnerable earthquakes have occurred with lots of damage of lives, and infrastructures. Recently a magnitude of 7.8 Richter Scale Earthquake caused loss of around 8686 lives and around 8,000,000 buildings destroyed. Currently in Nepal, seismic design code National Building Code of Nepal NBC 105:1994 and Indian Standard IS 1893:2002 are in practice. As NBC 105 has not been revised since long time, the practice of IS 1893 is most. These seismic codes are based on Force based Design (FBD) methodology which when applied on RC structure the member size is assumed before design forces are applied. Later these forces are distributed in their assumed stiffness. If the member size varies from initial assumption then the calculated forces are no longer valid and need recalculation thoroughly. Other drawbacks are: Initial stiffness is unknown, the use of characteristic force-reduction or ductility factor for design results in non-uniform risks, and there is no clear relationship between strength and damage (Priestley et al., 2000). To overcome the drawbacks of FBD approach various alternate design methodologies are used now a days. Among them Performance Based Seismic Design approach is most popular. Performance Based Seismic Design (PBSD) approach, continuously under development is the modern approach to design the buildings with predictable seismic performance.

Performance Based Seismic Design (PBSD)

Performance Based Seismic Design (PBSD) approach is the modern approach to design the buildings with predictable seismic performance.

It is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design and an assessment whether or not the design meets the performance objectives. Finally redesign and reassessment is carried out if required, until the desired performance level is achieved. The PBSD process evaluates how a building is likely to perform for the given potential hazard. It shows different performance levels like Operational (OP), Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP) for different earthquake ground motions Serviceability Earthquake (50% probability of exceedance in 50 year with return period 72 year),

![Figure 1. Performance State-Hazard Level Relationship](image-url)

Design Basis Earthquake (10% probability of exceedance in 50 year with return period 475 year) and Maximum Considered Earthquake (2% probability of exceedance in 50 year with return period 2475 year) (FEMA-445,2006).PBSD is a new approach for the design of new structures and evaluation and retrofitting of existing structures. Structures designed with PBSD approach is more realistic understanding of the risk of casualties, occupancy interruptions and economic losses. In development of preliminary building design step of PBSD procedure direct and indirect displacement approach can be...
used to obtain performance objective (Qiang Xue et al., 2008). Since the damages are related directly to displacements, this paper focus on Direct Displacement Based Design (DDBD) approach with which PBSD is implemented.

**Direct Displacement Based Design**

Direct Displacement Based Design (DDBD) is simple non-iterative method for design of structures proposed by Priestley (Priestley et al., 2000) based on PBSD approach (Malekpour and Dashti, 2013). DDBD approach consider the inelastic deformation for maximum displacement. Figure 3 shows fundamentals of DDBD approach proposed by Priestly (Priestley et al., 2000). Figure 3a shows a MDOF system is presented by an equivalent SDOF system presented by effective height ($H_e$) and effective mass ($m_e$) at the maximum displacement by a secant stiffness (i.e. effective stiffness figure 3b) and an equivalent viscous damping ($\xi_{eq}$,figure 3c). The effective stiffness of the SDOF system is significantly lower than initial stiffness of the structure (Priestly and Kowalsky, 2000). This is because the SDOF system presents the MDOF system at maximum inelastic response (Džakić et al., 2012).

Lower stiffness gives lower base shear force. In this paper DDBD approach is conducted for seismic design of irregular reinforced concrete frame buildings. If the length of the spans in a reinforced concrete frame building are not equal in the direction of the earthquake, and/or if the height of the stories are not equal, then according to DDBD it is counted as irregular reinforced concrete frame building (Priestley and Kowalsky, 2007). For this paper, a ten storied irregular reinforced concrete office building is taken into account. The performance objectives are immediate occupancy performance level under frequent earthquake hazard level (mean return period 72 years) and life safety performance levels under rare earthquake hazard Figure 3. Fundamentals of DDBD Approach (Priestley et al) level (mean return period of 475 years)

The immediate occupancy and life safety performance levels are presented in terms of story drift ratios, 1% and 2%, respectively [Applied Technology Council, ATC-40, FEMA 356]. For this paper the frame is analyzed by DDBD approach using rules and regulations of IS and NBC codes. The base shear force obtained for 2% drift ratio shall be larger than the base shear obtained for 1% drift ratio. Thus, calculation for base shear obtained for 2% drift ratio are used. Once the performance level has been selected, then target design displacement and ductility demand are calculated. The equivalent damping, which is the combination of 5% elastic damping and hysteretic damping due to inelastic deformation, for SDOF system can be read from Figure 3c for estimated displacement ductility (i.e. corresponding to ductility demand). Once the equivalent damping is determined, design displacement response spectrum for this damping is obtained, and from the design displacement response spectrum effective period corresponding to maximum design displacement is read (Džakić et al., 2012).

The procedure of DDBD has been discussed stepwise (Priestley et al., 2007):

**Step 1. Selection of performance objective(Priestley et al., 2007):** The first thing is to choose the performance objective for specific hazard level (Figure 1). It can be presented in terms of story drift ratio (Table 1). The earthquake with return period 475 years (10% chance of exceedance in 50 years) and 2475 years (2% chance of exceedance in 50 years) are considered as Design basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) respectively (FEMA 356).

**Table 1 Performance Drift Levels (FEMA 356)**

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>Drift value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate Occupancy (IO)</td>
<td>1%</td>
</tr>
<tr>
<td>Life Safety (LS)</td>
<td>2%</td>
</tr>
<tr>
<td>Collapse prevention (CP)</td>
<td>4%</td>
</tr>
</tbody>
</table>

**Step 2. Calculation of Design Story Displacement ($\Delta_d$(Priestley et al., 2007)**
Design displacement is obtained as:

$$\Delta_i = \omega_i \delta_i \frac{\Delta_\theta}{\delta_c}$$

(i)

Where, \(\omega_0\) = drift reduction factor to take into account the higher mode effects.

$$\omega_0 = 1.15 - 0.0034 H_n \leq 1.0$$

(ii)

where, \(H_n\) = Total height of structure

\(\delta_i\) = inelastic mode shape of different story

\(\delta_i = H_i / H_n \) for \(n \leq 4\)

(iii)

\(\delta_i = 4/3(H_i/H_n)(1-(H_i/H_n))\) for \(n > 4\)

(iv)

\(H_i\) = height of structure at \(i^{th}\) story

\(\delta_c\) = inelastic mode shape of critical story, (story having largest drift ratio) usually 1\(^{st}\) story is taken as critical.

\(\Delta_c = \)design displacement of critical story

$$\Delta_c = \theta d H_1$$

(v)

Step 3. Calculation of Design Displacement of Equivalent SDOF System (Priestley et al., 2007)

Design displacement of equivalent SDOF system is determined as,

$$\Delta_d = \sum_{i=1}^{n} \left( m_i \Delta_i \right) / \sum_{i=1}^{n} (m_i \Delta_i)$$

(vi)

Where, \(m_i\) = mass of \(i^{th}\) story

\(\Delta_i\) = design displacement of \(i^{th}\) story

\(n\) = number of stories

Step 4. Effective Height of Equivalent SDOF System \((H_e)\) (Priestley et al., 2007)

The effective height of equivalent SDOF System is given as,

$$H_e = \sum_{i=1}^{n} (m_i \delta_i H_i) / \sum_{i=1}^{n} (m_i \delta_i)$$

(vii)

Step 5. Effective Mass of Equivalent SDOF System (Priestley et al., 2007)

The effective mass of equivalent SDOF system is given as,

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

(viii)

Step 6. Calculation of Design Displacement Ductility Factor for Equivalent SDOF System (\(\mu\)) (Priestley et al., 2007)

This factor is calculated as,

$$\mu = \Delta_d / \Delta_y$$

(ix)

Where, \(\Delta_d\) = design displacement of equivalent SDOF system

\(\Delta_y\) = Yield displacement of equivalent SDOF system and is expressed as

$$\Delta_y = \frac{2M_1 \theta y_1 + M_2 \theta y_2}{2M_1 + M_2} H_n$$

(x)

Where,

\(M_1\) and \(M_2\) = moment contribution to the total overturning moment from outer and inner bays respectively

\(\theta y_i\) = yield drift and is expressed as

$$\theta y_i = 0.5 \varepsilon y \frac{L_{bi}}{h_{bi}}$$

(xi)

Where,

\(L_{bi}\) = Length of beam of \(i^{th}\) bay

\(h_{bi}\) = depth of beam of \(i^{th}\) bay

\(\varepsilon y\) = yield strain which is expressed as

$$\varepsilon y = \frac{f_{ye}}{E_s}$$

(xii)

Where,

\(f_{ye}\) = expected yield strength of steel reinforcement

\(f_{ye} = 1.1 f_y\) (xiii)

\(f_y\) = Yield strength of rebar

\(E_s\) = Young’s modulus of Elasticity of rebar

Step 7. Calculation of Equivalent Viscous damping for the Equivalent SDOF System (Priestley et al., 2007)

For RCC structure the equivalent viscous damping of SDOF system is combination of 5% viscous damping and hysteretic damping. It is expressed as

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

(xiv)

Step 8. Calculation of Effective Time Period at Peak Displacement Response (Priestley et al., 2007)

To find the effective period at peak displacement response, it is required to find the displacement response spectrum for effective or equivalent damping (i.e. the design displacement response spectrum). Using the procedure given in Euro Code, the expression can be obtained using following relation.

$$S_{D_S} = S_{D_e,5} \left( \frac{0.10}{0.05 + \xi_{eq}} \right)^{0.5}$$

(xv)

Where:

\(S_{D_e,5}\) is the elastic displacement response spectrum for 5% damping and it can be obtained through following equation...
Where:

\[ S_{D_e5} = S_{ae}(T) \frac{T^2}{4\pi^2} \]  

\[ S_{D_e5} \] is elastic acceleration response spectrum for 5% damping, and according to Seismic Design Code used in Nepal, it is given as follows:

As per IS 1893:2002 elastic acceleration response spectrum

\[ S_a(T) = \frac{Z}{2} \frac{(I/R)}{(Sa/g)} g \]  

And as per NBC 105:1994 elastic acceleration response spectrum

\[ S_a(T) = CZIKg \]  

\[ Z = \text{Zonal factor} \]
\[ I = \text{Importance factor} \]
\[ R = \text{Response reduction factor} \]
\[ Sa/g = \text{Structural response factor} \]
\[ C = \text{Basic seismic coefficient} \]
\[ K = \text{Structural performance factor} \]
\[ g = \text{acceleration due to gravity (9.81 m/s}\]²

Now using the equations (xiv), (xv) and (xvi) and plotting the results in graph for Δd, the effective time period (T_{eff}) is determined.

\[ T_c = 1 + 2.5(M_w - 5.7) \]  

(Faccioli et al., 2004)
\[ M_w = \text{moment magnitude} \]

**Step 9. Calculation of effective stiffness of Equivalent SDOF System (Priestely et al., 2007)**

The effective stiffness of equivalent SDOF System is given by

\[ K_{eff} = \frac{4\pi^2}{T_{eff}^2} m_e \]  

\[ m_e \]

\[ T_{eff} \]

**Step 10. Calculation of Base Shear (V_{b,s}) (Priestely et al., 2007)**

The base shear force is given by,

\[ V_{Base} = K_{eff} \Delta_d \]  

**Step 11. Calculation of Lateral Forces at the Top of Each Story (Priestely et al., 2007)**

The base shear obtained is then distributed to top of each story is given by

\[ V_{i} = \frac{F_i}{n} \frac{m_i \Delta_i}{\sum_{j=1}^{n} (m_j \Delta_j)} \]

for \( n < 10 \)

\[ V_{i} = \frac{F_i}{n} \frac{0.9V_{base} (m_i \Delta_i)}{\sum_{j=1}^{n} (m_j \Delta_j)} \]

for \( n \geq 10 \)

where, \( F_t = 0.1V_{base} \) at roof level, and \( F_t = 0 \) at all other story levels.

**Step 12. Calculation of the Total Overturning Moment (MOTM) (Priestely et al., 2007)**

Once the forces at the top of each story is obtained, then total overturning moment at the base of the building can be found from the following equation:

\[ M_{OTM} = \sum_{i=1}^{n} F_i H_i \]  

**Step 13. Check for P-Δ effect (Priestely et al., 2007)**

P-Delta effects should also be included if they are being required. For this purpose, the stability index is calculated by following relation:

\[ \theta_{\Delta} = \frac{P \Delta_{\max}}{M_D} \]  

\[ M_D \]
Where

\[ M_0 = M_{orf} \text{ and } \Delta_{max} = \Delta_d \] (Maseena B et al., 2010).

\( P \) is the total seismic weight of the building considering 100% of live load.

If \( 0.1 \leq \theta \Delta \leq 0.33 \) P-Delta effects should be considered. If \( \theta \Delta > 0.33 \), then the structure must be made stiffer (Maseena B et al., 2010). and the calculations should be revised. Further, if \( \theta \Delta < 0.1 \), then there is no need to take into account the P-Delta effects.

**Step 14. Amplification of Base Shear (Priestely et al., 2007)**

If stability index, is \( 0.1 \leq \theta \Delta \leq 0.33 \), then base shear must be amplified as

\[ V_{base} = K_{eff} \Delta_d + C \frac{P \Delta_d}{H_e} \] ………. (xxv)

For RCC structure \( c = 0.5 \).

This is the final base shear considering P-Δ effect and should be distributed along all the floors for design purpose using equation (xxi) or (xxii).

**Step 15. Modelling and Nonlinear Analysis**

Using any finite element program like SAP2000, the building is modelled and story forces obtained from equation (xxi) or, (xxii) by distribution of base shear considering P-Δ effect (if required) from step 14 are applied on each story of structure. Further non-linear pushover analysis is conducted to find the drift limit and other performance parameters.

**Step 16. Check of roof displacements, inter-story drift ratio (IDR) and Inelastic Displacement Demand Ratio (IDDR) with standard parameter**

If the roof displacements are within the acceptable limit given by FEMA 273, further mean inter-story drift ratio (IDR) and inelastic Displacement Demand Ratio (IDDR) is checked with acceptable parameter given by FEMA 273. If mean inter-story drift ratio exceeds the limit the preliminary design is revised. Revision may be in sector of grade of concrete of respective frame element (column especially), change in size of frame element (at first ground floor column then upper one). When the performance parameters like lateral drift ratio, inter-story drift ratio and inelastic Displacement Demand Ratio are within the limit, the design of the structural elements can be completed and the reinforcement can be designed.

Roof Displacement (%) = \( \delta / H \times 100 \) …… (xxvi)

Where, \( \delta = \) displacement on roof

\( H = \) height of structure

Inter-Story Drift Drift Ratio,

\[ IDR = (\delta_i - \delta_{i-1}) / h \] ………... (xxvii)

Where,

\( \delta_i = \) displacement at \( i^{th} \) story

\( \delta_{i-1} = \) displacement at \((i-1)^{th}\) story

\( h = \) story height

Inelastic Displacement Demand ratio (IDDR) is obtained from pushover curve and is calculated by:

\[ IDDR = \text{Inelastic Displacement Demand} / \text{Ultimate Inelastic Displacement Capacity} \] ……… (xxviii)

**Table 2. Acceptable Lateral Drift Limit. (FEMA 273)**

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>OP</th>
<th>IO</th>
<th>LS</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta / H % )</td>
<td>0.005</td>
<td>0.01</td>
<td>0.02</td>
<td>0.025</td>
</tr>
</tbody>
</table>

**Table 3. Acceptable Inter-Story Drift limit (FEMA 273)**

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>OP</th>
<th>IO</th>
<th>LS</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>( (\delta_i - \delta_{i-1}) / h )</td>
<td>0.0</td>
<td>0.2</td>
<td>0.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Table 4. Acceptable Inelastic Displacement Demand Ratio (IDDR) (FEMA 273)**

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>OP</th>
<th>IO</th>
<th>LS</th>
<th>CP</th>
</tr>
</thead>
<tbody>
<tr>
<td>IDDR</td>
<td>0.0</td>
<td>0.2</td>
<td>0.6</td>
<td>0.8</td>
</tr>
</tbody>
</table>

**Application of DDBD (Case study)**

For case study an irregular 10 storied RCC framed office building (Figure 6) of bay width 6 m each bay in x-direction and bay width 5 m each bay in y-direction is considered. Building is situated on medium soil in most vulnerable seismic zone. Dimension of beam and column is considered as 300 mm x 300 mm and 550 mm x 550 mm. Slab thickness is 125 mm. Concrete is of M25 grade for column and M20 for beam and slab. with young’s modulus of elasticity \( E_c = 25000 \text{ N/mm}^2 \) and reinforcement of Fe 500 grade with young’s modulus of elasticity \( E_s = 2 \times 10^5 \text{ N/mm}^2 \). Floor finish load is assuming as 3 kN/m², Wall load as 17 kN/m and Live load 5kN/m² is acting on building floors. Floor height is 3m. The building is analyzed with IS 1893: 2002 code, NBC 105:1994 code and DDBD approach. Further static pushover analysis is performed to check the performance parameters.

![Figure 6. Plan of Building](image-url)
When the same building is analyzed by using Seismic Code used in Nepal: IS 1893:2002 and NBC 105:1994, the base shear calculated by DDBD approach, IS 1893:2002 Seismic Code and NBC 105:1994 are compared and tabulated as:

Table 5. DDBD approach parameters and others

<table>
<thead>
<tr>
<th>Parameters</th>
<th>10 storied RCC building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drift Limit, ( \theta_b ) (%)</td>
<td>2.0</td>
</tr>
<tr>
<td>Total Seismic Weight of Structure W (Ton)</td>
<td>13180.43</td>
</tr>
<tr>
<td>Drift Reduction Factor, ( c_b )</td>
<td>1.0</td>
</tr>
<tr>
<td>Design Displacement of Critical story, ( \Delta_{bm} ) (mm)</td>
<td>60</td>
</tr>
<tr>
<td>Inelastic Mode Shape of Critical Story ( \delta )</td>
<td>0.13</td>
</tr>
<tr>
<td>Design Displacement, ( \Delta_{d} ) (mm)</td>
<td>323</td>
</tr>
<tr>
<td>Effective Height, ( H_{eff} )</td>
<td>19.31</td>
</tr>
<tr>
<td>Effective Mass, ( m_e (ton) )</td>
<td>10852.92</td>
</tr>
<tr>
<td>Expected Yield Strength, ( f_{iy}N/mm^2 )</td>
<td>550</td>
</tr>
<tr>
<td>Yield Strain ( \varepsilon )</td>
<td>0.00275</td>
</tr>
<tr>
<td>Yield Drift, ( \theta_{y} (x\text{-direction}) )</td>
<td>0.0165</td>
</tr>
<tr>
<td>Yield Drift, ( \theta_{y} (y\text{-direction}) )</td>
<td>0.01375</td>
</tr>
<tr>
<td>Yield Displacement, ( \Delta_{y} (mm) ) in x\text{-direction}</td>
<td>319</td>
</tr>
<tr>
<td>Yield Displacement, ( \Delta_{y} (mm) ) in y\text{-direction}</td>
<td>266</td>
</tr>
<tr>
<td>Design Displacement Ductility Factor, ( \mu (x\text{-direction}) )</td>
<td>1.01254</td>
</tr>
<tr>
<td>Design Displacement Ductility Factor, ( \mu (y\text{-direction}) )</td>
<td>1.2143</td>
</tr>
<tr>
<td>Equivalent damping (e (%) (x\text{-direction})</td>
<td>5.223</td>
</tr>
<tr>
<td>Equivalent damping (e (%) (y\text{-direction})</td>
<td>8.174</td>
</tr>
<tr>
<td>Effective Period, ( T_{e} (x\text{-direction}) ) sec</td>
<td>3.125</td>
</tr>
<tr>
<td>Effective Period, ( T_{e} (y\text{-direction}) ) sec</td>
<td>3.313</td>
</tr>
<tr>
<td>Effective Stiffness, ( K_{e} (x\text{-direction}) ) kN/m</td>
<td>43873.91</td>
</tr>
<tr>
<td>Effective Stiffness, ( K_{e} (y\text{-direction}) ) kN/m</td>
<td>39035.86</td>
</tr>
<tr>
<td>Base Shear, ( V_{kN} (x\text{-dir}) )</td>
<td>14171.27</td>
</tr>
<tr>
<td>Base Shear, ( V_{kN} (y\text{-dir}) )</td>
<td>12606.58</td>
</tr>
<tr>
<td>Stability Index, ( \beta_{x} (x\text{-dir}) )</td>
<td>0.158</td>
</tr>
<tr>
<td>Stability Index, ( \beta_{y} (y\text{-dir}) )</td>
<td>0.178</td>
</tr>
<tr>
<td>Final Base Shear, ( V_{kN} (x\text{-dir}) )</td>
<td>13556.73</td>
</tr>
<tr>
<td>Final Base Shear, ( V_{kN} (y\text{-dir}) )</td>
<td>13794.04</td>
</tr>
</tbody>
</table>

Further the performance parameters like lateral drift ratio, inter-story drift ratio and inelastic displacement demand ratio of building analyzed by DDBD approach are checked and compared with acceptable value.

Table 6. Comparison of Base Shear

<table>
<thead>
<tr>
<th>Design Approach</th>
<th>Direction</th>
<th>Base Shear, kN</th>
<th>% change from IS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDBD</td>
<td>x-dir</td>
<td>15356.73</td>
<td>-12.02</td>
</tr>
<tr>
<td></td>
<td>y-dir</td>
<td>13794.04</td>
<td>-20.98</td>
</tr>
<tr>
<td>IS 1893:2002</td>
<td>x-dir</td>
<td>17455.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>y-dir</td>
<td>17455.5</td>
<td></td>
</tr>
<tr>
<td>NBC 105:1994</td>
<td>x-dir</td>
<td>34135.2</td>
<td>+95.56</td>
</tr>
<tr>
<td></td>
<td>y-dir</td>
<td>31515.06</td>
<td>+80.89</td>
</tr>
</tbody>
</table>

Table 7. Lateral Drift Ratio (LDR)

<table>
<thead>
<tr>
<th>Displacement, ( \dot{\delta} ) (mm)</th>
<th>LDR = ( \delta / \delta_{MM} \times 100 ) %</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-dir</td>
<td>Y-dir</td>
<td>X-dir</td>
</tr>
<tr>
<td>364</td>
<td>374</td>
<td>1.21</td>
</tr>
</tbody>
</table>

Table 8. Inter-Story Drift Ratio (IDR)

<table>
<thead>
<tr>
<th>Story</th>
<th>Displacement, ( \dot{\delta} ) mm</th>
<th>Story Height mm</th>
<th>IDR = ( \delta_i / \delta_{i-1} h )</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>x-dir</td>
<td>y-dir</td>
<td>x-dir</td>
<td>y-dir</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>364</td>
<td>357</td>
<td>3000</td>
<td>0.002</td>
</tr>
<tr>
<td>8</td>
<td>343</td>
<td>350</td>
<td>3000</td>
<td>0.008</td>
</tr>
<tr>
<td>7</td>
<td>319</td>
<td>324</td>
<td>3000</td>
<td>0.011</td>
</tr>
<tr>
<td>6</td>
<td>285</td>
<td>288</td>
<td>3000</td>
<td>0.015</td>
</tr>
<tr>
<td>5</td>
<td>259</td>
<td>244</td>
<td>3000</td>
<td>0.018</td>
</tr>
<tr>
<td>4</td>
<td>184</td>
<td>189</td>
<td>3000</td>
<td>0.0197</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
<td>132</td>
<td>3000</td>
<td>0.019</td>
</tr>
<tr>
<td>2</td>
<td>87</td>
<td>65</td>
<td>3000</td>
<td>0.015</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
<td>24</td>
<td>3000</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Table 9. Inelastic Displacement Demand ratio (IDDR)

<table>
<thead>
<tr>
<th>Direction</th>
<th>Inelastic Displacement Demand (mm)</th>
<th>Ultimate Inelastic Displacement Capacity (mm)</th>
<th>IDR</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>y</td>
<td>x</td>
<td>y</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Conclusion

From the results obtained from case study, the following conclusion were drawn:

- Since base shear obtained by DDBD approach is less than base shear obtained from FBD approach i.e. using IS 1893:2002 and NBC 105:1994, DDBD approach is much economical design.
- Check for displacement performance parameter, LDR, IDR and IDDR, should be compulsory for DDBD approach design.
- Bi-directional ground motion must be considered in seismic design. DDBD approach focused on design parameters in x and y direction which is not followed in FBD approach in some context.
- NBC 105:1994 design the structure with large reinforcements and frame size even though the performance is same in design by DDBD and IS 1893. Thus, NBC code need immediate revision.

REFERENCES


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