Performance of Dual System Design Using UPBD Method

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Abstract- Shear walls are generally used in high rise structures because it has the ability to resist lateral load which provide stability to structures from lateral loads like wind and seismic Loads and providing shear wall is one of the most efficient methods of ensuring the lateral stability of tall buildings. This structural element, which provide strength, stiffness and stability to the structures. This paper contains a brief description and analysis of symmetrical frame having 3 different height of dual frame structures i.e 10, 12 and 15 storey and types of soil condition considered is medium. The design analysis of the high rise structures is done through software ETABS 2016 and designed have been done using UPBD method for various target performance objectives. In dual wall buildings lateral load is mainly taken by shear wall and gravity load is taken by frame. The designed buildings are subjected to static as well as dynamic nonlinear analyses. The shear wall is modeled as a layered shell element, whereas the beams and columns are designed as frame elements. The structures have been designed with expected strength and demand level of EC-8 spectrum at 0.45g. The target performance objective is considered as Life safety (LS) performance level with 2% drift. Various performance parameters like performance point, design drift, equivalent damping and base shear have been found out. It has been observed that the target performance objectives have been achieved.

Keywords. Performance-based design, UPBD method, RC dual system, Plastic hinge, Interstorey Drift

I. INTRODUCTION

Reinforced concrete framed buildings are adequate for resisting both lateral and horizontal forces acting toward the structures. In case of tall buildings, large reinforcement is required to place in beams and columns and therefore the sizes also became larger and because of this reason beam column joint became heavy and there is a lot of conflict at the joints and therefore it is very difficult to place the concrete and vibrate at that particular places, and it does not contribute to the safety of buildings. Due to these difficulties, there is a need of shear wall in multi-storey buildings. As Shear walls gives large strength and stiffness to buildings in all the directions, and this reduces horizontal movement of the buildings and decreases damage to the structure. In the recent years, the dual frame system building has been established because it provide great performance during the earthquake. In the present study the frame dual wall building of 12 storey is considered where the dual wall carries 70% of lateral load and frame carries 30% of lateral load. The pre-decided design drift, target performance level and hazard level of earthquake, the selected building is evaluated using UPBD method and various parameters like equivalent damping, time period and base shear are calculated according to choudhury and singh [1]. The shear wall is modeled as a layered shell element here the shear wall is modelled with two layers of reinforcement bars of longitudinal and transverse and it could be modeled with different techniques i.e multi layer shell and Mid-Pier frame with plastic hinges. The plastic hinges characteristics of the shear wall could be defined in ASCE 41-13 recommendation or Fiber based Hinge property by fahjan [2]. Check is done to ensure that the length of shear wall is capable to take the assigned lateral load. The building is designed using expected strength as per FEMA-356. The column size is decided on trial basis by keeping the percentage of steel 3% to 4% and to ensure the capacity design criteria as per 13920:2016. The push over analysis is carried out to find the performance level of the building. Design spectrum is considered is EC-8 for type B soil at hazard level of 0.45g. The target performance objectives considered is LS with 2% drift.

II. METHODS OF ANALYSIS

2.1 Unified performance based design (upbd) method for dual wall buildings

The main parameters of designing the structures are: Inter-storey drift and performance level of members. In this method size of the beam and length of the wall is designed according to DDBD where yield rotation is considered and is mentioned in ASCE 41-13

\[ \theta_{y} = \frac{0.5e_{l}l_{b}}{h_{b}} \]  

(1)
Where, $\theta_{yF}$ = frame yield rotation, $h_b$ = depth of beam, $\varepsilon_y$ = yield strain of rebar, $l_b$ = length of beam, $\theta_d$ = the sum of yield rotation and $\theta_{pb}$ = plastic rotation of beams.

\[ \theta_d = \theta_{yF} + \theta_{pb} \]  

(2)

And hence the depth of beam may be given as:

\[ h_b = \frac{0.5 \varepsilon_y l_b}{\theta_d - \theta_{pb}} \]  

(3)

\[ \theta_{yF} = \frac{0.5 \varepsilon_l l_b}{h_b} \]  

(4)

and length of wall ($L_w$) is obtained as

\[ L_w = \frac{\varepsilon_l h_{inf}}{\theta_d - \theta_{pw}} \]  

(5)

Where, $L_w$ = length of wall, $\varepsilon_y$ = yield strain of rebar, $h_{inf}$ = height of inflexion, $\theta_d$ = design drift and $\theta_{pw}$ = plastic rotation in wall taken from ASCE 41-13. The thickness of wall is obtained from base shear consideration and number of wall used in a particular direction. When the moments of the wall is zero that point is called the inflexion point and the height from the ground is the inflexion height.

2.2 Direct displacement based design (DDBD) of frame-wall structures

A DDBD method was first proposed by Petting and Priestly [3] for frame building. At later stage, this method was proposed by Sullivan et.al [4] for both frame and shear walls structures. The MDOF system has to be converted into an equivalent SDOF system by providing strength and subsequently using moment profile in the walls to set a design displaced shape. To establish the inflexion height ($h_{inf}$) of the building the moment and curvature should be zero. The inflexion height is used to find the displacement of the structure at yield of the walls and to develop the design displacement profile.

Equivalent single degree of freedom (ESDOF) properties are determined using the following relations:

Design displacement,

\[ \Delta d = \frac{\sum_{i=1}^{n} m_i \Delta i^2}{\sum_{i=1}^{n} m_i \Delta i} \]  

(6)

Effective mass,

\[ m_i = \frac{\sum_{i=1}^{n} m_i \Delta i}{\Delta d} \]  

(7)

Effective height,

\[ h_i = \frac{\sum_{i=1}^{n} m_i \Delta h_i}{\sum_{i=1}^{n} m_i \Delta i} \]  

(8)
Where, $h_i$ = storey height, $m_e$ = effective mass of the structure, $h_i$ = effective height. Frame and wall ductility demand are determined.

The yield displacement profile of wall is given by,

$\Delta_{i,y} = \phi_{i,w} h_i h_{inf} \frac{2}{6} - \phi_{i,w} h_{inf}^2$, when $h_i \geq h_{inf}$  \hspace{1cm} (9)

$\Delta_{i,y} = \phi_{i,w} h_i^2 - \phi_{i,w} h_i h_{inf} \frac{2}{6 h_{inf}}$, when $h_i \leq h_{inf}$  \hspace{1cm} (10)

Wall ductility demand,

$\mu_w = \frac{\Delta d}{\Delta_{he,y}}$  \hspace{1cm} (11)

Frame ductility,

$\mu_{f,i} = \left( \frac{\Delta_{i} - \Delta_{i-1}}{h_i - h_{i-1}} \right) \frac{1}{\theta_{y,f}}$  \hspace{1cm} (12)

Where,

$\theta_{y,f} = \frac{l_e e_y}{2h_b}$  \hspace{1cm} (13)

The equivalent viscous damping for the frame and walls is obtained adding the elastic and hysteretic component together as follows,

$\xi_{SDoF} = \left( \frac{M_{wall} \xi_{wall} + MOT_{frame} \xi_{frame}}{M_{wall} + MOT_{frame}} \right)$  \hspace{1cm} (14)

$\xi_w = \frac{95}{1.3 \pi} \left( 1 - \mu_w^{-0.5} - 0.1 \varphi \mu_w \right) (1 + \frac{1}{(T_{wall} + 0.85)^4})$  \hspace{1cm} (15)

$\xi_f = \frac{120}{1.3 \pi} \left( 1 - \mu_w^{-0.5} - 0.1 \varphi \mu_f \right) (1 + \frac{1}{(T_{wall} + 0.85)^4})$  \hspace{1cm} (16)

$T_{wall} = \frac{N}{6 \sqrt{\mu_{sys}}}$

Where $\xi_{SDoF}$ is equivalent viscous damping of system, wall is wall moment, $MOT$ is frame overturning moment, $\xi_{wall}$ is equivalent damping of wall, $\xi_{frame}$ is equivalent damping of frame.

Fig 2: Displacement Spectra of 0.46g corresponding to EC-8
(a) Equivalent damping versus ductility (b) Performance levels

The effective stiffness $k_e$ is determined by,

$$k_e = \frac{4\pi^2 me}{T_e^2} \quad (17)$$

Here, $T_e$ is obtained from displacement spectra corresponding to the equivalent damping versus ductility.

The base shear $V_b$ is determined, the base shear force $V_b$ is distributed up the height of structures

$$V_b = k_e \Delta d \quad (18)$$

Where the $F_i$ is the portion of base shear applied at the $i$-th floor.

$$F_i = \frac{m_i \Delta i}{\sum m_i \Delta i} \quad (19)$$

The load combinations are as below:

- $DL + LL$
- $DL + LL \pm F_x$
- $DL + LL \pm F_y$

Where $DL, LL \ F(X), F(Y)$ corresponds to dead load, live load, earthquake load in $x$ and $y$ direction respectively.

III. BUILDING DETAILS

In this paper 10, 12 and 15 storey reinforced concrete frame-shear wall buildings are considered as shown in Fig. 3 and have been designed by Unified performance based design (UPBD) method for target performance objective of 2% drift with life safety (LS) performance level. Analysis and design has been done using software ETABS-2016. Shear wall have been modeled as multi-layered shell elements. Here grade of steel considered is Fe 415 and M30 concrete is considered with expected strength as per ASCE 41-13. Height of entire floor is assumed to be same. steel of 3% to 4% of column is maintained to total cross sectional area. Buildings were designed for Life Safety (LS) performance level. 3D Model of 10, 12 and 15 story shear wall structures is shown in Fig. 5. The Design consideration of the building as shown in Table 1.

<table>
<thead>
<tr>
<th>Building Name</th>
<th>Column Sizes</th>
<th>Beam size (mm)</th>
<th>Shear wall thickness (mm)</th>
<th>Target Drift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual wall building</td>
<td>Inner column</td>
<td>Outer column</td>
<td>depth Width</td>
<td>10 LS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12 LS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15 LS</td>
</tr>
</tbody>
</table>
Capacity design is the best approach towards ductile design criteria. In capacity design the certain structural members are allowed to fail in some intended way whereas some other members are to remain undamaged. This concept applies to beam-column joint where the column is of higher capacity so that the beam fails earlier to make the failure a ductile one. IS code 13920:2016 suggest that the capacity design has to be carried out for ductile and on ductile members. According to IS code mentioned the design should be such that

\[ \sum M_{COLUMN} \geq 1.4 \sum M_{BEAM} \]

The column sizes were decided by trial so that the steel was within 3% to 4% to columns.

Table 2: Detail of artificial ground motion

<table>
<thead>
<tr>
<th>Sl. no</th>
<th>name</th>
<th>Year of occurrence</th>
<th>Place of occurrence</th>
<th>Duration (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PGA1</td>
<td>1990</td>
<td>baithalangso</td>
<td>26.940</td>
</tr>
<tr>
<td>2</td>
<td>PGA 2</td>
<td>1988</td>
<td>cherrapunji</td>
<td>21.24</td>
</tr>
<tr>
<td>3</td>
<td>PGA 3</td>
<td>1995</td>
<td>chamba</td>
<td>17.86</td>
</tr>
<tr>
<td>4</td>
<td>PGA 4</td>
<td>1995</td>
<td>haflong</td>
<td>12.94</td>
</tr>
<tr>
<td>5</td>
<td>PGA 5</td>
<td>1990</td>
<td>saitsama</td>
<td>26.60</td>
</tr>
</tbody>
</table>

IV. ANALYSIS OF BUILDING

Non-linear static analysis or push over analysis is the procedure to obtaining earthquake demands on building. Non linear analysis contributing the structures to determine the performance point (PP). Plan of the considered buildings is shown in Fig. 4. For performance based design buildings, ASCE 41-13 defines RC members in terms of plastic rotations. Inflexion height is achieved when the moments of wall is zero and that point from the base is the the height of inflexion as shown in Fig. 5

Figure 4: Plan of the buildings model
(a) 10 storey building  (b) 12 storey building  (c) 15 storey building
V. RESULTS AND DISCUSSIONS

The considered buildings are designed with multi-layered shell element shear wall and it is observed that performances of members have fulfilled the required performance level i.e Life Safety (LS) and Collapse Prevention (CP) which were identified by plastic hinge rotations as shown in Fig. 7. The performance level of LS which is target performance in this paper has attained its PP (Performance point) and it has been shown in Fig. 6. The hinge formation in the members that achieves the desired performance levels as shown in Fig: 7.
Nonlinear time history analysis (NLTHA) or dynamic analysis is carried out under 5 earthquake datas. The interstorey drift diagrams for typical buildings considered have been shown in Fig. 8 and it has fulfilled the assumed target drift considered.

VI. CONCLUSION

The present study has been carried out the earthquake response of tall building by using varying height of buildings with shear wall. The purpose of the study is to investigate whether the models provides adequate performance. The UPBD method of seismic design was proposed only for IO buildings without the presence of infill, here the dual frame buildings that is designed for LS performance level (PL). Using UPBD method has attained desired PL in terms of plastic hinges, thus validating the use of this method for design of frame wall building. With push over analysis it has been found that the building designed performed better. The outcome of the work clearly indicates that, the performance of dual wall building has achieved its targets.

VII. REFERENCES