Performance of RC Frame Buildings with Infill Using UPBD Method

[1]Panna Lal Kurmi, [2]Satyabrata Choudhury
[1]Assistant Professor, [2]Professor
[1]Department of Civil Engineering. Parul Institute of Technology, Vadodara
[2]National Institute of Technology, Silchar

***Abstract* - In the present paper, Unified Performance-Based Design (UPBD) of RC frame buildings with infill has been studied. The UPBD method (Choudhury and Singh) [1] enables the designer to design for both drift and performance level simultaneously in displacement-based design of RC frame buildings without incorporating infill strut elements. The performance objectives of the buildings are selected in terms of interstorey drift ratio (IDR) and member performance level. The selected target performance objectives are: 1% IDR with Immediate Occupancy (IO) performance level, 2% IDR with Life Safety (LS) performance level, and 3% IDR with Collapse Prevention (CP) performance level. A comparative study of performanceshas been carried out between RC frame buildings without incorporating infill strut and the corresponding RC frame buildings with infill strut elements, both designed using UPBD method. The buildings have been modeled using SAP2000 V 15.0 software [2]. The performance parameters have been evaluated by performing Nonlinear Time History Analysis (NLTHA) for the both RC frame buildings without infill strut and RC frame buildings with infill strut elements.**

***Keywords* - Performance-Based Design (PBD), Direct Displacement-Based Design (DDBD), Unified Performance-Based Design (UPBD), Interstorey Drift Ratio (IDR), Equivalent Single Degree of Freedom (ESDOF) system**

I. INTRODUCTION

Performance-Based design (PBD) is an alternative seismic design approach in place of traditional force-based method of design, where, a structure can be designed for intended performance objectives. The performance objectives may bedamage in members of building in terms of plastic rotation, interstorey drift, crack width etc.In PBD, the typical performance levels are Immediate Occupancy (IO) performance level, where the damage is least, Life safety (LS) performance level, where the damage is of intermediatelevel and life threat is prevented and Collapse Prevention (CP) performance level, where damage is substantial and the structure is on the verge of collapse.In the available study the effect of infill has been ignored so far in PBD. But, theinfill in RC frame buildings significantly changes the seismic behavior of the buildings in terms of drift and member performance level. The infill increases the stiffness of the building and thereby influences performance to a large extent.

The present study aims at comparing the seismic performance of RC frame buildings with and without infill strut elementswhileusing UPBDmethod. The NLTHA has been performed with five Spectrum Compatible Ground Motions (SCGMs) which have beengenerated by using software developed by Kumar [3]. This software can generate artificial ground motion compatible to a target design spectrum. In the present study, the design target spectrum considered is as per Euro Code (EC-8) [4] at acceleration of 0.45g level with soil type B. The background earthquakes used in the generating of SCGMs aregiven in Table 1.

Table.1. Detail of SCGMs considered

Sl	Name	Background earthquake	Record No.	Duration
1	SCGM_1	San Fernando, 1971	USGS 1015	30 sec
2	SCGM_2	Borrego, 1968	SCE, 280	40 sec
3	SCGM_3	Coalinga, 1983	CDMG, 46314	40sec
4	SCGM_4	Calidran, 1976	37, S49E	28 sec
5	SCGM_5	Loma Prieta,89	USGS,1161	39 sec

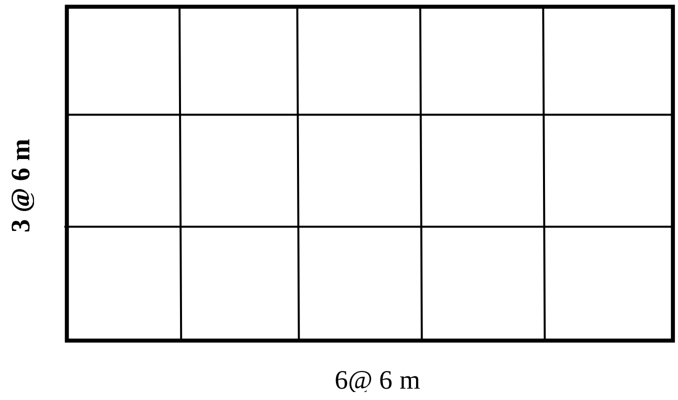


Fig.1. Plan **I** of the building considered

Table.2. Nomenclature and target performance objectives of the buildings considered

Name of buildings	Target member performance level	Target interstorey drift %	Type of RC building frame
AI6	IO	1	No Infill strut
BI6	LS	2	No Infill strut
CI6	CP	3	No Infill strut
A′I6	IO	1	With infill strut
B′I6	LS	2	With infill strut
C′I6	CP	3	With infill strut

Table.3. Member sizes adopted for the buildings

Building names	Floor level	Column sizes(mm)	Beam sizes(mm)
AI6 and A′I6	Below plinth to 2nd 3rd to 6th floor	800×800 700X700	650X1300
BI6 and B′I6	Below plinth to 2nd 3rd to 6th floor	600X600 500X500	450X900
CI6 and C′I6	Below plinth to 2nd 3rd to 6th floor	500X500 400X400	300X600

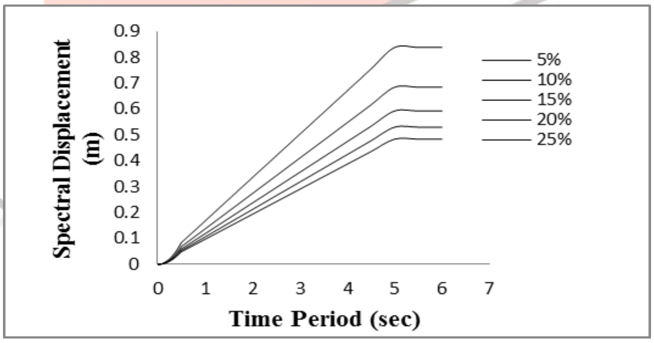


Fig.2. Displacement spectra corresponding to EC-8 design spectra at 0.45g level for various damping's.

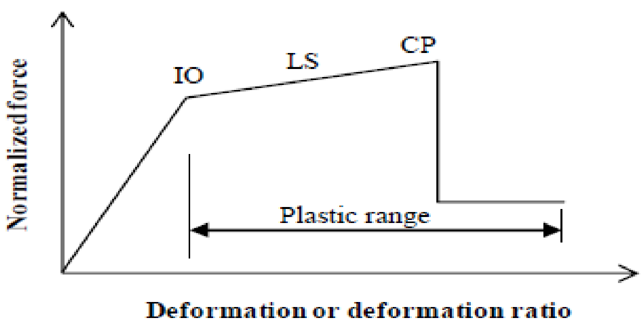


Fig.3. Force-deformation behavior (FEMA-356)

II. UNIFIED PERFORMANCE-BASED DESIGN METHOD

This method of PBD attempts to satisfy simultaneously performance objectives in the form of (i) interstorey drift and, (ii) member performance level (Choudhury and Singh 2013) [1]. The member performance level is expressed in terms of allowable plastic rotation in beams for a desired damage state. Plastic hinges are allowed to form in the beams only and the column remains elastic and it is ensured by the concept of capacity design. The target objectives in terms of design drift and member performance level can be achieved by estimating the depth of beam.The design angular drift (θ_d) is the sum of frame yield rotation (θ_{yf}) and plastic rotation (θ_p) of the ESDOF system given in Eq. (2) and shown in fig.4. whereH_e is the effective height of the system. The plastic rotation of the system comes from the plastic rotation in beams (θ_{pb}) only. The frame yield rotation (θ_{yf}) given in Eqn.(1), where $\in_y$ is the expected yield strain of rebar, l_b is the length of beam and h_b is the depth of beam.

$$\theta_{yf} = 0.5 \in_y l_b/h_b \quad (1)$$

$$\theta_d = \theta_{yf} + \theta_{pb} \quad (2)$$

From the Eq. (1) and Eq. (2), Eq. (3) can arranged

$$h_b = \frac{0.5\in_y l_b}{\theta_d - \theta_{pb}} \quad (3)$$

Eq. (3) gives the depth of beam that shall satisfy the performance objectives. Here θ_{pb} is the average plastic rotation in beams corresponding to desiredperformance level can be taken from FEMA-356 [5].

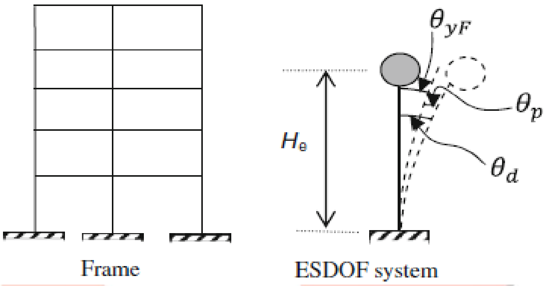


Fig.4.Equivalent SDOF system (Choudhury and Singh, 2013) [1].

III. DESIGN METHODOLOGY

The design steps are same as it is followed in UPBD method of S. Choudhury and S. M. Singh (2013) [1] and for the ready reference, the steps are described below.

1. The design starts with the selection of target objectives in terms of interstorey drift and member performance level. The depth of beam has been estimated from Eq. (3).
2. The width of beam is taken as half to two third of depth of beam.
3. Initially the column sizes have been adopted as per general design practice.
4. Further design steps are same as DDBD method of Pettinga and Priestly[6]. The ESDOF system properties are determined as follows

$$\Delta_d = \frac{\sum m_i \Delta i^2}{\sum m_i \Delta_i} \quad (4)$$

$$m_e = \frac{\sum m_i \Delta_i}{\Delta_d} \quad (5)$$

$$H_e = \frac{m_i \Delta_i h_i}{\sum m_i \Delta_i} \quad (6)$$

Here m_i,h_i ad Δ_i are the mass, height from base and displacement from i^{th} storey. Δ_d is the target or spectral displacement, m_e is the equivalent mass, H_e is the effective height of ESDOF system. The deflection profile suggested by Pettinga and Priestly [6] have been used and shown in Eq. 7(a) and 7(b).

Here,$\emptyset_i$ is the first mode shape profile at i^{th} floor of the building and n is the total number of storey.

$$n \leq 4,\ \emptyset_i = \frac{h_i}{H} \quad (7a)$$

$$n > 4,\ \emptyset_i = \frac{4}{3}\frac{h_i}{H}\left(1 - \frac{1}{4}\frac{h_i}{H}\right) \quad (7b)$$

Storey displacement, Δ_i is given by

$$\Delta_i = \emptyset_i\left(\frac{\Delta_c}{\emptyset_c}\right) \quad (8)$$

Where, Δ_c and $\emptyset_c$ are the displacement and mode shape at critical storey.

The ductility in the frame (μ) is given by

$$\mu = \frac{\Delta_d}{\Delta_y} \quad (9)$$

Here, Δ_y is the yield displacement of ESDOF system given by Eq. (10) and damping in the system (ζ) is given by Eq. (11)

$\Delta_y = \theta_{yf} H_e$ (10)

$\zeta = 5 + 120(\frac{1-\mu^{-0.5}}{\pi})$ (11)

The displacement spectra corresponding to EC-8 at 0.45g level for various damping's with extended corner period that has been applied as per Pettinga and Priestly [6] is shown in fig.2.

5. The design base shear (V_b) is determined as given in Eq. (13) and the effective time period (T_e) is computed from the displacement spectra shown in fig.2, corresponding to damping (ζ) and target displacement (Δ_d) of the system. The effective stiffness of the ESDOF system is given by Eq. (12).
   $K_e = 4\pi^2 \frac{m_e}{T_e^2}$ (12)
   $V_b = K_e \Delta_d$ (13)
6. The base shear is distributed in the floors with the Eq. 14(a) and if the building is more than 10-storey high, to consider the higher mode effect Eq. 14(b) can be used.
   $F_i = V_b \frac{m_i \Delta_i}{\sum m_i \Delta_i}$ (14a)
   $F_i = F_i + 0.09 V_b \frac{m_i \Delta_i}{\sum m_i \Delta_i}$ (14b)
   Where, F_t is the 10% of base shear put at roof level.
7. The design is carried out with the expected strength or mean strength of the material as per FEMA-356 [5], the expected strength of concrete is 1.5 times of characteristic strength and for steel 1.25 times of yield strength of HYSD rebar.
8. The load combinations used in the design are D + L, D + L $\pm F_x$, D + L $\pm F_y$, where D is dead load, L is live load, F_x and F_y are the storey forces computed from Eq. (14a) and (14b) in two mutually perpendicular directions.
9. Capacity design is carried out to ensure strong column weak beam and the sizes of the column are adjusted to 3% to 4% steel of the sectional area.
10. After the design, default plastic hinges have been assigned to the members as per FEMA-356 [5]. The post elastic force-deformation behavior as per FEMA-356 [5] shown in fig.3.
11. The performance of the buildings has been evaluated throughNLTHA at MCE level. Effective stiffness for beams and columns hasbeen usedas proposed by Priestley [7].
   For buildings with infill strut element, the infill struts are introduced after step 3 above.

IV. MODELING OF INFILL STRUT ELEMENTS

The unreinforced masonry penal has been replaced by equivalent diagonal compression strut as per FEMA-273[8]. The width of compression strut 'a' is given by equation 16(a) and 16(b) as follows

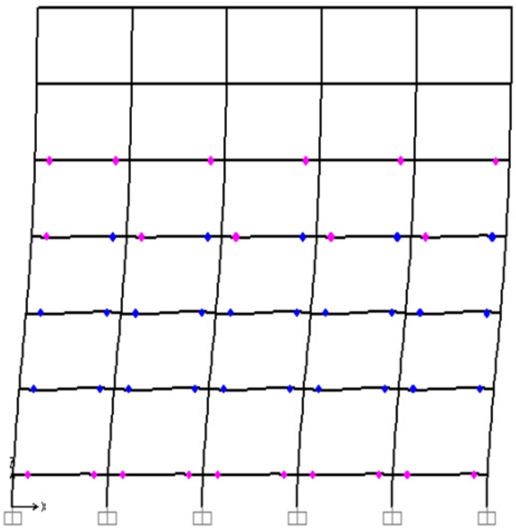
a= $0.175(\lambda_1 h_{col})^{-0.4} r_{inf}$ 15(a)

$\lambda_1 = [\frac{E_{me} t_{inf} \sin 2\theta}{4 E_{fe} I_{col} h_{inf}}]^{\frac{1}{4}}$ 15(b)

Where, h_{col} = column height between center lines of beams (in), r_{inf} = diagonal length of infill panel (in), E_{me} = expected modulus of elasticity of infill material (psi), t_{inf} = thickness of infill panel and equivalent strut (in), θ = angle whose tangent is the infill height to length aspect ratio (radian), E_{fe} = expected modulus of elasticity of frame material (psi), I_{col} = moment of inertia of column (in^4), h_{inf} = height of infill panel. Post elastic axial load deformation behavior of infill strut has been assigned as suggested in FEMA-273 [8].

V. RESULTS

The interstorey drift diagram of RC frame without infill strut and RC frame buildings with infill strut elements have been displayed in graphical form.



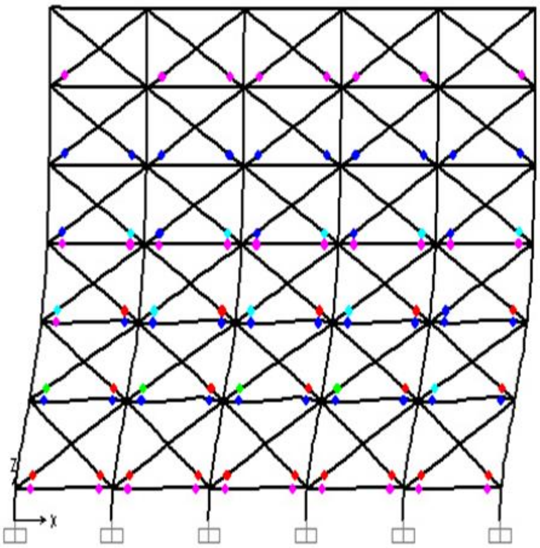
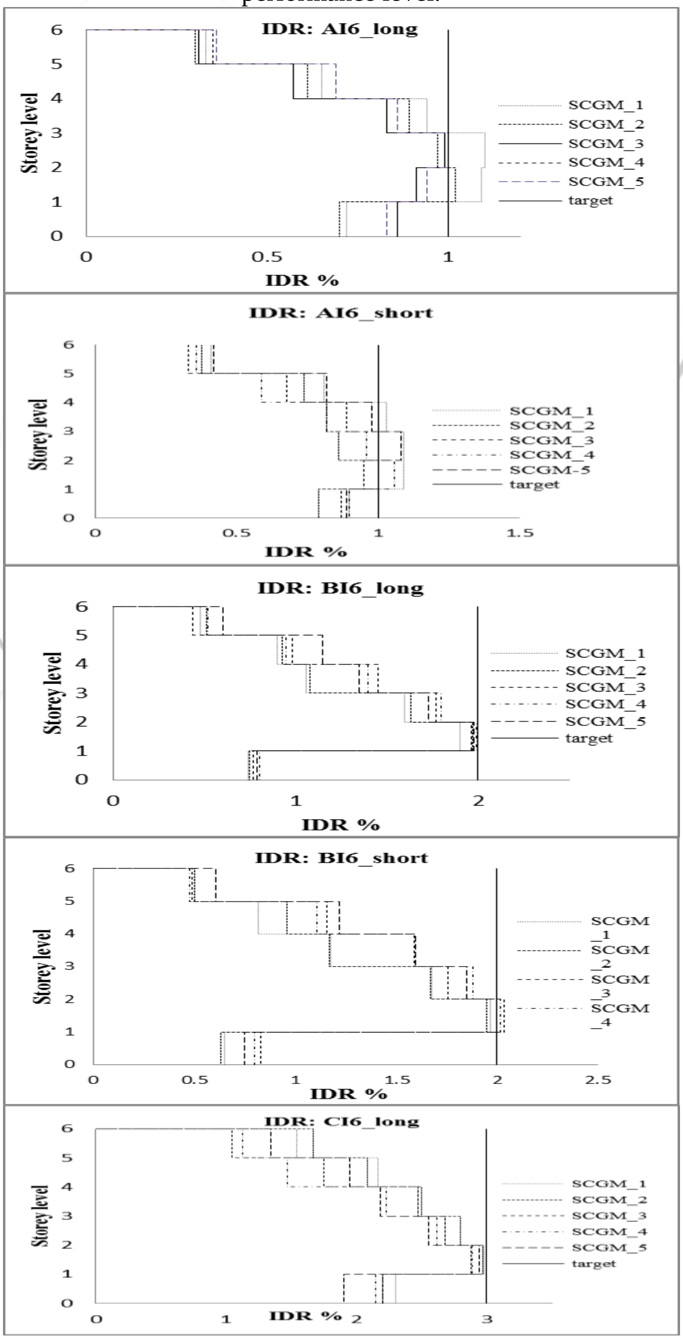


Fig.5. Plastic hinge formation at MCE level at last step of a typical ground motionin BI6 & B´I6 buildings showing LS member performance level.



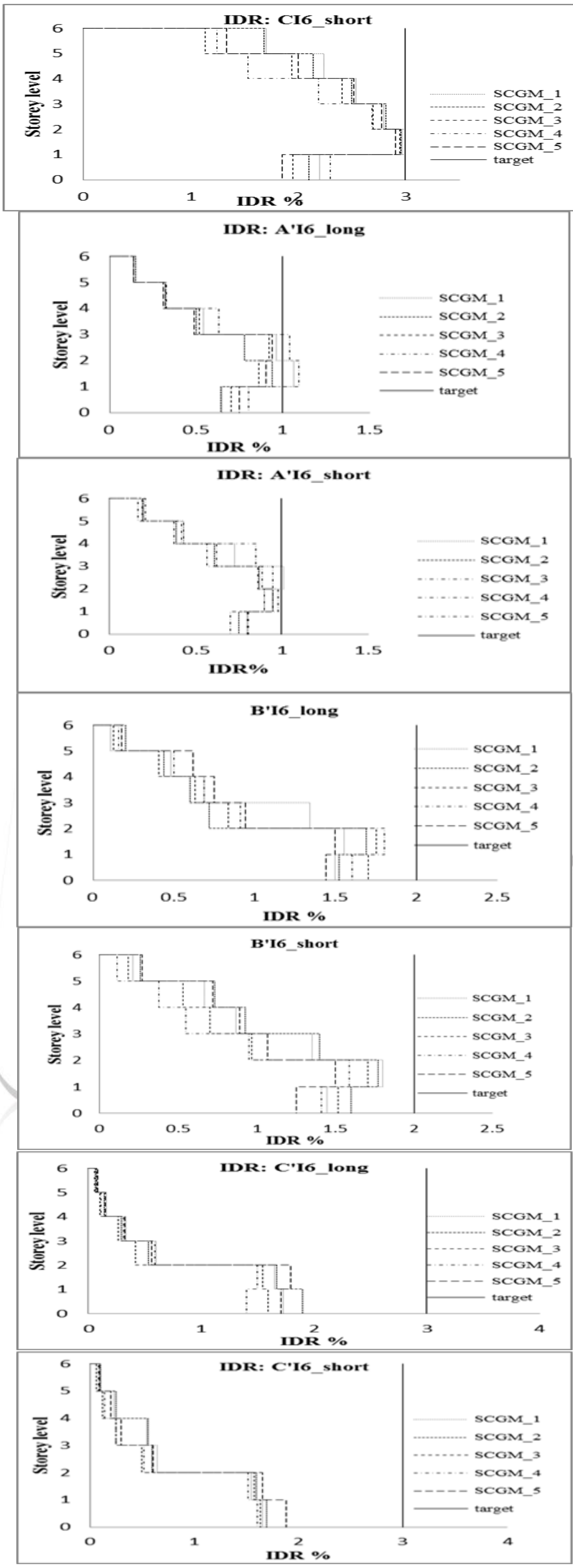


Fig.6. Interstorey drift diagram of all buildings considered.

Table.3. Achieved performance of RC bare frame buildings and RC frame buildings with infill strut elements

Building names	Target performance objectives	Achieved member performance level	Achieved drift % long	Achieved drift % short
AI6	1% with IO	IO	1.07	1.10
BI6	2% with LS	LS	1.99	2.04
CI6	3% with CP	CP	2.98	2.97
A´I6	1% with IO	IO	0.98	1.05
B´I6	2% with LS	LS	1.75	1.8
C´I6	3% with CP	CP	1.8	1.88

VI. CONCLUTIONS

It has been observed from the study that RC frame buildings without infill strut elements designed with UPBD method has achieved successfully, member performance level and interstorey drift within $\pm10\%$ of target drift.

For IO buildingswith infill strut elements,the target performance level has been attained. The target drift has been attained within $\pm5\%$ of target drift.For LS and CP buildings performance levels have been achieved but the drift achieved has been found to be much conservative.

In general, infill struts shows complete failure at bottomstoreyes and do these not reflect desired performance level.As the seismic demand is more in the bottom storey and due to that the deformation capacity of infill exceeds which leads to failure of infill and increase in the drift abruptly. The presence of infill also increases the global stiffness and its presence reduces the drift in the upper storey's.

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