Effect of Ductility Ratio with SSI on Steel Moment Resisting Frame Designed By Performance Based Plastic Design Method

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ABSTRACT

This paper presents, the study of seismic design considerations and design methodologies for steel moment resisting frame by performance based plastic design method considering the effect of ductility ratio with soil structure interaction (SSI). Performance-Based Plastic Design (PBPD) method has been recently evolved from the Performance based seismic design (PBSD) to achieve enhanced performance of earthquake resistant structures considering the participation of inelastic state of the material. The concept of design is mainly based on pre-selected target drift and yield mechanism as performance criteria. Performance Based Plastic design depends on "strong column-weak beam" theory, in which the pattern of failure is pre-determined. The ductility ratio of soil structure when included in PBPD method gives better approach towards the method. A brief study on effects of ductility ratio with soil structure interaction on steel moment resisting frame is presented in this paper.

Keywords : Pre-selected target drift, Yield mechanism, Ductility Ratio, steel moment resisting frame, PBPD, soil structure interaction

I. INTRODUCTION

Design for seismic resistance has been undergoing a critical reappraisal in today's era due to major earthquakes in the seismic regions. Code design practices have been traditionally based on the force-based design (FBD) concept in India, in which individual components of the structure are proportioned for strength on the basis of internal forces computed from the elastic analysis.

Now a days in India, steel structures are designed based on the limit state procedure as per IS 800: 2007 and IS 1893:2002 to ensure a good seismic resistant design which at times may fail in case of a severe earthquake. If a predetermined failure pattern based on "strong column weak beam" concept is used at certain points of a structure, it will assure possible inexpensive repairs even after failure of the structure.

The inelastic activity, which may include severe yielding and buckling of structure member, can be unevenly and widely distributed in the structure. This may result in rather undesirable and unpredictable response including total collapse or difficult and costly repair work at best. Therefore, societal demand are pushing the practice to achieve higher levels of performance, safety and economy, including life-cycle costs. Thus, codes are moving toward adopting performance-base design framework.

In order to achieve more predictable structure performance under strong earthquake ground motions, knowledge of the ultimate structural behavior such as nonlinear relation between force and deformation and the yield mechanism of the structure are essential. Consequently, design factor such as determination of appropriate design lateral force and member-strength hierarchy, selection of a desirable yield mechanism, and structure strength and drift for given hazard levels should become part of the design process from the beginning.

One such complete design methodology, which accounts for structure inelastic behavior directly and practically eliminates the need for any assessment or iteration after initial design, such method is called Performance Base Plastic Design (PBPD). The key performance limit states applied in the PBPD method are the target drift and pre-selected yield mechanism, which are directly related to distribution and level of structural damage, respectively.

The target yielding mechanism for the steel moment frame structure is selected assuming that the plastic hinges only occur at near column of beam. The design base shear for a selected seismic hazard level is calculated by energy balance equation. A distribution of lateral design forces is used that is based on relative distribution of maximum storey shears consistent with inelastic dynamic response results.

In the past decades, many studies have been conducted on Strength reduction factor (R_μ). It was seen that when soft soil is consider there is significant effect of strength reduction factor on it. It is also observed that SSI have significant effects on ductility demand of structures. The SSI provisions of seismic design code are allow designers to reduce the design base shear of building by considering soil-structure interaction as a beneficial effect. The main idea behind the provisions is that the soil-structure system can be replaced with an equivalent fixed-base model with a longer period and usually a larger damping ratio. Researchers concluded that SSI reduces the R_μ values, especially for the case of buildings located on soft soils, which can predict and give results on seismic design forces [9].

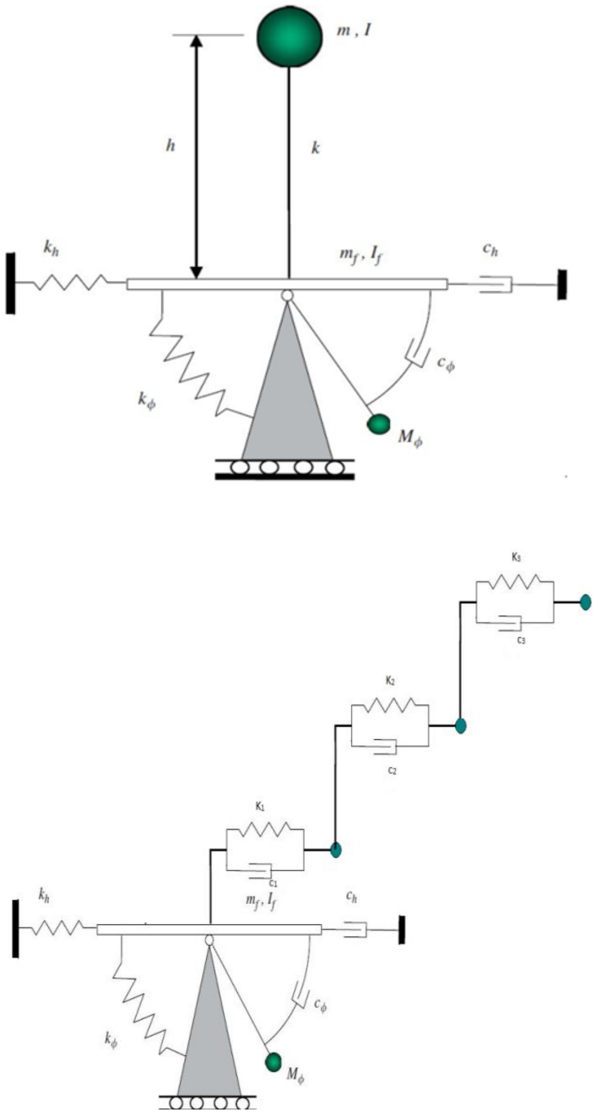

Fig. 1: Soil structure model for sway and rocking motion for SDOF and MDOF systems.

II. METHODOLOGY

The Performance-Based Plastic Design Method has suggested by Goel and Chao, 2009. In PBPD Method the structure is designed for pre-determined target drift and yield mechanism, which prevention of total collapse. There are no guidelines available in our recent Indian codes about PBPD method so it is advisable to calculate base shears, lateral forces and its distribution force as per suggestions given by Chao, 2007. The calculation of axial forces and beam and column moments is also calculated as per suggestions given by Chao, 2006.

III. LATERAL FORCES AND VERTICAL DISTRIBUTION

For various loading classes specified in IS 875, design seismic force shall be estimated using full dead load plus percentage of imposed load as given in table 7 of IS 1893-2016. The seismic weight of each floor is calculated by appropriately splitting the weight of columns and walls in any story to the floors above and below the story. The seismic weight of the building is the sum of seismic weight of all floors.

Fundamental Natural Time Period (T) for RC frame can be calculated as per IS-1893-2016 clause 7.6.2(c).

$$T = 0.085\ h^{0.75}$$

Where,

h = height of structure (in m)

Step: 1 Select a desired Target Yield Mechanism for design earthquake hazard. Figure shows the design yield mechanism of moment resisting frame subjected to lateral force and pushed through the design target plastic drift, "Δ_p".

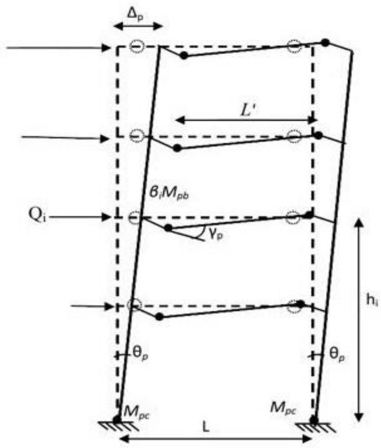

Fig. 2: Pre-Selected Yield Mechanism of Moment Frame with Beam Plastic Hinges away from Column Faces

Step: 2 Calculation of shear distribution factor "β_i" of each floor. [4]

$$\beta i = \frac{V_i}{V_n} = \left(\frac{\sum_{j=1}^{n} w_j h_j}{w_n h_n}\right)^{0.75 T^{-0.2}}$$

Where,

β_i = Shear distribution factor at level i ,

V_i = Story shear force at level i,

V_n = Story shear force at roof level (nth level),

w_j = Seismic weight at level j ,

h_j = Height of level j from base,

w_n = Seismic weight at the top level,

h_n = Height of roof level from base ,

T = Fundamental time period.

Step: 3 Calculation of A_h (Dimensionless parameter) can be carried out by following formula

$$A_h = \left(\sum_{i=1}^{n}(\beta_1 - \beta_{i-1})h_i\right).\left(\frac{w_n h_n}{\sum_{j=1}^{n} w_j h_j}\right)^{0.75 T^{-0.2}}.\left(\frac{\theta_p 8\pi^2}{T^2 g}\right)$$

Where,

θ_p = Global inelastic drift ratio of the structure

$= \theta_u - \theta_y$,

θ_u = Target drift Ratio,

θ_y = Yield drift Ratio,

β_i = Shear distribution factor at level i ,

g = Gravitational Acceleration

Step: 4 Calculation of Story shear "V_b" [2]

$$V_b = \left(\frac{-A_h + \sqrt{A_h^2 + 4\Upsilon Sa^2}}{2}\right) * W$$

Where, $\Upsilon = \frac{2\mu_s - 1}{R_\mu^2}$

$$S_{a,\,inelastic} = \frac{S_{a,\,elastic}}{R_\mu}$$

Where,

V_b = Base shear force,

γ = Energy modification factor,

μ_s = Structural ductility Factor = θ_u / θ_y ,

θ_u = Target drift Ratio ,

θ_y = Yield drift Ratio ,

R_μ = Ductility Reduction factor,

$S_{a,inelastic}$ = Spectral acceleration due to inelastic response,

V_b = total story shear at base,

W = Total design Seismic Load.

R_μ is related to time period of structure and can be obtained by using inelastic spectra [8].

$$R_\mu = a_i T^{b_i}$$

Where,

T = Fundamental period of the corresponding fixed-base structure,

a_i & b_i = Constant coefficient, which depend on ductility ratio, aspect ratio, number story and equivalent frequency.

Step: 5 Calculation of the Design Lateral force "Q_n" of Roof Floor.

$$Q_n = \frac{V}{\Sigma(\beta_i - \beta_{i+1})}$$

Where,

Q_n = Lateral Force at n^{th} level (roof level)

Step: 6 Calculation of the Design Lateral force "Q_i" of each level.

$$Q_i = Q_n\,(\beta_i - \beta_{i+1})$$

Where,

Q_i =Lateral Force at i^{th} level

IV. ANALYSIS OF BEAMS

Step: 1 Calculation of required plastic moment of column (M_{pc})

$$M_{pc} = \frac{1.1\,V'\,h_1}{4}$$

Where,

$$V' = \frac{V_b}{\text{number of bays}}$$

h_1 = Height of the first story

Step: 2 Calculation of required moment strength of beam (M_{pb})

$$M_{pb} = \frac{\sum_{i=1}^{n} Q_i h_i - 2\,M_{pc}}{2\sum_{i=1}^{n}(\beta_i \frac{L}{L'_i})}$$

Where,

Q_i = Lateral Force at i^{th} level,

h_i = Height at i^{th} level,

M_{pc} = Required plastic moment of column,

β_i = Shear distribution factor at level i ,

L = Distance between two column,

L_i'= Distance between centre of RBS cuts.

V. DESIGN OF BEAMS

Step: 1 After getting required moment strength of beams, beams are to be designed as per

IS-800:2007 (clause 8.2 for flexure and clause 8.4 for shear and checked for deflection as per clause 5.6.1.) and Reduced Beam Section is consider as per ANSI/AISC 358-05.

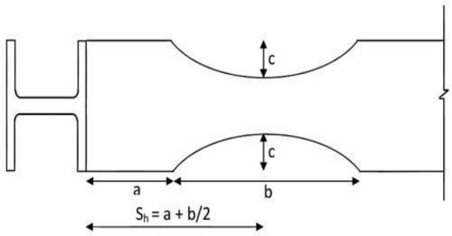

Fig. 3: Reduced Beam Section

$$0.5b_{bf} \leq a \leq 0.75b_{bf}$$

$$0.65d \leq b \leq 0.85d$$

$$0.1b_{bf} \leq c \leq 0.25b_{bf}$$

Where,

b_{bf} = Width of beam flange,

d = Depth of beam section,

a = Distance of cut at the face of column to start of RBS cut,

b = Length of RBS cut,

c = Depth of cut at centre of reduced beam section,

S_h = Distance from a column face to the centre of RBS cut = a + b/2

Step: 2 Calculation of plastic section modulus at the centre of RBS (Z_e).

$$Z_e = Z - 2ct_{bf}(d - t_{bf})$$

Where,

Z_e = Plastic section modulus at centre of the reduced beam section,

Z = Plastic section modulus for full beam cross-section

Step: 3 Calculation of the probable maximum moment (M_{pr}) at the centre of RBS.

$$M_{pr} = C_{pr} R_y F_y Z_e$$

Where,

C_{pr} = Factor of peak connection strength
= 1.0 for roof beam
= 1.075 for other beam

R_y = 1.1, which is ratio of expected yield stress to specified min. yield stress

Step: 4 Calculation of shear force at the centre of RBS.

It is determined by free-body diagram of the portion between the centre of RBS and this calculation assumes that the moment at the centre of RBS is M_{pr} and gravity loads are included.

$$V_{RBS} = \frac{2\,M_{pr}}{L'} + \frac{wL'}{2}$$

$$V'_{RBS} = \frac{2\,M_{pr}}{L'} - \frac{wL'}{2}$$

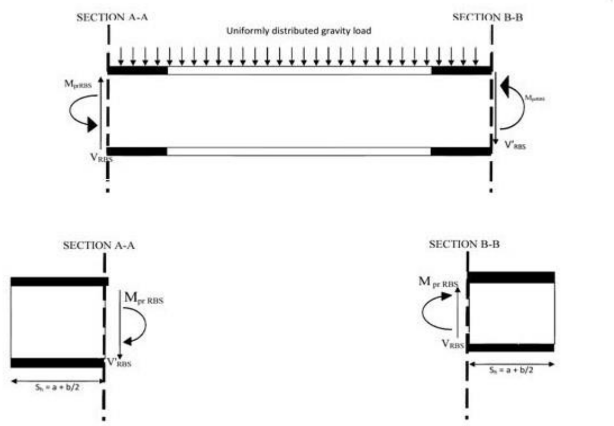

Fig. 4: Free-Body Diagram between Centre of RBS and Face of Column

Step: 5 Calculate the probable maximum moment at the face of the column.

$$M_f = M_{pr} + V_{RBS} S_h$$

$$M'_f = M_{pr} + V'_{RBS} S_h$$

VI. ANALYSIS OF COLUMN

Step: 1 Calculation the sum of lateral forces (F_L) for Exterior Column Tree.

$$F_L = \frac{\sum_{i=1}^{n}(M_{pr})_i + \sum_{i=1}^{n}(V_{RBS})_i.(S_h + \frac{d_c}{2})_i + M_{pc}}{\sum_{i=1}^{n}\psi_i h_i}$$

Where,

M_{pr} = Probable maximum moment at the centre of RBS,

V_{RBS} = Shear force at the centre of RBS,

S_h = Distance from a column face to the centre of RBS cut = a + b/2,

d_c = Depth of the column ,

M_{pc} = Required plastic moment of column

$$\psi_i = \frac{(\beta_i - \beta_{i+1})}{\sum_{i=1}^{n}(\beta_i - \beta_{i+1})} \qquad \text{When } i = n,\ \beta_{i+1} = 0$$

Step: 2 Calculation the sum of lateral forces (F_L) for Interior Column Tree.

$$F_L = \frac{2\sum_{i=1}^{n}(M_{pr})_i + \sum_{i=1}^{n}[(V_{RBS})_i + (V'_{RBS})_i].(S_h + \frac{d_c}{2})_i + 2\,M_{pc}}{\sum_{i=1}^{n}\psi_i h_i}$$

Where,

M_{pr} = Probable maximum moment at the centre of RBS,

V_{RBS}, V'_{RBS} = Shear force at the centre of RBS,

S_h = Distance from a column face to the centre of RBS cut = a + b/2,

d_c = Depth of the column ,

M_{pc} = Required plastic moment of column

$$\psi_i = \frac{(\beta_i - \beta_{i+1})}{\sum_{i=1}^{n}(\beta_i - \beta_{i+1})} \qquad \text{When } i = n,\ \beta_{i+1} = 0$$

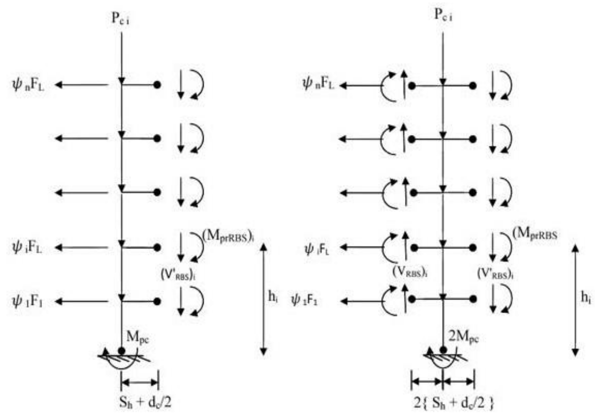

Fig.5: Free-body Diagram of Exterior Column Tree and Interior Column Tree

Step: 3 Calculation of Total axial Force on a column section (N)

$$N = \sum_{i=1}^{n} P_{ci} + V_{RBS} \qquad \text{OR}$$
$$N = \sum_{i=1}^{n} P_{ci} - V'_{RBS}$$

Where,

$(P_c)_i$ = Axial force on column section

Step: 4 Calculation of Total bending moment on column section (M)

$$M = (V_{RBS} + V'_{RBS})(S_h + \frac{d_c}{2}) + M_{prRBS} + \psi_i F_L h_i$$

VII. DESIGN OF COLUMN

After getting the proper design bending moments, shear force and axial force for columns by Free-body diagram, the columns are designed for bending moment as per clause 7.1 of IS 800:2007.

VIII. SUMMARY

In this paper, proper design methodology for steel moment resisting frames using PBPD method with soil structure interaction proposed by researchers have been briefly reviewed. In

PBPD method, it is important to note that drift control and yielding are taken into account in the beginning itself, so there is no need for lengthy iterative process to arrive at the final design results. Also the proper research has not been done in the direction of considering soil structure interaction in PBPD method, so more research in this direction is considered. New distribution of lateral design forces is used which is based on relative distribution of maximum story shears consistent with inelastic dynamic response results. If analysis is done by PBPD method considering Soil Structure Interaction gives accurate results. Because PBPD method directly accounts for structural inelastic behavior. SSI reduces the Strength reduction factor (R_μ) values, especially for the case of buildings located on soft soils.

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