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ANALYSIS OF STEEL FRAME INCORPORATING EFFECT OF SEMI-RIGID STEEL CONNECTIONS

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Abstract

IS 800:2007 for design of steel structures has provided an opportunity for modern design philosophy as per Limit State Method of design. Steel connections are key elements of steel frame, which affects the behaviour of the steel structures. Shear connections offered little stiffness and rigid connections allow some rotation based on the size parameters of designed connection instead of behaving ideally pinned and rigid connections respectively. Real behaviour of connections is important to understand for safe and economical design of steel structures.

In this article to obtain the real behaviour of steel frame with different types of connections, steel frame is analysed considering ideally pinned and rigid end conditions using STAAD Pro. The shear connections are designed for obtained shear force in pinned ended steel frames, while moment connections are designed for shear force and bending moment obtained in rigid ended steel frames. The secant stiffness of the designed connections is obtained using Frye-Morris polynomial mathematical model suggested in IS 800:2007. A steel frame with various connections is presented to demonstrate effectiveness of the method. It has been concluded from the study carried out that economical solutions can be achieved by incorporating the actual behaviour of semi rigid steel connection.

Key words: Limit State Design, Steel Connections, Semi-Rigid Connections, STAAD Pro Analysis

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1. Introduction

"Limit State Design" is globally referred design philosophy of steel structures. This method has proved inexpensive for structures constructed in past. Philosophy of limit state design method (LSM) represents significant advancement over traditional design philosophies for steel structures. The Limit state design method has presented a new era for safe and economic construction for steel structures.

Steel structures assembled by beams, columns, bracings, flooring, and roofing systems are properly connected to form a composite unit. Beam-to-column connections are an integral element of a steel frame, and their behaviour affects the overall performance of the structure under loads. In common engineering practice, it is usually assumed that connections are either rigid or pinned. In reality, steel connections are not providing ideal rigid or pinned end conditions. Rigid connections experienced some rotation and pinned connections experienced some rigidity. This behaviour of connections which falls between two extremities ideal pinned and rigid has been classified as semi rigid steel connections.

IS 800 (Limit State Design) is a new era of safe and economical design for steel construction. The revised standard has enhanced the confidence of designers, engineers, contactors, technical institutions, professional bodies and industries for economical construction in steel [2].

2. Literature Survey

Most connections that connect beam and column using angles, plates, welds, and bolts are deformable and exhibit a nonlinear behaviour. It is more reliable to consider all connections as semi rigid, with rigid and pinned being ideal cases. Connection flexibility affects both force distribution and deformation in beams and columns of the frame, and must be accounted for in a structural analysis [3]. To establish guidelines for design of semi rigid frames, it is necessary to know the m-θ_r behaviour of actual beam to column connections and to formulate appropriate m-θ_r model for use in analysis and design of semi rigid frames. [5].

A connection rotates through angle θ_r caused by applied moment M. This is the angle between beam and column from their original position. Several moment-rotation relationships have been derived from experimental studies for modeling semi-rigid connections of steel frames. Relative moment-rotation curves of extensively used semi-rigid connections are shown in Fig.1 [3] .

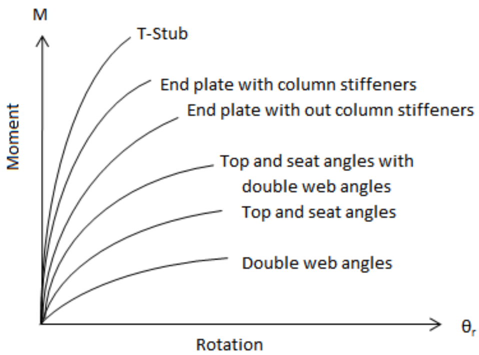

Fig 1 Moment-rotation curves of semi-rigid connections

Frye and Morris polynomial model as suggested in IS 800:2007 is used for analysis and design of 3-storey semi-rigid steel frames, values of secant stiffness were incorporated in analysis for all alternatives using STAAD Pro. [1] The effect of connection stiffness on overall stability of structure is studied. Stiffness of connections is to be modeled as rotational springs to accurately model effect of semi rigid connections in analysis.[3] Mixed use of rigid connections with semi-rigid connections for tall building frames is incorporated to reduce costs [4].

It has been observed from literature reviewed on semi rigid connection as suggested in IS 800:2007 that considering the effect of semi-rigid connections makes analysis somewhat difficult, however leads to economy in member designs. Analysis of semi-rigid connections is account for non-linear moment-rotation characteristics hence modeling of semi-rigid connection yielded more economical solutions. Hence, this paper aims to study the behaviour of steel frames as suggested in IS 800:2007 by incorporating actual stiffness of semi rigid steel connections at the beam-column junction instead of considering ideally pinned or rigid connections.

3. Modelling Of Semi Rigid Connections

IS 800 [2] recommends Frye-Morris polynomial model to develop moment rotation relationship curvature for modeling of semi rigid steel connection. The Model is based on polynomial equation as follows:

$$\theta_r = C_1(KM)^1 + C_2(KM)^3 + C_3(KM)^5 \qquad (1)$$

Where, K is a standardization parameter and is dependent upon connection type and geometry.

C_1, C_2, C_3 are curve fitting constants. Curve fitting constant C_1, C_2, C_3 and standardization constant K for each type of connection have been given in table 1.

Stiffness of different types of connections recommended by IS : 800 has been evaluated from the equations of standardized constants K as shown in Table 1 for different types of connections and its size parameters for preliminary analysis using a bilinear Moment-Rotation relationship. The values have been evaluated based on secant stiffness at a rotation of 0.01radian. Typical dimension of connecting elements and other components have been evaluated.

Table 1 Connection constants in Frye-Morris Model [2]

No	Connection type	Curve fitting Constants	Standardization constants
1	Single web angle connection	$C_1 = 1.91 \times 10^4, C_2 = 1.3 \times 10^{11}$ $C_3 = 2.7 \times 10^{17}$	$K = d_a^{-2.4} t_c^{-1.81} g^{0.15}$
2	Header plate connection	$C_1 = 3.87$, $C_2 = 2.71 \times 10^5$ $C_3 = 6.06 \times 10^{11}$	$K = d_p^{-2.3} t_p^{-1.81} g^{1.63} t_w^{-0.5}$
3	Double web angle connection	$C_1 = 1.64 \times 10^3, C_2 = 1.03 \times 10^{14}$ $C_3 = 8.18 \times 10^{25}$	$K = d_1^{-2.4} t_c^{-1.81} g^{0.15}$

4	Top and seat angle connection	$C_1 = 1.63 \times 10^3$,$C_2 = 7.25 \times 10^{14}$ $C_3 = 3.31 \times 10^{23}$	$K = d^{-1.5} t_a^{-0.5} l_a^{-0.7} d_b^{-1.1}$
5	End plate with column stiffeners	$C_1 = 2.6 \times 10^2$, $C_2 = 5.37 \times 10^{11}$ $C_3 = 1.31 \times 10^{22}$	$K = d_g^{-2.4} t_p^{-0.6}$
6	T-Stub connection	$C_1 = 4.05 \times 10^2$,$C_2 = 4.45 \times 10^{13}$ $C_3 = -2.03 \times 10^{23}$	$K = d^{-1.5} t_a^{-0.5} l_t^{-0.7} d_b^{-1.1}$

Where, Nomenclature used in Table 1 is given as follows.

d = depth of beam, d_a = depth of angle in mm, d_b = diameter of bolt in mm, d_g = center to center of outermost bolt of end plate connection in mm, g = guage distance of bolt line, t_a = thickness of top angle in mm, t_c = thickness of web angle in mm, t_f = thickness of flange T-stub connector in mm, t_w= thickness of web of the beam in connection in mm, t_p = thickness of end plate and header plate in mm, l_a = length of angle in mm, l_t = length of T-stub connector in mm

4. Analysis and Design of A Frame Considering Ideal Rigid or Pinned End Conditions

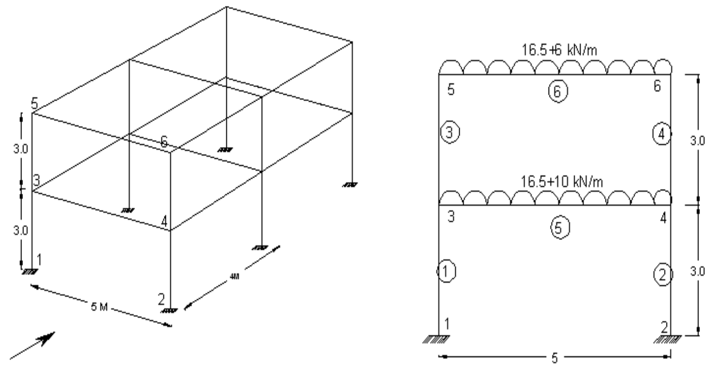

Fig. 2 (a). Typical Steel structure (b). Typical Steel Frame

Analysis and design of a typical frame of a steel structure shown in fig 2(a) is carried out using STAAD Pro. 2006. The typical two-storey one-bay frame with dimensions, loading and numbering of members and nodes is shown in Fig.2(b). The connections are design as per IS 800 [2] and size parameters like length of angle, depth of plate, thickness of plate, diameter of bolts, gauge distance of bolts etc. have been evaluated details for design of member end forces.

4.1 Analysis of a frame

Details of considered parameters for analysis and design of frame is as follows.

Slab thickness is 125 mm, Floor finish is 1.0 kN/m^2, Live load = 2.5 kN/m^2 on typical flooring, and 1.5 kN/m^2 on roof of frame. Center to center spacing of frame is 4 m. Dead load of slab = 3.125 kN/m^2, Dead load of floor finish = 1.0 kN/m^2, Total dead load of slab incorporating floor finish= 4.125 kN/m^2, Total dead load per meter length of beam = 16.5 kN/m

Live load in typical frame per meter length of beam on floor = 10 kN/m

Live load in typical frame per meter length of beam on roof = 6 kN/m

Load cases considered in analysis and design are as follows:

1. Dead Load + Live Load

2. Earthquake Load

Initially analysis of frame is carried out considering ideal pinned and rigid end conditions at the end of beams. Governing forces like bending moment and shear forces at ends of beams have been evaluated from analysis for design of steel connections. End span forces shown in table 2 are obtained considering rigid and pinned end conditions.

Table2: Shear force and Bending Moment at end of beam

End Condition	Bending Moment (kNm)	Shear Force (kN)
Rigid Frame	187.14	74.85
Pinned Frame	0	66.19

4.2 Secant stiffness of designed connections based on moment rotation curvature

Connections are designed for shear forces and bending moment values as shown in table 2 using IS 800 [2] provisions. Different types of bolted shear connections like single web angel connections, double web angel connections, top and seat angel connections and header plate connections are to be designed for 66.19 kN shear force. Moment resisting connections like End plate with column stiffener, T-Stub connections are to be designed for 74.85 kN Shear force and 187.14 kNm bending moment.

Secant stiffness is evaluated for different types of connections designed are presented in table 3.

Table 3 Secant Stiffness calculated considering semi rigid steel connections

No	Type of connection	Dimensions in (mm)	Secant stiff. (kNm/rad)
1	Single angle web connection	d_a=200, t_a=8, g=38.85	434
2	Header plate connection	d_p=150, t_p=6, g=60, t_w=7.7	1001
3	Double angle web connection	d_a=200, t_a=8, g=77.7	1890

4	Top and seat angle connection without double web angle connection	d_b=300, t_a=6, l_a=140, d_b=20	2668
5	End Plate with column stiffeners	d_g=535, t_p=14,	7362
6	T-Stub Connections	d=550, t_f=16, l_t=200, d_g=24	385854

In problem of a typical frame as shown in fig 2(b) connections at node 3, 4, 5 and 6 have been designed by IS 800 [2]. For these connections secant stiffness has been evaluated using polynomial equation 1. Secant stiffness have been calculated from size parameters for all six types of semi-rigid steel connections. Moment rotation relationship curve is drawn based on polynomial Equation 1. From moment rotation curves, slope at 0.01 radian rotation has been selected. This slope at 0.01 radian gives the secant stiffness for a typical connection.

5. Analysis And Design Of Frame Considering Semi Rigid Connections

Analysis and design of the typical steel frame has been carried out incorporating semi rigid end conditions. Computed secant stiffness as presented in table 3 is assigned at the end of the beam to incorporate the behaviour of semi rigid connections. The following conclusion has been made for ideal pinned and rigid end conditions with different considered semi rigid end connections.

6. Concluding Remarks

Analysis and design have been conducted for the steel frame with semi rigid connections accounting non-linear behaviour of the frame. Software based analysis and design procedure of repetitive nature has been carried out for safe and economical sections. Design is also performed to demonstrate influence of connection behaviour on the steel frames. Secant stiffness has been calculated for connection as per Frye and Morris polynomial modeling. It has been observed that end span moments in beam and columns are enhances at end of beam and column under vertical loads with increase in stiffness of connections. Under lateral load, end span moments in beam increase with rigidity of connection and in column reduction in end span moment has been observed with rigidity of connections. Beam mid span moment is reduced effectively with provision of semi rigid connection under vertical load. Hence, change in behaviour of connections resulted into balancing span and end moments in beams. By iterative method of design economical sections have been obtained using software. Variation in magnitude of sway for frames with different semi rigid connections is also observed. Parameters considered are indicative of recognition of additional cost-effective design of steel frames with semi-rigid connections.

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