OPTIMIZATION OF STEEL FRAMES USING SEMI-RIGID CONNECTIONS

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The true behavior of the connections is usually semi-rigid. Neglecting the real behavior of the connection in the analysis may lead to unrealistic predictions of the response and reliability of steel frames. In this paper the methodology for determination of rotational stiffness of semi-rigid connection in steel constructions according to Eurocode 3 componential method has been analyzed. By application of this concept the determination of rotational connection response comes down to determination of geometrical characteristic of different connection components. This paper considers the effects of semi-rigid behavior of the connections in analysis for steel frames and ways for global optimization of structural members and optimization of joint especially. In this paper, steel frames are analyzed by using computer program. Having the same geometry and cross-section, the static analysis for frames is examined for three different type of connections. The first frame is analyzed with ideally rigid connection, second one with semi-rigid connection and third one with ideally pinned connection.

Keywords: semi-rigid, joint, moment resistance, steel frame, rotational stiffness

1. INTRODUCTION

A steel frame as a plane of linear members, such as beams and columns, joined together by connections. These joints between members play an important role. From an economic point of view the costs for design and fabrication form a considerable part of the total cost. From a structural point of view the properties of the joint essentially influence the response of the structure to actions. Traditionally, in the design and analysis of steel frames it is assumed that all structural beam-to-column connection behave either as: simply pinned or fully rigid.

Simply pinned, which implies that no moment will be transmitted between the beam and the column and thus the connection is only capable of transmitting shear and axial force. As far as rotation is concerned, the beam and the column that are jointed together by a pin will behave independently.
Fully rigid, which implies that no relative rotation will occur between the adjoining members and the beam end-moment is transmitted to the

column. The angle between the beam and the column remains unchanged as the frame deforms.

Existing methods of design and analysis of steel frames still firmly rely on these simplifies idealized models, despite the fact that it has been recognized for more than half a century that connection behavior lies somewhere between the two extreme idealizations. Thus the design of the structure is not fully based on the actual load-deformation characteristic of the joint. This is due to a member of factors, two of which are the relative complexity of the necessary design calculations and lack of comprehensive information on the performance of the full range of modern days connections. This has resulted in a rapid growth of investigation on this topic, leading to continuous innovations in the analysis and design of steel frames and the testing of beam-to-column connections. Experiments carried out during the last decades have shown that the behavior of real bolted connection is neither rigid nor pinned; rather, they possess some degree of rotational restraint which depend on type of connection used. The term "Semi-rigid" is used to describe such connections. In addition to the classification by rigidity beam-to-column connection may be classified as well by strength with respect to the design moment resistance. Under such classification beam-to-column connection behave wither as: nominally pinned, full-strength; partial-strength connection.

2. GENERAL DESCRIPTION OF ANALYTICAL MODEL

In this paper is analyzed a single span steel frame with dimensions 6.00x4.00m (L x H). Two columns are with cross-section HEA 180, beam with cross-section IPE 270. Base support for columns are ideally rigid connecting with concrete foundation. For this study connection beam-column is taken in three ways: ideally rigid, semi-rigid, ideally pinned. Frame is analyzed by two type of load. First load, include self-weight and uniform linear load 8.00kN/m'. Second load include vertical support displacement in column support for 5.0cm. Base support displacement is taken into account because this load can best determinate the behavior of frames in dependence of real connection rotation. In real situation non uniform foundation displacement shows in a lot of forms. For example, when we have to build very close to another building. In this situation in that older building is done soil consolidation, that's mean a foundation for new building who is close to that have to do less consolidation in comparison on another foundation in same new building (in another column).

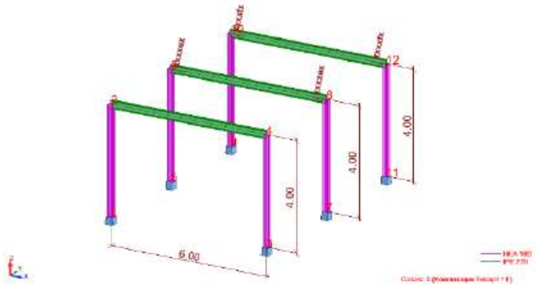

Figure 1. Steel frame, dimensions, cross-sections

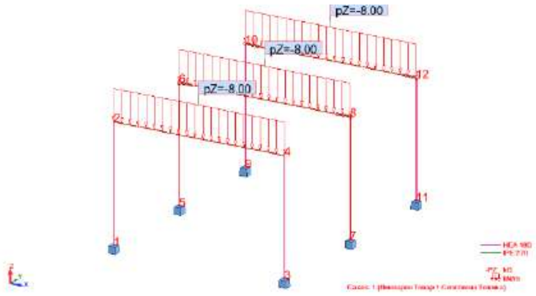

Figure 2. First load, self-weight and uniform linear load

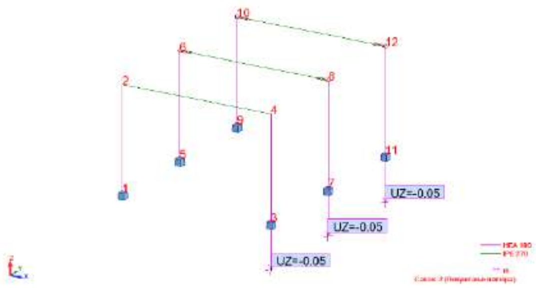

Figure 3. Second load, base support displacement

3. RESPONSE OF JOINT AND DESIGN TOOLS

Beside the need for background information the engineer requires simple design tools to be able to design joint in an efficient way. Three different types of design aids can be provided: -design tables; -design sheet; -software. Response of the joints in terms of stiffness, resistance and ductility is a key aspect for design purposes. From this point of view, three main approaches may be followed:

− experimental;
− numerical;
− analytical

In this paper is used the analytical approach. Analytical procedures enable a prediction of the joint response based on the knowledge of the mechanical and geometrical properties of the so-called "joint components". Component method applies to any type id steel joint whatever the geometrical configuration, the type of loading (axial force and/or bending moment, …) and the type of member cross sections.

However, the analysis of a frame with semi-rigid connections is difficult to perform unless the exact moment-rotation relation od such joint is known.

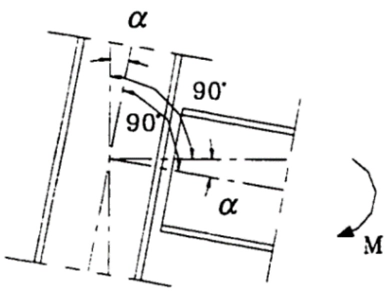

Figure 4. Loaded rigid connection

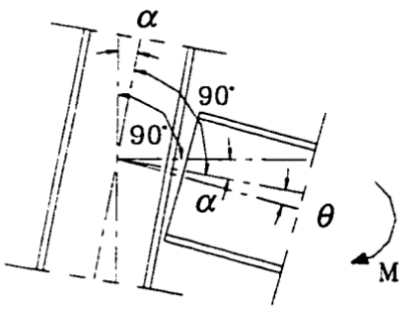

Figure 5. Loaded semi-rigid connection

At rigid connection moment-rotation relation is known before starting design of joint, at loaded rigid connection relative rotation between elements in elastic area is always 90°. Relative rotation between elements in elastic area at semi-rigid connection is show with moment - rotation curve.

$$\theta r = \frac{M}{S_{j,ini,s}} \quad (1)$$

where:

- θ_r: relative rotation between elements
- M: bending moment
- $S_{j,ini,s}$: Initial stiffness

3.1 DESIGN OF JOINTS ACCORDING EC3

Identification of the active components in the joint are regulated in EC3 part .1-8 (table 6.10). In this joint in figure 5, active components are: 1. Column web panel in shear; 2. Column web in compression; 3. Column web in tension; 4. Column flange in bending; 5. End-plate in bending; 10. Bolts in tension. For this connection in analytical way is calculated bending resistance, secant and initial stiffness.

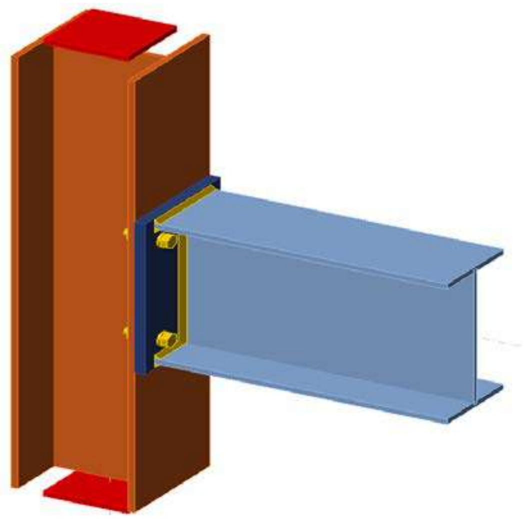

Figure 6. Single-sided bolted end plate connection used in this paper

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Table 1. Joint components

Component	Stiffness coefficient k_i (mm)	Design Resistance $_{min}F_{Rd,i}$ (kN)
1.Column web panel in shear	2.374	177.30
2. Column web in compression	5.700	181.85
3. Column web in tension	6.540	199.6
4. Column flange in bending	3.419	115.13
5. End-plate in bending	11.320	180.86
10. Bolts in tension.4M16	4.567	180.86

3.1.1 Design moment resistance:

$$M_{j,Rd} = F_{Rd} * z = 27.05 kN/m' \quad (2)$$

3.1.2 Design elastic moment resistance:

$$M_{j,el,Rd} = \frac{2}{3}F_{j,Rd} = 18.03kN/m' \quad (3)$$

3.1.3 Initial stiffness:

$$S_{j,ini,s} = \frac{Eh^2}{\sum_i \frac{1}{k_i}} = 8614.12\text{kNm/rad} \quad (4)$$

3.1.4 Secant stiffness:

$$S_j = \frac{S_{j,ini,s}}{2} = 4307kNm/rad \quad (4)$$

3.1.5 EC3 classification of connections by stiffness:

$$k = \frac{S_{j,ini}L_b}{EI_n} = 4.250 \quad (5)$$

4. DESIGN OPPORTUNITIES FOR OPTIMISATION OF FRAMES

The various approaches can be used to design steel frames with due attention being paid to the behave of the joints. For the design of steel frames, the designer can follow one of the following design approaches: 1. Traditional design approach; 2. Consistent design approach; 3. Intermediate design approach.

In this paper is used consistent design approach, the global analysis is carried out in full consistency with the presumed real joint response. Both members of steel frame and joint properties are accounted for when starting the global frame analysis.

In the pre-design phase, joints are selected by the practitioner based on his experience. Proportions for the joint components are determined: end-plate or cleat dimensions, location of bolts, number and diameter of bolts, sizes of column and beam flanges, thickness and depth of column web, etc. First the joints are characterized with the possible consequence of having a non-linear behave. This characterization is followed by an idealization, for instance according to a linear or bi-linear joint response curve, which becomes a part of the input for global frame analysis. For the purpose of global frame analysis, any joint structural response is assigned to a relevant spring in the frame model.

5. NUMERICAL MODEL AND RESULTS

In this case study, the numerical analysis of steel frame is made with Autodesk Robot Structural Analysis Professional). Globally speaking, four main analysis approaches may be contemplated according to Eurocode 3:
−linear elastic first order analysis;
−plastic first order analysis;
−linear elastic second order analysis;
−plastic second order analysis;

In this case study analysis is made with: linear elastic first order. Results for bending moments are shown in Combination of first load type together with second load type.

5.1 BENDING MOMENTS

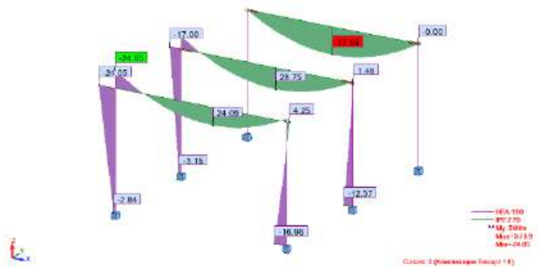

Figure 7. Bending moment on steel frame

Table 2. Bending moments

	Bending moments "My" from combination I+II (kN/m')		
	Negative moment "left joint"	Positive moment in middle of beam	Negative moment "righ" joint"
Frame with rigid connection	-24.05	23.44	-4.25
Frame with semi- rigid connection	-17.00	28.75	-1.48
Frame with pinned connection	0.00	37.59	0.00

From the results at table 2. we can see that the maximum negative moment is at frame with rigid connection and maximum positive moment is at frame with pinned connection.

Joint designed in chapter 3 has elastic moment resistance 18.03kN/m'. From the table we can see that frame with rigid connection has negative moment value more than elastic moment resistance of joint. Also frame with pinned connection has higher positive bending moment than frame with semi-rigid and rigid connection.

5.2 DISPLACEMENTS

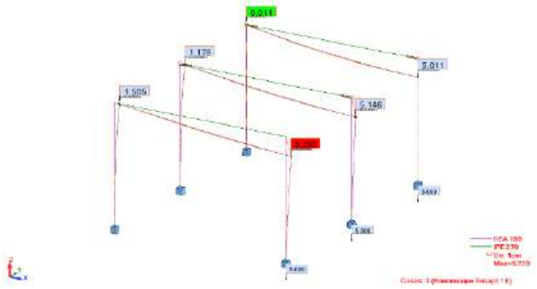

Figure 8. Deformation on steel frame

Table 3. Displacements

Frame	Node	Case	UX (cm)	UZ (cm)
Steel frame with “rigid” connection	1	3 (C)	0.000	0.000
	2	**3 (C)**	**1.505**	**-0.012**
	3	3 (C)	0.000	-5.000
	4	**3 (C)**	**1.501**	**-5.009**
Steel frame with “semi-rigid” connection	5	3 (C)	0.000	0.000
	6	**3 (C)**	**1.179**	**-0.012**
	7	3 (C)	0.000	-5.000
	8	**3 (C)**	**1.177**	**-5.010**
Steel frame with “pinned” connection	9	3 (C)	0.000	0.000
	10	**3 (C)**	**0.000**	**-0.011**
	11	3 (C)	0.000	-5.000
	12	**3 (C)**	**0.000**	**-5.011**

From the results at table 3. We can see that maximum node displacement (nodes where are connecting beam-column) has frame with rigid connection.

5.3 RELATIVE ROTATION BETWEEN MEMBERS

Table 4. Relative rotation between members

Frame	Node	Bending Moment (kN/m’)	Initial stiffness (kNm/rad)	θ_r (rad)
Steel frame with “semi-rigid” connection	6	-17.000	8614.12	-0.00197
	8	-1.480	8614.12	-0.0001718

At rigid connection relative rotation between elements in elastic area is always 90°. At pinned connection there are no developing significant moments which might adversely affect members of the frame.

6. CONCLUSION

Based on the numerical results the following can be concluded:

1. In general designers when have to design a frame with support displacement goes with pinned connection, due the fact frame can rotate and not showing extra bending moments and lateral displacement. In this case frame with pinned connection have higher positive bending moments, which brings larger cross-section of beam.
2. Frame with rigid connection are more usually used in steel industries. From the table we can see that frame with rigid connection has negative moment value more than elastic moment resistance of joint (18.03kN/m’), which brings design a new joint detailing, more complex, more stiffener that brings increasing fabrication cost.
3. From the table we can see frames with rigid connection have higher lateral displacement, the higher lateral displacement can bring in more complex analysis (second order analysis)
4. Using semi-rigid connection shows a real optimization of steel frames. From the tables we can see, lower positive moments compare with pinned connection, and lower negative moments compare with rigid connection. Lateral displacement are lover compare with rigid connection.

5. A real advantage of using semi-rigid connection is taking relative rotation of members in joint for global displacements in frames. Which members can rotate and not showing extra bending moments.
6. Consistent design approach is more complex, need more time and work, but using this design we can bring more reliable results with taken care a real joint response. Consistent design approach brings optimization of joints components and cross-sections of members.

7. REFERENCES

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