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Effects of Semi-Rigid Connection on Structural Responses

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ABSTRACT: There are several idealizations in numerical analysis of structures. In the joints and supports, which is usually assumed to be pinned or rigid, semi-rigid connection should be considered to obtain more realistic, reliable and also economical results. In this study, rotational spring stiffness-connection ratio relation is clearly explained and revealed. A finite element program SEMIFEM is developed in FORTRAN language for the numerical analysis. This program provides to define semi-rigid connections in terms of rotational spring stiffness or connection ratio simultaneously. In the numerical applications, rotational spring stiffness - connection percentage relation of the semi-rigid connected structural members is submitted. Semi-rigid connections are considered in column-to-foundation connection of a portal frame, beam-to-column connection of a prefabricated structure, steel brace connection to reinforced concrete (RC) frame of a steel X-braced RC frame and truss member connection to joint of a steel truss system. The variation of moment, shear force, axial force, displacement and stress is investigated in a selected axis of the structures. Numerical examples are performed with respect to connection percentage of the related structural members by using finite element method. According to finite element analysis results, the degree of the semi-rigid connection is important as much as its existence in the design phase. This study reveals that the effect of semi-rigid connections on structural systems shows different variations from structure to structure.

1 INTRODUCTION

In the structural analyses, some assumptions are supposed for process facility in the design phase. One of those is semi-rigid connections (partially fixity or restrained) which are assumed rigid or pinned connections in peculiar to structure. Actually, rigid and pinned connections may be evaluated as a specific case of semi-rigid connections. Frame system supports are assumed to be fixed, but if those are constructed on elastic foundations, they should be considered as semi-rigid. In addition to this, beam-to-column connections in prefabricated structure are taken for granted as pinned connection though they are actually semi-rigid. Furthermore, steel brace connection to reinforced concrete (RC) frames in steel braced RC buildings and truss element connection to joints in truss systems are presumed as pinned connection. These connections, which are stated above, are actually semi-rigid and their existence in structural analysis provides more realistic and reliable results.

Three types of connection: rigid; semi-rigid and pinned were described in steel frames (AISC 1989; Eurocode 3 1992). Bjorhovde et al. (1990) reported that the actual stiffness or restraint of connections lies between the two extremes of pinned and rigid, resulting in the development of connection stiffness models. Semi-rigid connections in frames have attracted attention of the researchers in last decades (Abdalla and Chen 1995; Migliozzi 1997; Kim and Chen 1998; Goto and Miyashita 1998; Dhillon and O'Malley 1999; Sekulovic et al. 2002). In addition to semi-rigid beam-to-column connections, column-to-foundation connections in steel frames were also investigated by a number of researchers (Chan et al. 2005; Degertekin and Hayalioglu 2004). Liu and Burns (2003) submitted a computational study on which the effect of connection flexibility on the nature of the fully stressed designs in steel frames was discussed. Three multistory and multibay fully restrained and partially restrained steel frames were analyzed using plastic-zone method by Foley and Vinnakota (1999). Partially fixity in frames, which was defined as independent from the properties of the connected beam was used in optimal design efforts by various researchers (Xu and Grierson 1993; Xu, et al. 1995; Simoes 1996). Al-Salloum and Almusallam (1995) inspected the optimal design of partially-restrained steel frames by fixing the connection stiffness and performing solution for the member sizes using a predictor-corrector optimization algorithm. In recent years, the numerical analyses of the frames with semi-rigid-connections have mostly been carried out using the defined moment-rotation curves (King and Chen 1993; Kishi et al. 1993; Liew et al. 1993; Leon et al. 1996, Sekulovic and Salatic 2001; Lee and Moon 2002). Three dimensional steel tubular braced frames and truss systems including semi-rigid connections were analyzed by Liew et al. (2000). Moment-rotation curves were also used to determine structural behavior of prefabricated structures (Fatema and Islam 2006). Semi-rigid connections in both steel (Dubina and Zaharia 1996, 1997; Zaharia and Dubina 2000; Fülöp and Iványi 2004) and wood truss systems became another research topic of the investigators (Foschi 1977; Gupta 1990; Riley et al. 1992; Larsen and Jensen 2000; Rittenburg and Kunnath 2003). In addition, different approaches to model semi-rigid connections of metal-plate-connected wood truss joints were developed by the other researchers (Cramer et al. 1993; Dung 2000). Semi-rigid connections in the preceding studies were considered by rotational spring stiffness. However, there is very little study in which the degree of the connection was indicated as proportional.

In this study, the effect of semi-rigid connections on the structural behaviors is comprehensively investigated. Finite element analyses are performed considering semi-rigid connections in column-to-foundation connection of the portal frame system, beam-to-column connection of the prefabricated structure system, steel brace connection to RC frame of the steel braced RC building system and truss element connection to joint of the steel truss system. There are numerous studies relevant to semi-rigid connections in the literature. Almost all of these studies were carried out using rotational spring stiffness. However, connection percentage of the used spring stiffness values was scarcely presented in these studies. Because of that reason, a set of equations, which establishes relations with rotational spring stiffness and connection percentage, is clarified and utilized. Four different structural systems including semi-rigid connection are researched. Finite element analyses of these systems are performed by using SEMIFEM program developed in FORTRAN language. The user can easily employ this program either entering rotational spring stiffness or connection ratio for structural element connection to joint.

2 SEMI-RIGID CONNECTIONS

Structural elements and joints are modelled considering some idealizations. The joints of idealized frame elements are assumed to be constituted by ideally rigid connections. However, another assumption is that structural members of truss systems have ideally pinned connection at joints. Actually, structural connections should be named according to their moment-rotation curves. These curves are usually derived by fitting suitable curves to the experimental data. Various types of M-θ_r models have been developed as described by Chen and Lui (1991). As seen from M-θ_r curves given in Figure 1 the moment (M) is depended on a function of relative rotation between structural members connected to the same joint. The finite element analyses are mostly performed assuming semi-rigid connections as rigid or pinned connections for simply calculation.

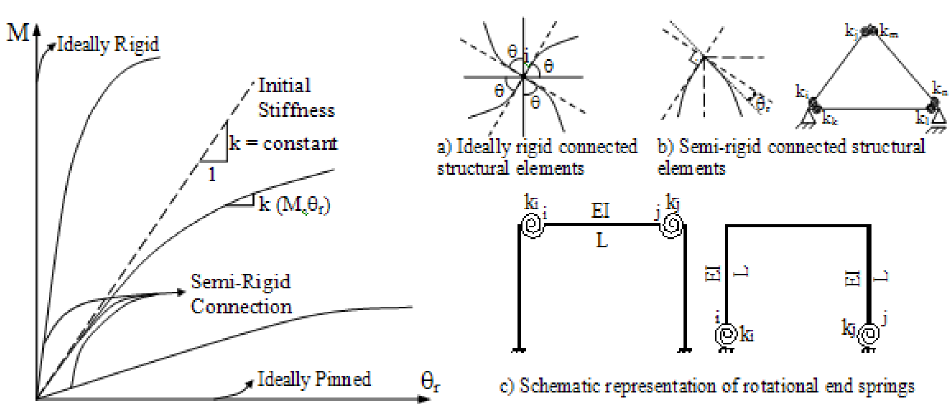

Figure 1. Structural connections.

Connection flexibility is defined by various methods. To obtain an initial opinion on stiffness of rotational springs, use the modulus of elasticity (E), moment of inertia (I) and length (L) of related beam with constant cross-section is very effective and understandable approach. Stiffness matrix of a beam in local coordinates can be written using these attributes of this beam as follows (McGuire et al. 1999).

$$[k] = \begin{bmatrix} \frac{12EI}{L^3}\theta_1 & \frac{6EI}{L^2}\theta_2 & -\frac{12EI}{L^3}\theta_1 & \frac{6EI}{L^2}\theta_3 \\ \frac{6EI}{L^2}\theta_2 & \frac{4EI}{L}\theta_4 & -\frac{6EI}{L^2}\theta_2 & \frac{2EI}{L}\theta_5 \\ -\frac{12EI}{L^3}\theta_1 & -\frac{6EI}{L^2}\theta_2 & \frac{12EI}{L^3}\theta_1 & -\frac{6EI}{L^2}\theta_3 \\ \frac{6EI}{L^2}\theta_3 & \frac{2EI}{L}\theta_5 & -\frac{6EI}{L^2}\theta_3 & \frac{4EI}{L}\theta_6 \end{bmatrix} \tag{1}$$

where $\theta_{1\text{-}6}$ are the coefficients and given as follows,

$$\theta_1 = \frac{\alpha_i + \alpha_j + \alpha_i\alpha_j}{4(3+\alpha_j) + \alpha_i(4+\alpha_j)} \tag{2.a}$$

$$\theta_2 = \frac{\alpha_i(2+\alpha_j)}{4(3+\alpha_j) + \alpha_i(4+\alpha_j)} \tag{2.b}$$

$$\theta_3 = \frac{\alpha_j(2+\alpha_i)}{4(3+\alpha_j) + \alpha_i(4+\alpha_j)} \tag{2.c}$$

$$\theta_4 = \frac{\alpha_i(3+\alpha_j)}{4(3+\alpha_i) + \alpha_j(4+\alpha_i)} \tag{2.d}$$

$$\theta_5 = \frac{\alpha_i\alpha_j}{4(3+\alpha_i) + \alpha_j(4+\alpha_i)} \tag{2.e}$$

$$\theta_6 = \frac{\alpha_j(3+\alpha_i)}{4(3+\alpha_i) + \alpha_j(4+\alpha_i)} \tag{2.f}$$

Here, α_i and α_j are the stiffness indexes and can be used to obtain rotational spring stiffness as follows,

$$k_i = \alpha_i \frac{EI}{L} \tag{3.a}$$

$$k_j = \alpha_j \frac{EI}{L} \tag{3.b}$$

where, k_i and k_j are the rotational spring stiffness at i and j ends of the beam, respectively, and those change in 0-∞ range.

Semi-rigid connection may also be identified by connection percentage. Then, the parameters of θ_i can be written as follows (Chen and Lui 1991; Kartal 2004; Filho et al. 2004).

$$\theta_1 = \frac{r_i + r_j + r_{ij}}{3} \tag{4.a}$$

$$\theta_2 = \frac{2r_i + r_{ij}}{3} \tag{4.b}$$

$$\theta_3 = \frac{2r_j + r_{ij}}{3} \tag{4.c}$$

$$\theta_4 = r_i \tag{4.d}$$

$$\theta_5 = r_{ij} \tag{4.e}$$

$$\theta_6 = r_j \tag{4.f}$$

where, r_i, r_j and r_{ij} are the correction factors and obtained as follows,

$$r_i = \frac{3\nu_i}{4 - \nu_i\nu_j} \tag{5.a}$$

$$r_j = \frac{3\nu_j}{4 - \nu_i\nu_j} \tag{5.b}$$

$$r_{ij} = \frac{3\nu_i\nu_j}{4 - \nu_i\nu_j} \tag{5.c}$$

Here, ν_i and ν_j are the fixity factors and represent the semi-rigid connection as percentage. If the Eqns 2 and 4 are equalized, a set of equations, which provides a direct relation with initial spring stiffness and connection percentage, is achieved as presented in Eqn 6 (Monforton and Wu 1963; Sekulovic and Salatic 2001),

$$k_{i,j} = \frac{3EI\nu_{i,j}}{(1-\nu_{i,j})L} \quad (6)$$

where $\nu_{i,j}$ is the fixity factor, which represents the connection percentage.

After the stiffness matrix [K] and force vector {F} of the system is formed, the displacement vector {U} is obtained from Eqn 7.

$$\{F\} = [K]\{U\} \quad (7)$$

Then the internal forces and moments occurred in the structure including semi-rigid connections are may easily be acquired.

3 NUMERICAL APPLICATIONS

Structural behavior of the constructed structures can be different from the computer simulations. There can be several reasons of this difference. One of them is the semi-rigid connections in joints and at supports. In the scope of this study, four different structural systems including semi-rigid connections, which are portal frame system, prefabricated structural system, steel braced RC frame system and steel truss system are investigated comprehensively. The variation of moment, shear force, axial force, displacement and stress distribution is evaluated for each system. The effect of semi-rigid connection on structural behavior is clearly indicated for these systems.

In the numerical examples, different cross-sections are used in structural systems. Using the Eqns 6, rotational spring stiffness-connection percentage relation is given for the structural elements including semi-rigid connections of the various systems. Since the spring stiffness changes in 0-∞ range, connection percentage range is considered between 0.01% and 99.99% and concerned relation is submitted as logarithmically in the figures. Finite element analyses are performed using various connection ratios. Equivalent rotational spring stiffness values of the preferred connection ratios in the analyses and more can be distinguished from these figures.

3.1 *Verification of SEMIFEM*

Finite element analyses are performed using SEMIFEM program developed in FORTRAN language. Users can define semi-rigid connection entering either rotational spring stiffness or connection ratio. It should be clarified that, researchers can only define semi-rigid connections in the package programs such as ANSYS (2008) and SAP2000 (2008) by rotational spring stiffness at the end of the structural element or joint. In this section of the study, numerical results of the finite element analyses obtained from SEMIFEM are compared with ANSYS for verification. Semi-rigid connections are modeled using zero-length rotational spring elements in ANSYS as proposed by (Chen et al. 1996). Accordingly, a steel truss system given in Figure 2 is utilized. The connection ratio and equivalent rotational spring stiffness at joints of the truss elements, which are calculated using the Eqns 6, are submitted in Table 1. Moments, internal forces, displacements and stresses obtained from the SEMIFEM are compared with ANSYS in Table 2. According to Table 2, numerical results of the SEMIFEM provide too high consistency with ANSYS.

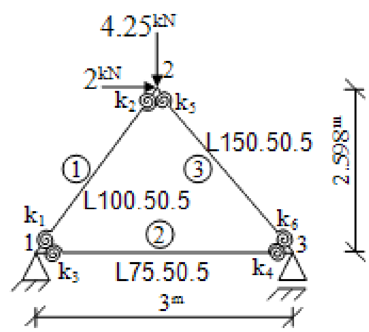

Figure 2. Finite element model of the truss system used for verification

Table 1. Connection properties of truss members used in the sample truss system.

Cross-Section Type	Length (m)	Modulus of Elasticity (kN/m^2)	Moment of Inertia (cm^4)	Connection (%)	Rotational Spring Stiffness (kNm/rad)	
L100.50.5	3	2.1x10^8	76.7243	25	k_1	53.7070
				75	k_2	483.363
L75.50.5	3	2.1x10^8	34.8516	25	k_3	24.3961
				50	k_4	73.1884
L150.50.5	3	2.1x10^8	231.6454	75	k_5	1459.37
				50	k_6	486.455

3.2 *Application 1: A Portal Frame System with Semi-Rigid Boundary Condition*

Frame systems are assumed to have fixed boundary conditions. In fact, columns at foundation may be translated and rotate depending on soil conditions. Therefore, semi-rigid boundary conditions should be considered for elastic soil conditions. In this study, semi-rigid connections are evaluated for column-to-foundation connection. A four story RC frame system with a span is analyzed for this purpose. Finite element model and loading conditions are shown in Figure 3. Modulus of elasticity of the concrete used in analyses is 2.8×10^7 kN/m^2.

Table 2. Comparison of the numerical results of the SEMIFEM and ANSYS.

		Axial Force (kN)		**Shear Force** (kN)		**Moment** (kNmm)	
El.-Node		**SEMIFEM**	**ANSYS**	**SEMIFEM**	**ANSYS**	**SEMIFEM**	**ANSYS**
1	1	-0.453	-0.453	0.001	0.001	-0.550	-0.550
1	2	-0.453	-0.453	0.001	0.001	3.304	-3.304
2	1	2.225	2.225	0.000	0.000	0.550	0.550
2	3	2.225	2.225	0.000	0.000	0.023	-0.023
3	2	-4.453	-4.453	-0.001	-0.001	3.304	3.304
3	3	-4.453	-4.453	-0.001	-0.001	-0.023	0.023
Node		**Ux** (mm)		**Uy** (mm)		**Rz** (rad)	
1		0	0	0	0	-0.0000301984	-0.0000301984
2		0.0828077	0.0828077	-0.0581206	-0.0581206	-0.0000079543	-0.0000079543
3		0.0529878	0.0529878	0	0	0.00000438054	0.00000438054

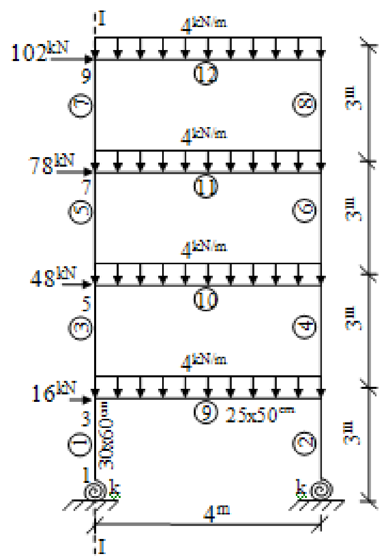

Figure 3. Finite element model of the portal frame system.

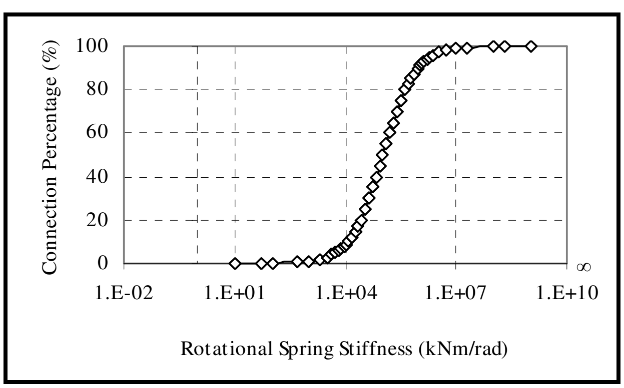

Figure 4. Rotational spring stiffness-connection percentage relation for base columns.

Rotational spring stiffness-connection percentage relation of the "k" spring constants in column-to-foundation connection is given in Figure 4. In the numerical examples, the values of the rotational spring stiffness obtained from Eqn. 6 are selected from this figure. Using different connection ratios, the variation of moment, shear force and axial force in I-I axis of the frame system is evaluated according to connection ratio of the columns (Figures 5 - 7). In addition, horizontal displacements are also submitted to show semi-rigid boundary condition effects on lateral drifts (Figure 8).

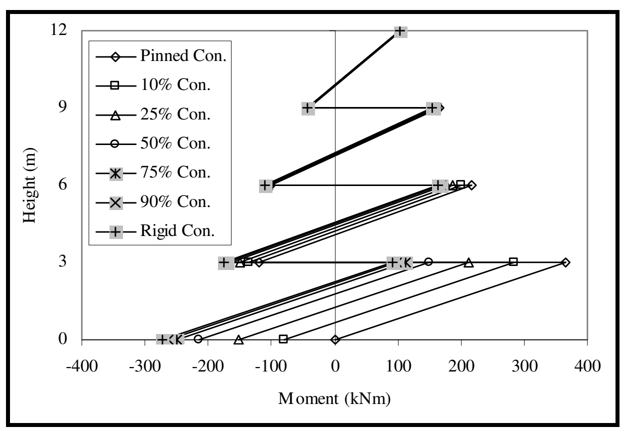

Figure 5. Moment diagram in I-I axis of the portal frame.

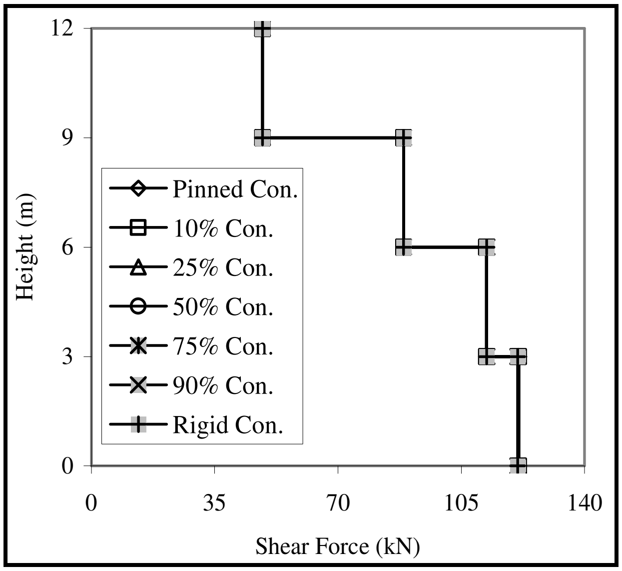

Figure 6. Shear Force diagram in I-I axis of the portal frame.

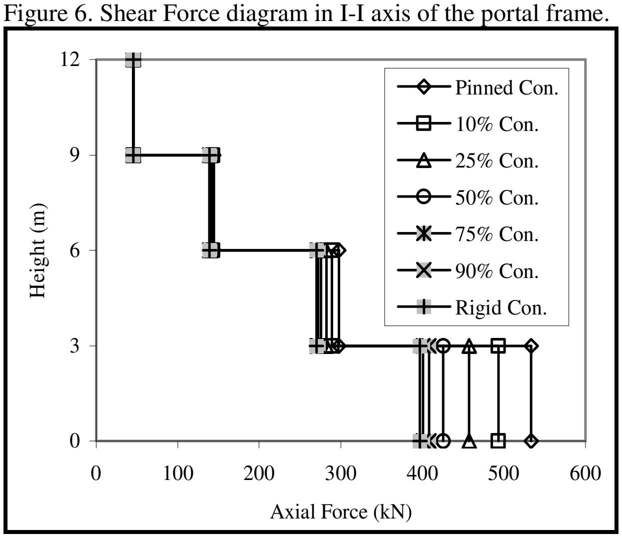

Figure 7. Axial Force diagram in I-I axis of the portal frame.

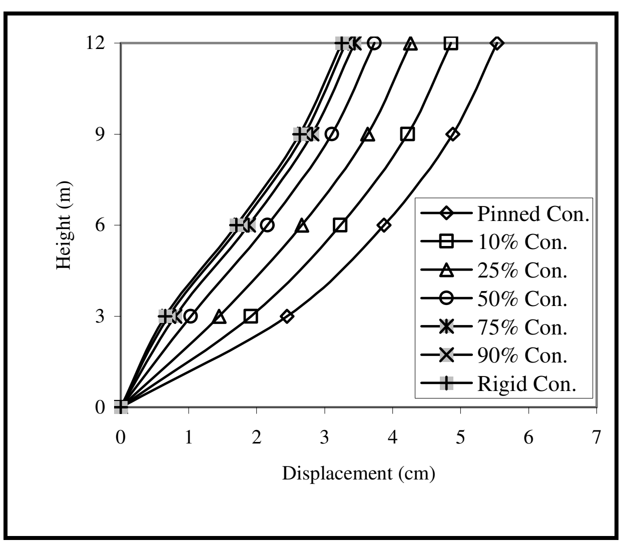

Figure 8. Horizontal displacements in I-I axis of the portal frame.

The frame system subjected to uniform distributed and equivalent earthquake forces is studied for different boundary conditions. As seen from Figure 5, end moments are intensively affected by boundary conditions, especially, in low-story columns. It is clearly distinguished from this figure that optimum absolute moment differences occur in 25-50% connection ratio range. Although the base moments increase by increasing connection ratios, it seems no change occur in upper structural members. However, shear force is not affected by boundary conditions. As seen from Figure 7 axial forces decrease by increasing connection ratios. It should be clarified that the variation of moment and axial force take after each other. In addition to this, if the changing of moment and axial force in 0-10 and 90-100 percentage ranges is compared, the rotational spring stiffness is more effective in the 0-10 percentage range than 90-100. This is also valid for horizontal displacements. It is obviously seen from Figure 8 that connection ratio of the columns are very effective to limit story drifts. For instance, horizontal displacements increase 1.5 times at fourth-story and more than 2 times in first-story as the connection percentage decreases from 50 to 0.

3.3 *Application 2: A Prefabricated Structure System with Semi-Rigid Connection*

Structural members of prefabricated structures are constituted individually in a factory and assembled in construction site where the structure is to be located. Prefabricated systems depart from conventionally reinforced concrete RC structures with construction features. Nowadays, precast concrete is usually used in each type of the structures. However, structural members are constituted casting concrete in-situ. Therefore, the joints in RC structures are considered as rigid connections in design stage. But, they should be evaluated as semi-rigid connections in prefabricated structures. In this part of the paper, a four-story prefabricated structure with a span under equivalent earthquake forces is studied (Figure 9). Modulus of elasticity of the concrete used in analyses is $2.8\text{x}10^7$ kN/m^2.

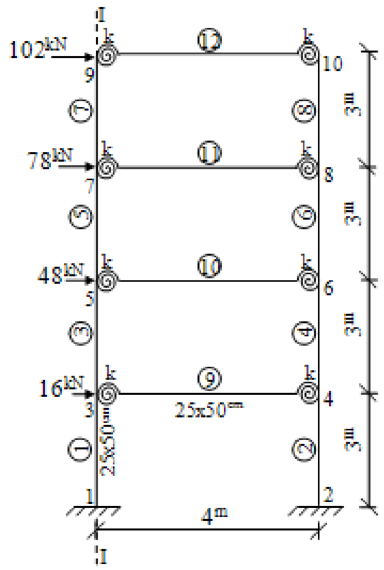

Figure 9. Finite element model of the prefabricated structure system.

Vertical elements of the structures are considered as one-piece and column-to-column connections are modeled as rigid. Since the beams are assembled between columns after the columns have been constructed, beam-to-column connections are assumed to be semi-rigid. In the performed analyses, different connection percentages are taken into consideration at beam-ends. Each of the beams has the same cross section and their rotational spring stiffness-connection percentage relation is given in Figure 10.

The variation of moment, shear force, axial force and horizontal displacements obtained using various connection ratios are given in Figures 11 - 14 respectively. Submitted results are evaluated in I-I axis of the prefabricated structure system which includes vertical structural elements.

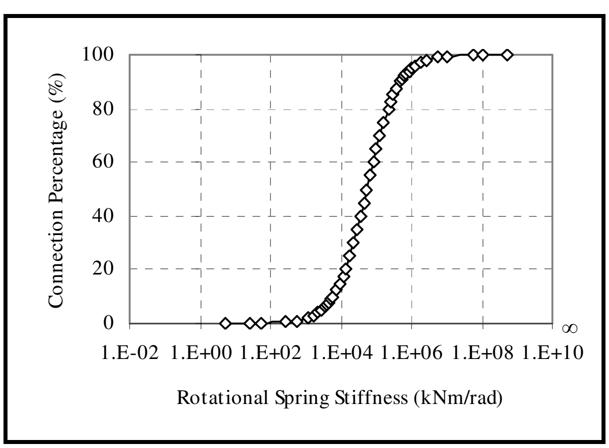

Figure 10. Rotational spring stiffness-connection percentage relation for beam-to-column connections.

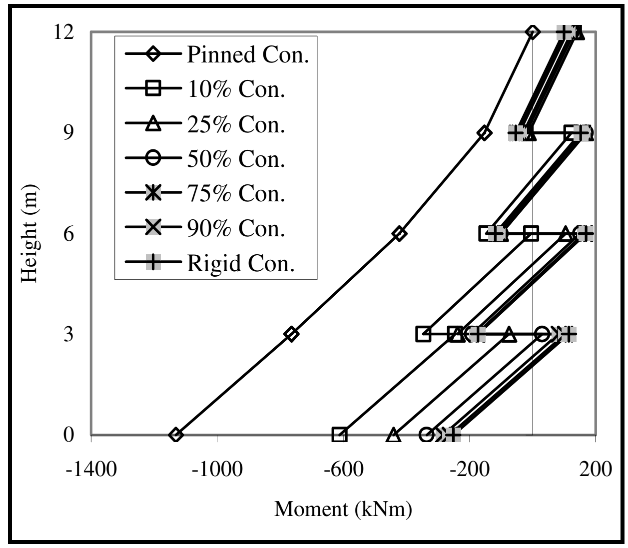

Figure 11. Moment diagram in I-I axis of the prefabricated system.

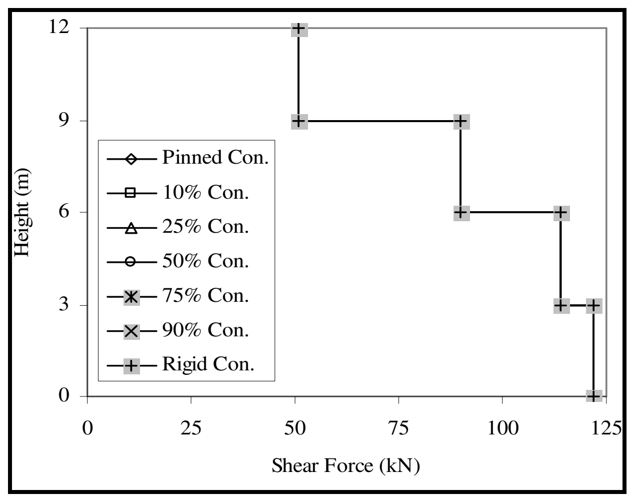

Figure 12. Shear force diagram in I-I axis of the prefabricated system.

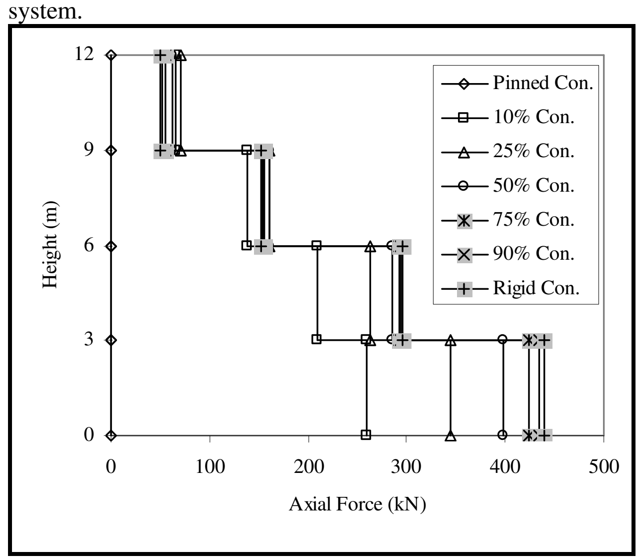

Figure 13. Axial force diagram in I-I axis of the prefabricated system.

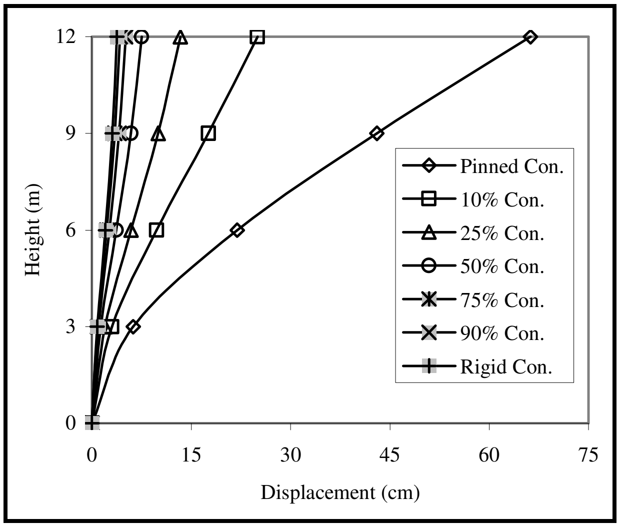

Figure 14. Horizontal displacements in I-I axis of the prefabricated system.

Fully pinned connections at beam ends result a cantilever beam behavior for columns as seen from Figure 11. As the rotational spring stiffness increases, frame system behavior appears. Base moment for pinned connection at beam ends is greater about 1.85 times than 10% connection ratio and furthermore, it is greater about 1.3 times than 50% connection ratio for 25% connection ratio. However, it is almost equal for 90% connection ratio and rigid connections. Besides, shear forces in I-I axis of the prefabricated system and portal frame system are identical and don't change with connection ratios. Since the columns behave as a cantilever beam in case of pinned connections are defined at beam ends, if vertical loads ignored as seen in this example, lateral forces do not result in axial forces on columns. But, the increase of the connection ratio at beam ends causes axial force forming and increasing. This is more evident in 0-10 percentage range than 10-100 percentage range. The variation of the displacements obviously reveals the effect of connection ratio. Numerical examples point out that higher spring constants provide more safety in these structures from the point view of lateral drifts. It should be careful in the design stage, because, if beam-to-column connections are not sufficiently connected, excessive drift problems may take place under lateral loads.

3.4 *Application 3: A Steel X-Braced RC Building System with Semi-Rigid Connection*

Conventionally built frame structures may not bear to strong ground motions. One of the best ways to provide resistance to frames is to use steel bracing in these structures. Steel braced buildings are named concentrically or eccentrically steel braced frame according to their design type. They provide high resistance to limit displacements and internal forces. Steel brace connection to beam and column is considered as pinned connection in design phase. Actually, steel brace connections are semi-rigid such that they may not be constituted as fully pinned. In this study, a concentrically braced RC frame, steel X-braced, is chosen as an example. Steel brace connections are considered as semi-rigid and different spring stiffness are used in numerical analyses. Finite element model of the steel X-braced frame is shown in Figure 15. U15.5.5 handmade steel profiles are used for bracing. Moment of inertia and cross-section area of the profiles are 6.74×10^{-6} m^4 and 2.3×10^{-3} m^2 respectively. Modulus of elasticity of the concrete and steel are 2.8×10^7 and 2.1×10^8 kN/m^2 respectively.

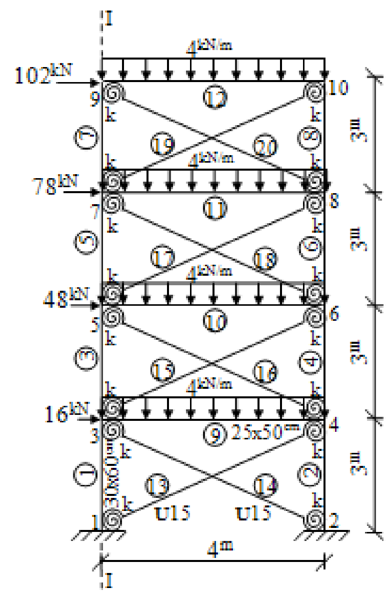

Figure 15. Finite element model of the steel X-braced RC frame system.

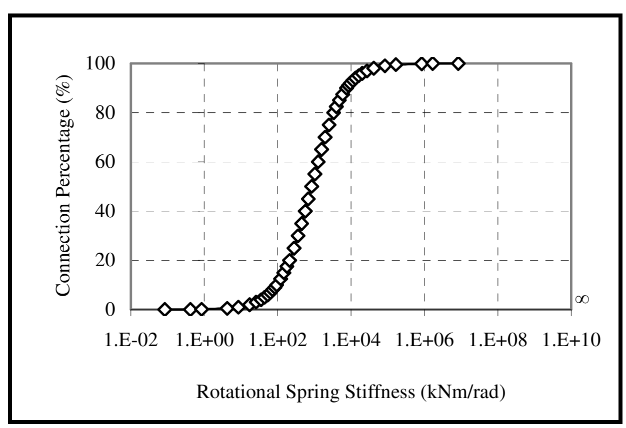

Figure 16. Rotational spring stiffness-connection percentage relation for steel braces connections to RC frame.

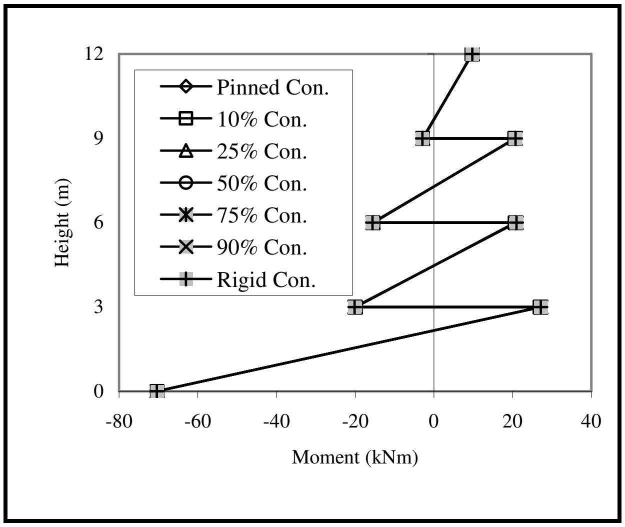

Figure 17. Moment diagram in I-I axis of the steel X-braced RC frames.

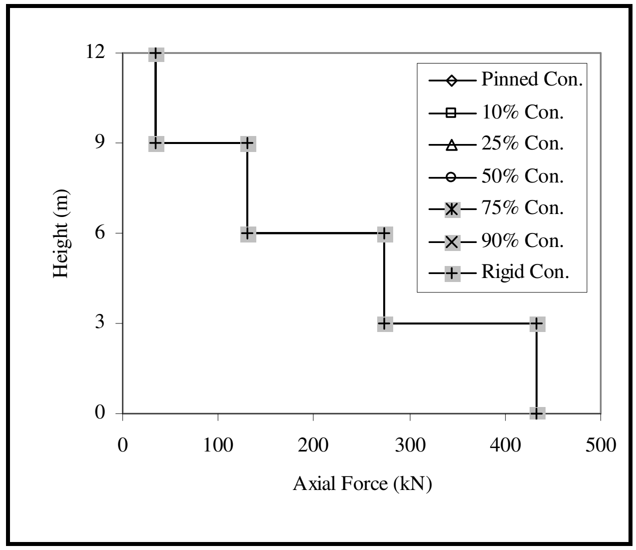

Figure 19. Axial force diagram in I-I axis of the steel X-braced RC frames.

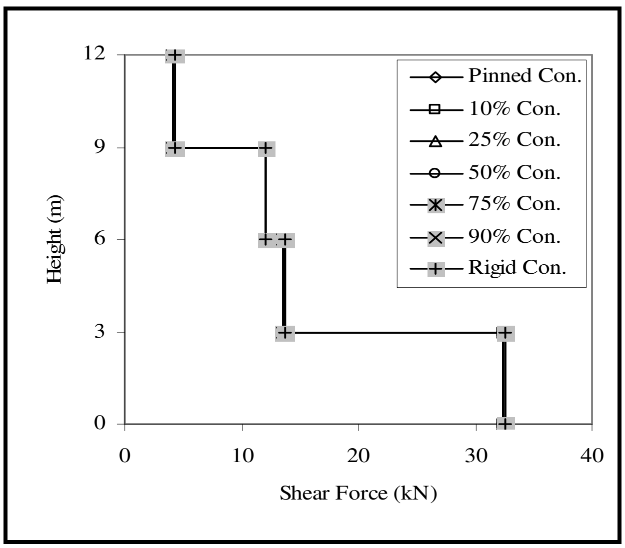

Figure 18. Shear force diagram in I-I axis of the steel X-braced RC frames.

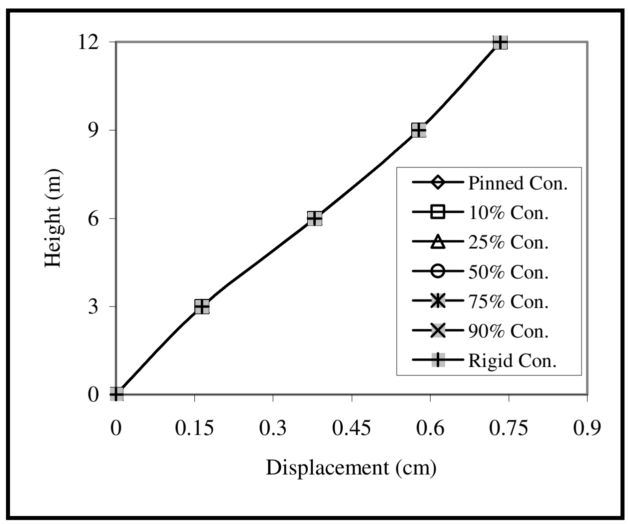

Figure 20. Horizontal displacements in I-I axis of the steel X-braced RC frames.

In the design stage of the steel braced frame, beam-to-column and column-to-column connections are considered rigid as distinct from steel brace connections to frame system. In the finite element model of the system, each of the steel profiles used for bracing has the same cross-section and connection ratios. The rotational spring stiffness-connection percentage relation of the steel bracings is given in Figure 16.

The change of moment, shear force, axial force and horizontal displacements along the I-I axis is evaluated for various connection ratios of steel braces to RC frame (Figures 17 - 20). The variation of normal stresses at the selected steel profile, of which element number is 15, is also assessed considering semi-rigid connections as given in Figure 21.

Semi-rigid steel brace connections to beam-column joints result almost no change in moment, shear force, axial force and horizontal displacements (Figures 17 – 20) in I-I axis of the steel X-braced RC frame on the contrary to portal and prefabricated frame systems. According to these results, the design type of steel braces is more and more effective than the steel brace connection to RC frame. However, normal stresses occurred in steel braces show an evident variation. If steel element number 15 is taken into account, stresses occurred in this steel member for rigid connection is higher about 4500 kN/m^2 than pinned connection and change by length and height of the steel element as seen from Figure 21. It should be clarified that while the steel brace connection to RC frame is effective on stresses of the steel braces, it is ineffective on structural behavior of the RC frame. If the distribution of the stress is observed by the section height of the steel brace, while it is constant at upper and lower ends for pinned connection, it varies with end moments by section height for rigid and semi-rigid connection.

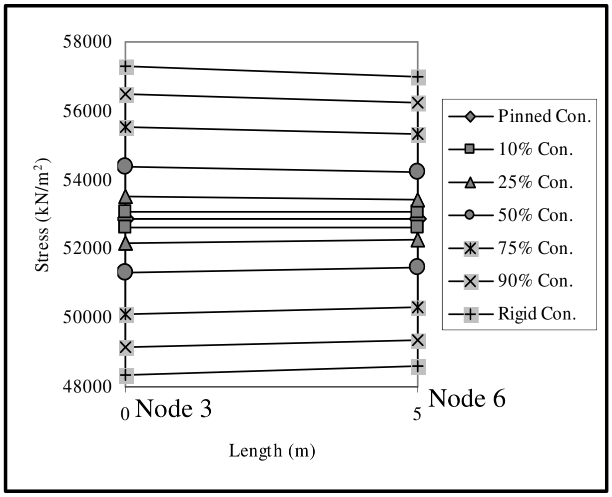

Figure 21. Normal stresses in steel element number 15 of the steel X-braced RC frames.

3.5 *Application 4: A Steel Truss System with Semi-Rigid Connection*

Truss systems are widely used in civil engineering applications especially to cross wide spans. There are many types of truss systems which are named depending on their design type. These type structures are modeled considering pinned connections in joints. Structural elements of plane truss systems are usually constituted by welded or bolted in the joints. But, it is impossible to constitute fully frictionless connection in the joints of truss systems unlike the assumption in the design phase. The connections of the truss elements are, actually, semi-rigid and they should be considered in this way in design.

In the numerical analyses of truss systems, if pinned connection is considered, only axial force is obtained in a truss element. Therefore a constant stress distribution along the length and height of this element is attained. However, if semi rigid connection is taken into account in numerical applications, moment and shear force are also acquired. Therefore, secondary stresses occur in the truss elements. This may provide larger stresses if compared with ones obtained for pinned connections. In this study, a steel truss system, which has various connection conditions, is used for numerical applications. Finite element model of the system is given in Figure 22. Three different handmade cross sections used in the truss system and their section properties are submitted in Table 3. In this model, the bottom chord members, top chord members and diagonal chord members of the truss system are constituted from L75.50.5, L100.50.5, and L150.50.5 handmade profiles respectively.

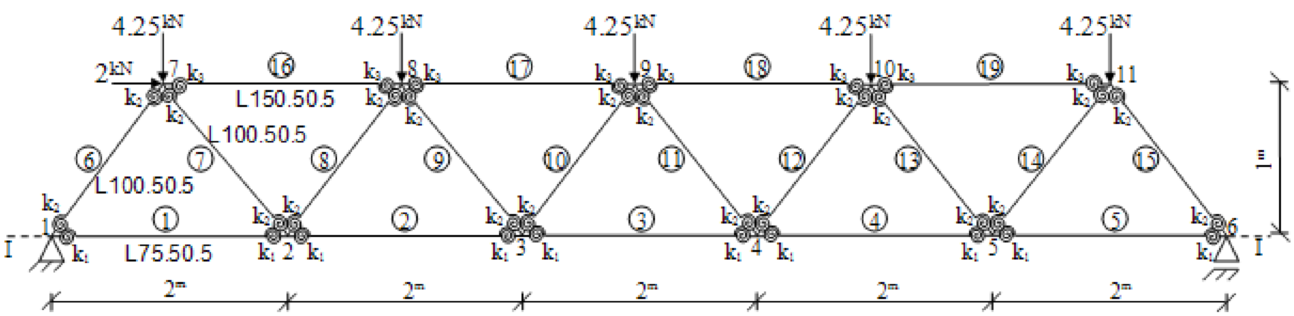

Figure 22. Finite element model of the steel truss system

Table 3. Cross-Section properties of the steel profiles used in the truss system.

Cross-Section Type	Cross-Section Area (cm^2)	Moment of Inertia of Cross-Section (cm^4)	Height of Cross-Section (cm)	Distance from the Top to Neutral Axis (cm)
L75.50.5	6.00	34.8516	7.5	5.06250
L100.50.5	7.25	76.7243	10.0	6.47414
L150.50.5	9.75	231.6454	15.0	9.17308

In the numerical examples, all connections of the truss elements to joints are assumed to have the same connection ratio. Rotational spring stiffness-connection ratio relations of these steel structural elements are presented in Figure 23.

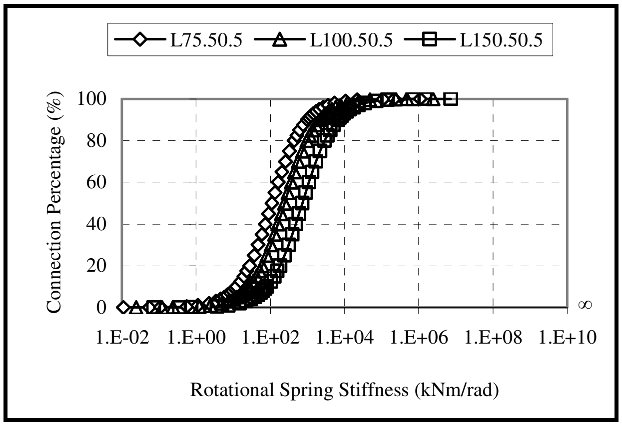

Figure 23. Rotational spring stiffness-connection percentage relations in the steel truss system.

The effect of steel truss element connections to joints on structural behavior of the truss system is investigated for various connection ratios. For this purpose, the variation of moment, shear force, axial force in I-I axis and vertical displacements at node 3 and 4 are given in Figures 24 - 27. In addition, the change of normal stress along the truss element number 5 is also given in Figure 28.

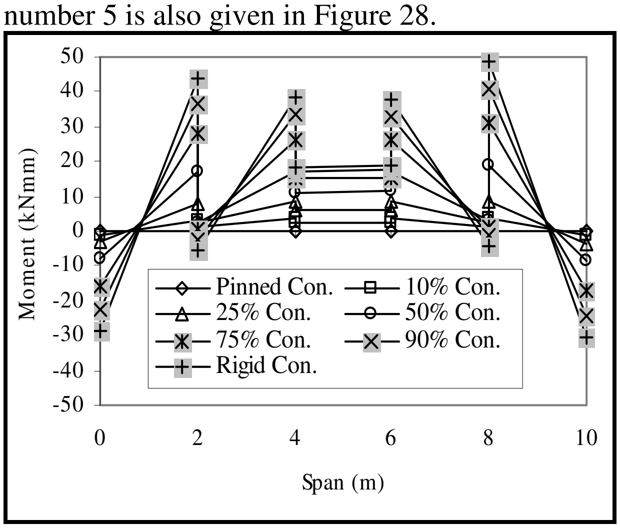

Figure 24. Moment diagram in I-I axis of the steel truss system.

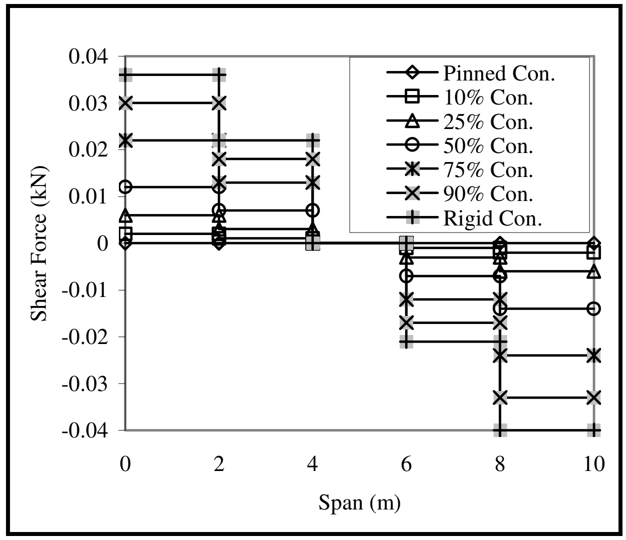

Figure 25. Shear force diagram in I-I axis of the steel truss system.

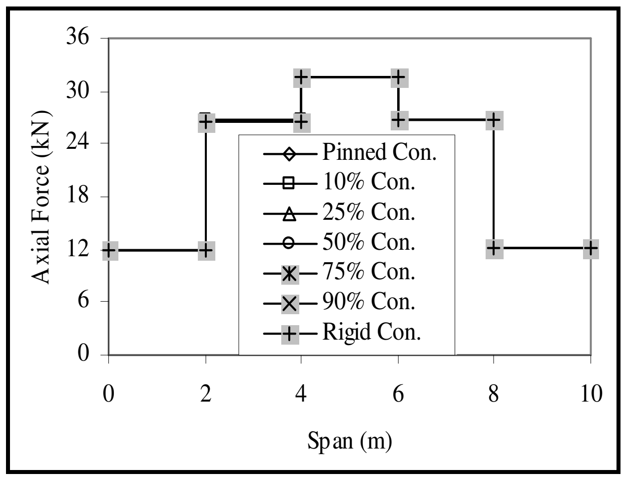

Figure 26. Axial force diagram in I-I axis of the steel truss system.

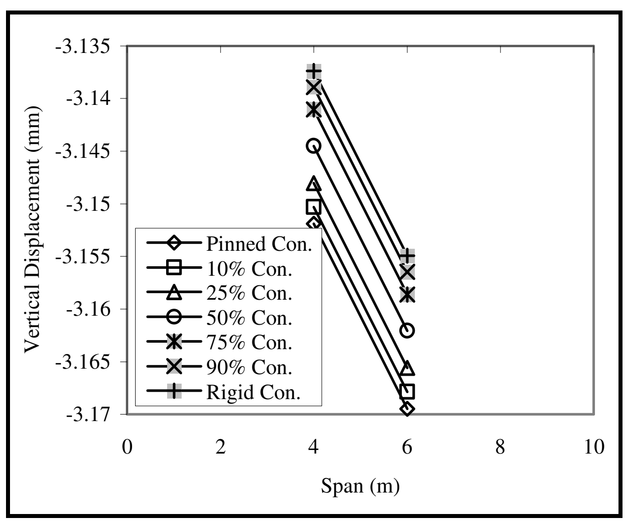

Figure 27. Vertical displacements at node 3 and 4 of the steel truss system.

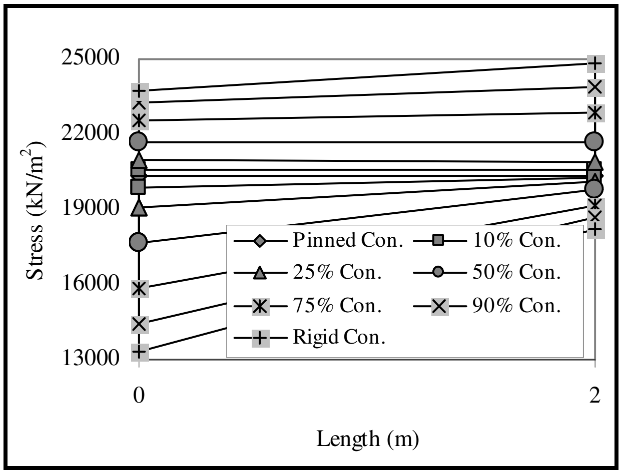

Figure 28. Normal stresses in element number 5 of the steel truss system.

Performed numeric analyses obviously reveal the effect of connection ratio on structural behavior in truss systems. According to Figure 24 and 25, moments and shear forces appear and increase for ascending connection percentages in I-I axis of the truss system. The most critical moment and shear force values are obtained for rigid connections. It should be clarified that if the increment in moment and shear force is compared for the equivalent ranges as 0-10% and 90-10%, 10-25% and 75-90%, and 25-50% and 50-75%, it is higher for the range consisting of big connection ratios. However, there is almost no change in axial forces in steel truss elements. Besides, vertical displacements, which have very little change, decrease by increasing connection percentages. While a constant stress distribution occurs in structural elements for pinned connections, different stress distributions take place in these elements for semi-rigid and rigid connections. In addition to this, the higher connection percentages lead to the higher stresses in the truss members. The increase and decrease in stresses are also higher for the range formed by high connection percentages.

4 CONCLUSIONS

In the structural analyses, semi-rigid connections are ignored for process facility. However, most of the structural connections in joints such as at prefabricated structure and truss systems are actually semi-rigid. In finite element analyses where the connections to joints are considered as semi-rigid, those are defined with only rotational spring stiffness but equivalent connection percentage of them is not indicated.

In this study, a set of equations, which provides a direct relation between rotational spring stiffness and connection percentage, is used. A finite element program SEMIFEM, in which the users can model semi-rigid connection with either rotational spring stiffness or connection ratio, is developed. Four different types of structures such as portal frame, prefabricated frame, steel X-braced RC frame and steel truss systems, which have various connection conditions at joints and supports, are investigated in the numerical examples. The connection percentage-rotational spring stiffness relations of the semi-rigid connected structural members are shown in figures.

According to this detailed research, several outcomes are obtained from the performed finite element analyses including semi-rigid connections. In the comparison of the portal frame and prefabricated systems, semi-rigid beam-to-column connections are more effective than column-to-foundation connections. In the portal frame system subjected to both lateral and vertical loads, semi-rigid boundary conditions are very influential on moments and axial forces, especially at lower stories of the system, and also horizontal displacements, but not shear forces. In the prefabricated frame system subjected to lateral loads, as beam-to-column connection ratio increase, moments and horizontal displacements decrease and axial forces increase. In the steel X-braced RC frame system subjected to both lateral and vertical loads, steel brace connection to RC frame has almost no effect on displacements, internal forces and moments. However it is very effective on stress distribution of the steel braces such that stresses increase by increasing connection ratios in some parts of the braces. Structural behavior of the steel truss system resembles the steel X-braced RC frame system. Because the steel truss element connection to joints is more effective on stress distribution than internal forces, moments and displacements. On the other hand, shear forces and moments, which are ignored in accordance with conventional analyses, occur and increase by increasing connection ratios.

It is clearly distinguished from this study that semi-rigid beam-to-column and column-to-foundation connections are more effective on general structural behavior than steel brace and truss member connections to joints. If the connection level to joints is determined more sensible, more realistic and reliable structural behavior is obtained. Besides, if prefabricated frame systems are taken into consideration, semi-rigid beam-to-column connections may provide more economical results. According to this study, the effect of semi-rigid connections on structural systems shows different changes from structure to structure. Consequently, semi-rigid connections should be considered in structural analyses to obtain the most optimum results. However, designers should be careful while selecting the degree of connection to be used in analyses.

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