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Structural Performance of Semi-Rigid Connection Steel Frames

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ABSTRACT

In most engineering designs, steel connections are usually considered as fully rigid connections or perfectly pinned connections, for simplicity of design work. In reality, this assumption is incorrect. The behaviour of the beam-column connection is in between of rigid connection and perfectly pinned connection. This type of connection is termed semi-rigid connection. This article represents a numerical analysis using finite element method of structural steel frames to investigate the effect of semi-rigid beam-column connection on the behaviour of the frame. ANSYS software was used for the finite element modelling of the frames. The beam-column connection was modelled as rotational spring with specified rotational stiffness using COMBIN14 element. The study includes investigation the effect of semi-rigid on different study cases such as: support types and number of stories. The obtained results reveal that changing the beam-column connection from rigid case to semi-rigid case with different rotational stiffness can increase the vertical and horizontal displacement of the frame with a percentage depends on the rotational stiffness of the beam-column connection. Changing the support type of the frame from fixed to pinned support or increasing the number of stories with semi-rigid connection can decrease the strength capacity of the frame. This indicates the importance of including the semi-rigid connection in the design and analysis of steel frames to obtain more realistic results.

1. Introduction

The steel structures usually consist of beams, columns and connections between them. The behavior of steel structures is mainly depending on the behavior of the connection between columns and beams. In engineering design and analysis, the beam-to-column connections are assumed to be perfect rigid or fully pinned connection, however, in realistic behavior of beam-column connection, there is no perfect rigid connection or fully pinned connection. The rigid connection can provide flexibility and pinned connection can provide rigidity. The realistic behavior of the beam-column connection is between the rigid and pinned connection and the connection is termed as semi-rigid beam-column connection [1]. The behavior of semi-rigid beam-column connection might affect the design and analysis calculations of steel structures.

The steel structure connection like other structural members is subjected to the four main external loads (axial force, shear force, bending moment, and torsion). Most of the deformation of the connection area is came from the bending moment subjected to the steel frame, which produce rotation to the connection area. This rotation can drift the whole frame; therefore, the studies of steel connections are related to the bending moment only [2].

On the other hand, The American Institution of Steel Construction (AISC, 2010) [3] classified the steel connection into three main types: unrestrained (simple frame), fully restrained (rigid frame), and partially restrained

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(semi-rigid frame), the simple connection can transfer shear and axial forces only while moment transferring can be neglected, rigid frame can transfer moment and neglect the rotational deformation between the members. While semi-rigid can transfer the moment with the rotational deformation [2].

Many investigations were performed over the past decades to estimate the actual behavior of the beam-column connection. The most important contributions and researches about this field can be reviewed as follows:

Jones et al., (1980) [4] investigated the effect of the beam-column connection stiffness on the behavior of steel column using finite element method with the help of FORTRAN computer program. The model consists of one-dimensional beam element. The material assumed to be elastic-perfect plastic material. From this study, it was concluded that the stiffness of the column is increased when the stiffness of the beam-column connection is increased and the deformation is reduced.

Degertekin and Hayalioglu (2004) [5] presented a theoretical investigation the behavior of semi-rigid beam-column connection and semi-rigid column bases on steel frames. Non-linear geometry and non-linear stiffness of the beam-column connection was considered in the analysis. The semi-rigid beam-column connection was modeled using rotational spring. From this study it was concluded that, the top horizontal displacement of the frame of semi-rigid frame is increased with a percentage of 12-64%, while the percentage is 46-86 % if the number of stories is increased comparing with the rigid case.

Ozturk and Secer (2005) [6] studied the semi-rigid beam-column connection behavior on two-dimensional frame with dynamic determinates. The semi-rigid connection was modeled with linear elastic rotational spring. Two types of connection models were used in the study. The first type, was modeled with the semi-rigid beam-column connection at the intersection of the beam and column. In the second model the rotational springs were located at the end of the beam. The material of the sections used in the analysis was taken to be steel material with the same modulus of elasticity. It was concluded from this study that the location of the semi-rigid beam-column connection can affect the behavior of the frame, moreover with the increase of the rotational spring stiffness, the behavior of the frame becomes more rigid than the semi-rigid behavior.

Ibrahim and Murtada (2016) [7] studied the effect of post buckling behavior of prismatic structural steel frames with the presentation of semi-rigid beam-column connection in the frame. The models were produced using finite element method. The semi-rigid connection was modeled using spring element with linear rotational stiffness. The results indicated that changing the connection from rigid to semi-rigid can decrease the ultimate load with percentage of 20.2% and increase the vertical displacement with a percentage of 16.1%. For one-bay two-story frame the ultimate load is decreased by a percentage of 15.3% and increase the ultimate vertical displacement by a percentage of 10.9%, while for three-bay two-story frame the ultimate load is decreased by 13.1% and the vertical displacement is increased by 9.4%.

Mohammed and Ismael, (2019) [8] studied the post-buckling behavior of semi-rigid two-dimensional frames. Finite element method was used for the numerical analysis of the study in ANSYS software. The frames used for the analysis are William Toggle frame and portal frame. From the results of this study, the following conclusions were found: The vertical displacement is more influenced by the stiffness of the semi-rigid connection. The lateral load decreases the vertical displacement with a percentage of 3.23% and decrease the influence of connection rotational stiffness. The semi-rigid connection should be considered in the design and analysis of steel frames due to the realistic behavior of semi-rigid connection frame.

Semi-Rigid connection was studied in column to beam connection by Chan and Cho (2005) [9] and column to foundation connection by Degertekin and Hayalioglu (2004) [10]. Brognoli et al. (1998) [11] investigated the semi-rigid connection on braced frames in structural optimization approach rather than a component analysis.

Other researchers, such as [12] studied design optimization of steel structures with generic algorithm and providing a solution to discrete optimum design problems. Moreover, [13] and [14] studied the effect of semi-rigid connection on the optimum design of structures. Hernández et al. (2005) [15] represent a design optimization for the steel portal frames.

Researchers realized that adding a semi-rigidity at the joint can give a better modeling of the joint which is a better option instead of modifying stiffness of adjacent beams [16].

The objective of this study is using a numerical analysis for different finite element models using ANSYS software to investigate the effect of semi-rigid beam-column connection with different rotational linear stiffness values on the behavior of different frame cases such as: support type and number of stories Also, a comparison will be produced between the variables of each case. The bending moment and shear force values on different nodes of the frames were studied for different rotational stiffness values. Moreover, the effect of the semi-rigid connection on the behavior of the frame deformation was investigated.

2. Methodology

In this study, numerical analysis will be produced by using finite element method with the help of ANSYS software to investigate the effect of the semi-rigid beam-column connection on the behavior of steel frames with different rotational stiffness. Different study cases were taken into account of the analyses such as: support type and number of stories. Moreover, a comparison will be produced between the variables of each case.

In the numerical model used for this study, two types of elements were used for the analysis. The element used are defined by ANSYS program as (BEAM3 and COMBIN14). BEAM3 was employed to model the beams and columns of frame structures, while COMBIN14 were used to model the beam-column connection with linear determinates. Figure 1 shows the BEAM3 element while Figure 2 shows the COMBIN14 element (from ANSYS guide manual [17]).

The rotational stiffness of the beam-column connection can be specified with the use of COMBIN14. The semi-rigid connection was constructed with two nodes at the ends of the column and beam with the rotational spring between them as can be shown in Figure 3, while in the rigid connection the beams and columns were connected with same node for the beam and the column.

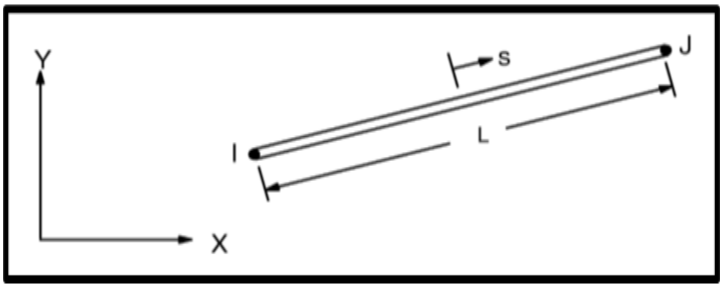

Figure 1. BEAM3 element [17]

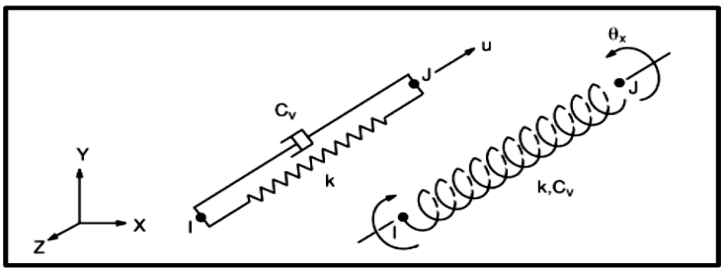

Figure 2. COMBIN14 element [17]

3. Model verification

The results of the numerical models of steel frames with semi-rigid connection produced by finite element methods will be compared with the results of other previous studies that were achieved using different approaches in order to check the validity and accuracy of finite element models.

3.1 One-bay one-story frame with linear analysis

This frame was analyzed by [18] using element stiffness formulation with the help of GMNAF-ED program. In this study, the same frame was analyzed using finite element method. The geometry, and loading condition of the frame is shown in Figure 3. The material properties of the frame are: modulus of elasticity of (205,000) MPa and Poisson's ratio of (0.3). The material used in the numerical analysis was assumed to linear elastic material. The height of the structure is (8 m) and the span is (16 m). Moreover, moment of inertia and cross-section area of the members used are shown in Figure 3, where Kb is the stiffness of the beam-column connection. Two analyses were performed, the first one with rigid connection and the second is with semi-rigid beam-column connection.

The columns of the frame model were divided into 10 elements and the beam was divided into 20 elements. Several attempts were made to find the required number of elements for more accuracy of the results. It was found that the number of elements mentioned is the optimal number that gives the required accuracy, taking into account the time of analysis. The finite element model constructed in ANSYS program is shown in Figure 4 with the boundary conditions and loading.

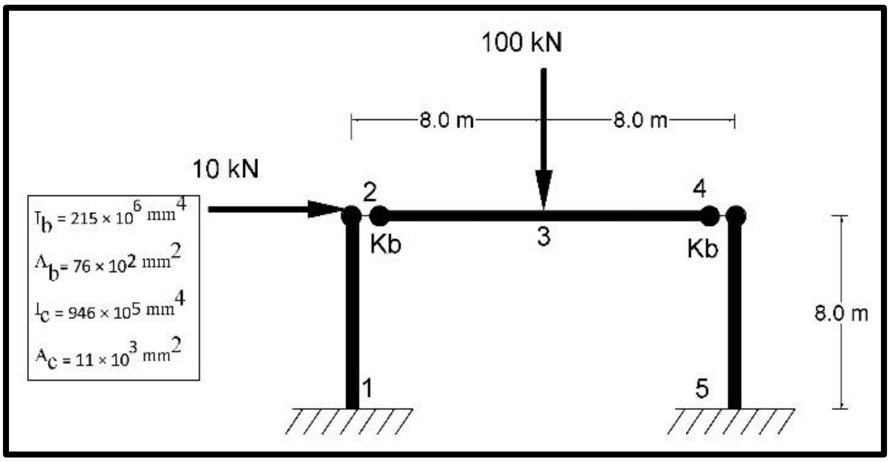

Figure 3. One bay – one story steel frame (Chan and Chui, 2000)

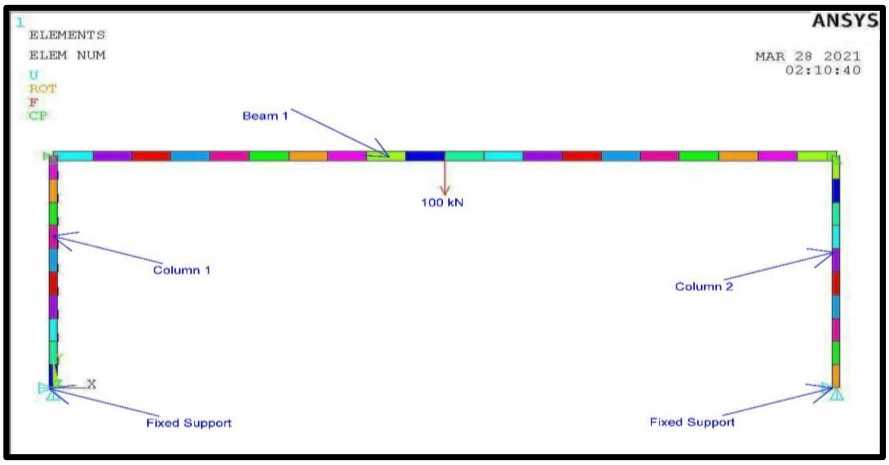

Figure 4. Finite element model of one bay – one story frame

3.2 Results of the numerical models

In rigid case, the beam-column connection was assumed to be fully rigid. The bending moment diagram extracted from finite element analysis was compared with the bending moment diagram obtained from Chan and Chui model. The results showed good agreement between the bending moment diagram of finite element analysis and Chan and Chui analysis. This prove the validation of rigid connection model which is modeled by finite element method. A comparison between the bending moment diagram of finite element method and bending moment diagram obtained from [18] is listed in Table 1. From this table it can be shown that the maximum difference between the two results is about 2.5 %.

Figure 5 shows the load-displacement curve of the finite element method and Chan and Chui model, from this figure the maximum difference between the two results is about 4.7 %, which is a proof for the validity of the results obtained from finite element method.

For the semi-rigid frame, the beam-column connection area was assumed to be semi-rigid connection as can be shown in Figure 3. The beam-column connection was modeled as rotational spring with specified linear stiffness. Moment of inertia and cross-sectional area are illustrated in Figure 3 obtained from [18]. As mentioned before, COMBIN14 element was used for the modeling of the beam-column connection with two coincident nodes. Each pair of nodes in the connection area should be coupled in the x and y direction for stability requirement. The results showed good agreement between the bending moment diagram of finite element analysis and Chan and Chui analysis foe semi-rigid beam-column connection frame. Table 1 lists comparison between the bending moment magnitudes of this study with the bending moment of [18]. It can be noted that the difference percentages of the bending moment at different nodes did not exceed 3.70 %. The load-displacement relationship at mid-span of the beam, obtained from the results of this study along with that reported by Chan and Chui [18] are presented and compared in Figure 6, it can be seen that the difference between the two models is about 1%. Which another proof for the validation with rigid connection modeled using finite element method.

Table 1. Bending moment magnitudes at different nodes of one story – one bay frame rigid connection

Node	Bending Moment kN.m for rigid frame		Difference, %	Bending Moment kN.m for semi-rigid frame		Difference, %
	FEM	Chan and Chui Model		FEM	Chan and Chui Model	
1	51.3	52.2	1.72	32.8	31.7	- 3.35
2 (column)	131.6	127.5	- 3.1	97.2	93.6	- 3.70
2 (beam)	114.5	115.8	1.12	93.8	91.3	- 2.67
3	273.0	280.0	2.5	296.7	296.3	0.0
4 (beam)	144.8	146.3	1.04	102.5	105.7	3.03
4 (column)	145.4	152.6	4.7	107.3	113.6	5.55
5	65.9	67.1	1.8	74.3	71.5	- 3.77

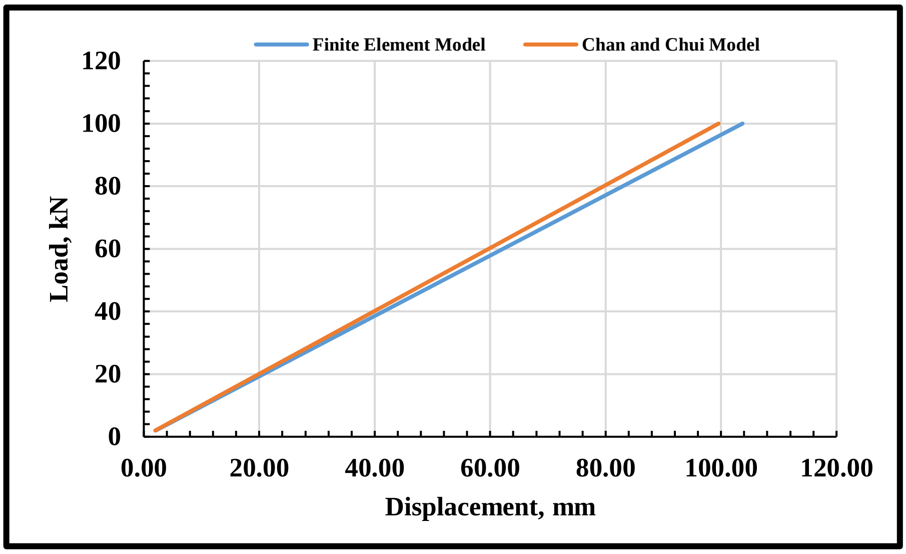

Figure 5. Load – Displacement curve for the rigid model of one story – one bay model

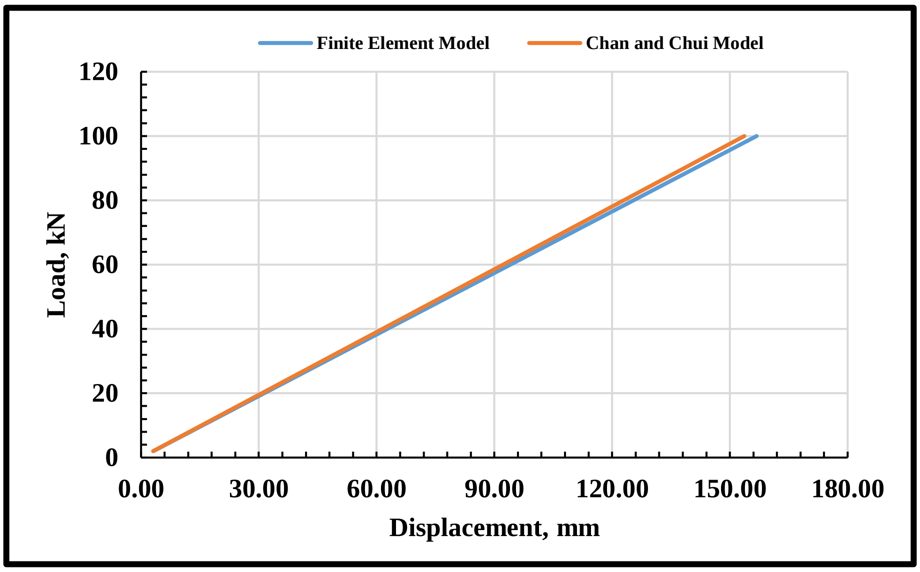

Figure 6. Load – Displacement curve for the semi-rigid model of one story – one bay model

4. Results and discussion of the numerical models

In this section the model of Chan and Chui discussed in the validation model was modeled with various parameters and semi-rigid rotational stiffness. The properties of the semi-rigid rotational stiffness and the material used in the model are same as in the validation model.

4.1 Effect of Semi-Rigid Beam-Column connection on different support type

One-bay one-story frame will be studied with different support type (fixed-fixed and pinned-pinned) in terms of different rotational stiffness values (10EI/L, 15EI/L, 25EI/L and fully rigid case). Figure 3 shows the geometry and loading system of the frame used in the analysis. This frame was first analyzed by [18] using element stiffness formulation with the help of GMNAF-ED program.

4.1.1 Fixed-Fixed Support

In this type of frame supporting, the supports at the end of the columns were modeled to be fixed supports (node 1 and 5) Figure 3. Figure 7 shows the effect of the rotational stiffness of the beam-column connection on the load-displacement curve which was taken from finite element analysis at node 3. This figure shows the increase in the displacement with the increase of the applied load on the frame until reaching maximum load value. The maximum load applied on the frame was 100 kN.

Figure 7 and Table 2 show the changing in the beam-column connection from fully rigid to semi-rigid case with different rotational stiffness values.

Table 2 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (25EI/L, 15EI/L and 10EI/L) makes the stiffness decreases as the displacement increase in all stages of loading and the maximum vertical displacement increases with percentages (4.23%, 6.64% and 9.34%).

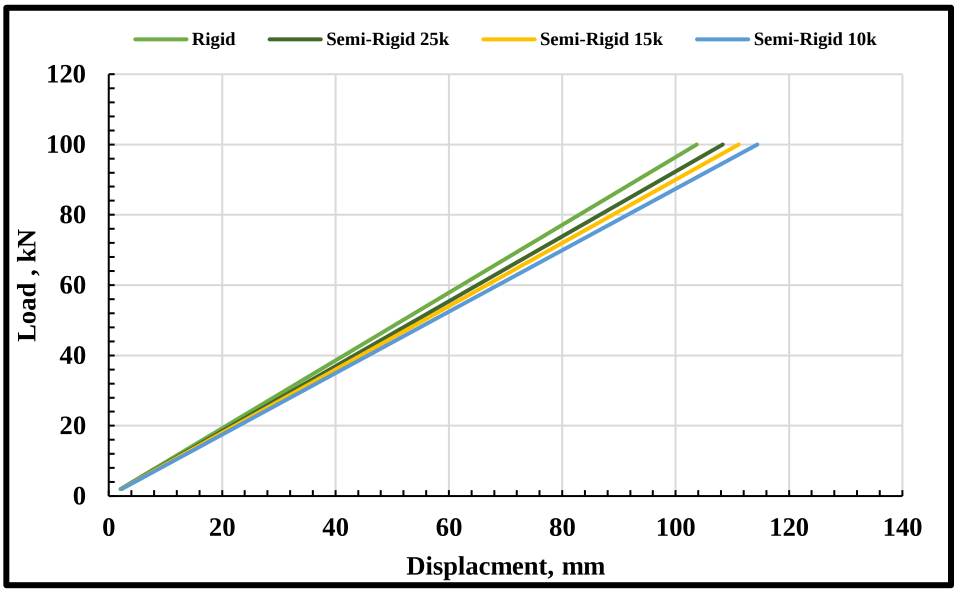

Figure 7. Effect of rotational joint stiffness value on load-vertical displacement at node 3 with fixed-fixed support type

Table 2: Effect of rotational joint stiffness on vertical and horizontal displacement and maximum bending moment

Stiffness	Rigid	25EI/L	15EI/L	10EI/L
Ultimate vertical displacement (mm) at node 3	103	108	111	114
Percentage increase (%)	-	4.23	6.64	9.34
Ultimate horizontal displacement (mm) at node 4	15.43	16.30	16.90	17.53
Percentage increase (%)	-	5.40	8.53	12.01
Maximum Bending Moment kN-m at node 2	114.5	104	101	97
Percentage Decrease (%)	-	9.17	11.79	15.28

The bending moment and shear force diagrams of the frame with different rotational stiffness (10EI/L, 15EI/L, 25EI/L and rigid case) listed in Table 3. As can be shown that the maximum bending moment at the mid span is decreased when the stiffness of the beam-column connection is increased. This can be attributed to the increase in the stiffness of the frame when the stiffness of the beam-column connection is increased which will lead to increase the moment strength capacity at the connection area and decrease the moment at the mid span of the frame. The shear force values at the beam is almost not affected by the changes of the beam-column connection stiffness values. Figure 8 and 9 show the bending moment diagram and the shear force diagram respectively for the for with rotational stiffness of 10EI/L.

On the other hand, the load-horizontal curve of the frame extracted from finite element analysis at node 4 is shown in Figure 10. Figure 10 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (25EI/L, 15EI/L and 10EI/L) leads to increase the maximum horizontal displacement with percentages (5.40%, 8.53% and12.01%).

It can be noted from the above results that changing the beam-column connection from the rigid case to semi-rigid connection has a greater effect on the horizontal displacement as compared with vertical displacement, this behavior can be attributed to that frame in the lateral direction is less stable as compared with the vertical direction. Figure 11 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (25EI/L, 15EI/L and 10EI/L) leads to increase the maximum rotation at node 2 with percentages (2.97%, 4.76% and 6.83%).

The increase in ultimate displacement and rotation can be attributed to the fact that, changing the beam-column connection from rigid to semi-rigid connection with low rotational stiffness result in decrease the strength of the frame and increase of the flexibility, thus the frame exhibit less carrying capacity against the applied loads and increase of the displacement and rotation.

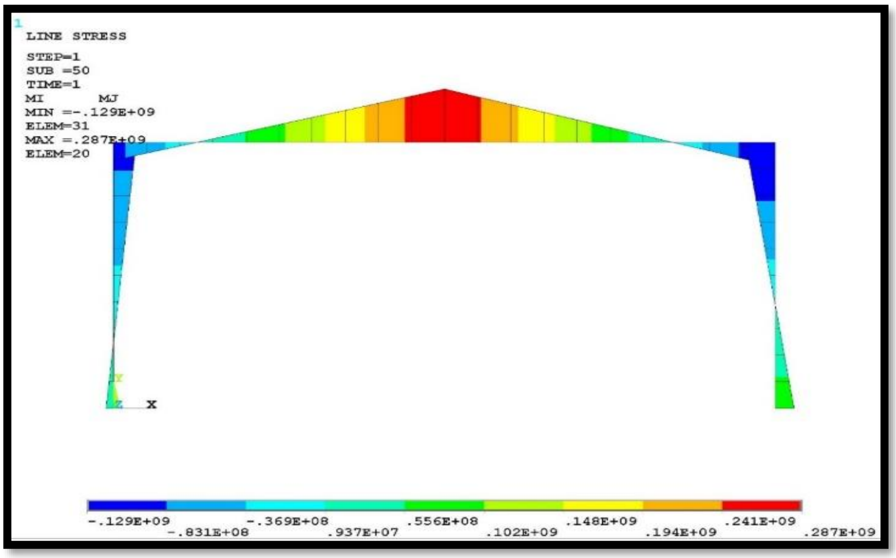

Figure 8. Bending moment diagram with semi-rigid connection of rotational stiffness 10EI/L (fixed –fixed case)

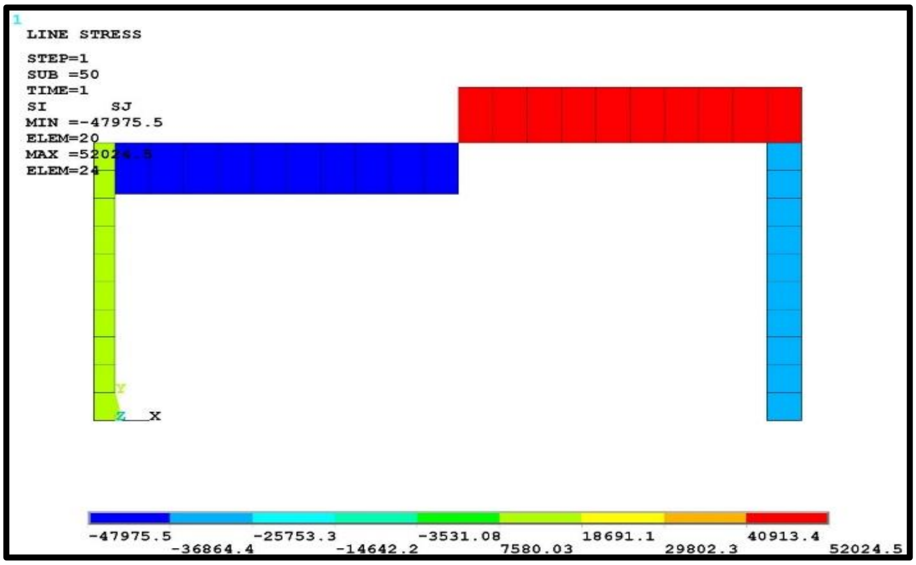

Figure 9. Shear Force diagram with semi-rigid connection of rotational stiffness 10EI/L (fixed –fixed case)

Table 3: Effect of rotational joint stiffness on bending moment values on different nodes of fixed-fixed frame

Node	Bending Moment, kN.m			
	10EI/L	15EI/L	25EI/L	RIGID
1	9	25	33	51
2 (column)	128	131	132	132
2 (beam)	97	101	104	115
3	287	282	279	273
4 (beam)	94	103	102	١٤5
4 (column)	115	125	126	145
5	47	51	56	66

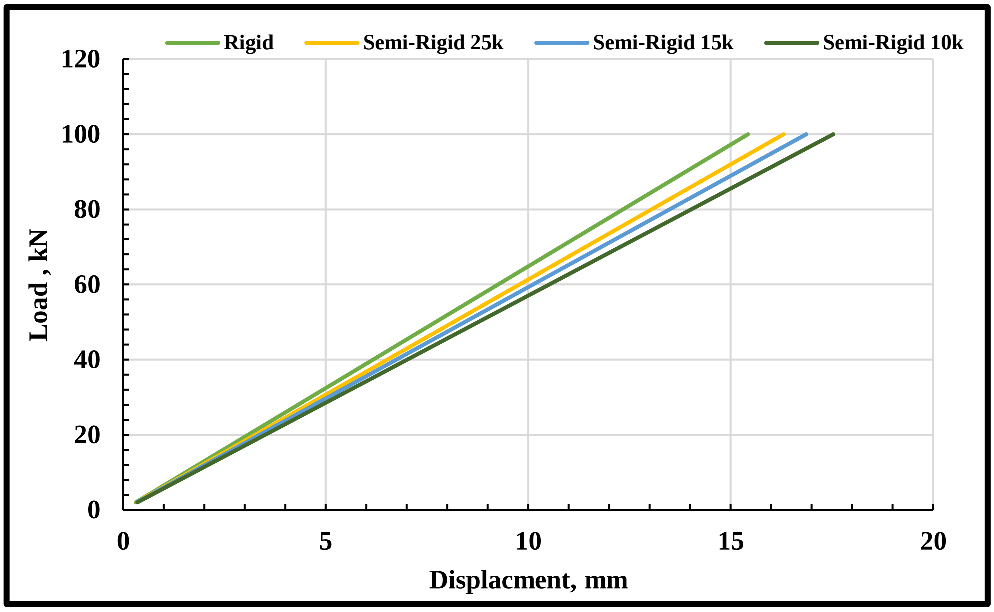

Figure 10. Effect of rotational joint stiffness value on load-horizontal displacement at node 4 with fixed-fixed support type

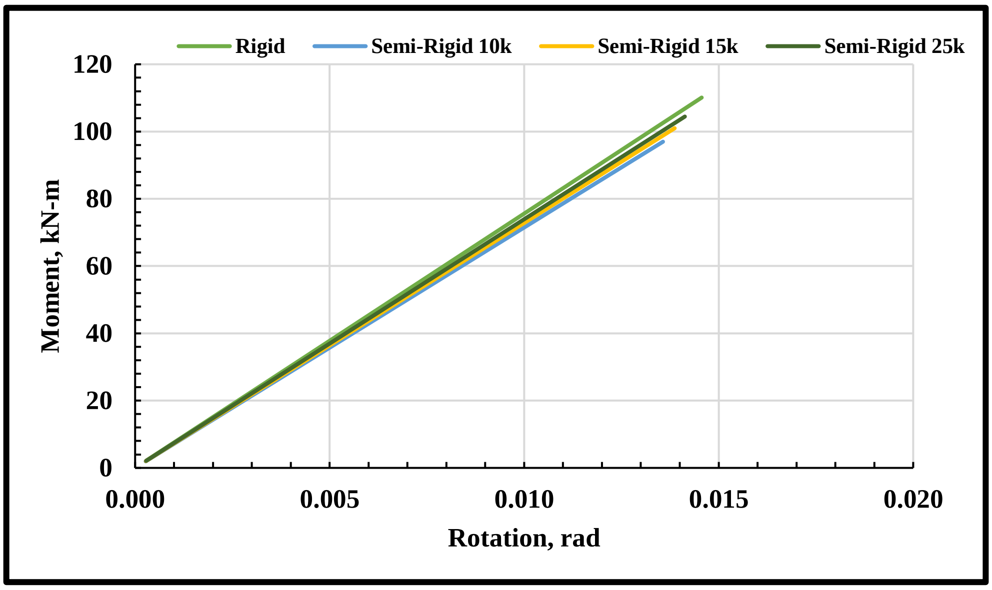

Figure 11. Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for fixed-fixed support type

4.1.2 Pinned-Pinned support

In this type of frame supporting, node 1 and 5 were modeled to be pinned-pinned support type Figure 3. The load-vertical displacement curve of the frame with different rotational stiffness of 10EI/L, 15EI/L, 25EI/L and rigid case is shown in Figure 12. The load-vertical displacement curve shown in Figure 12 was extracted from finite element analysis at node 3 of the frame as shown in Figure 3. Figure 12 shows that the increase in the displacement with the increase of the applied load on the frame until reaching maximum load. The maximum load applied on the frame was 100 kN. The maximum load is reached at 123 mm vertical displacement when the rotational stiffness value is 10EI/L, while in the fixed-fixed case, the displacement value at the maximum applied load is 114 mm at the same rotational stiffness. The difference is about 7.5 % between the fixed-fixed case and pinned support type case, which indicate the semi-rigid beam-column connection can increase the vertical displacement of the frame when the support is changed from fixed to pinned support.

Figure 12 and Table 4 show the changing in the beam-column connection from fully rigid to semi-rigid case with different rotational stiffness values. Table 4 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (25EI/L, 15EI/L and 10EI/L) makes the stiffness decreases as the displacement increase in all stages of loading and the maximum vertical displacement increases with percentages (3.13%, 4.96% and 7.04%) when compared with the rigid case.

Table 4: Effect of rotational joint stiffness on vertical and horizontal displacement and maximum bending moment

Stiffness	Rigid	25EI/L	15EI/L	10EI/L
Ultimate vertical displacement (mm) at node 3	113.90	117.57	119.85	122.53
Percentage increase (%)	-	3.13	4.96	7.04
Ultimate horizontal displacement (mm) at node 4	64.77	69.51	72.67	76.63
Percentage increase (%)	-	6.82	10.87	15.47
Maximum Bending Moment kN-m at node 2	73.9	68.9	65.9	62.3
Percentage Decrease (%)	-	6.69	10.8	15.7

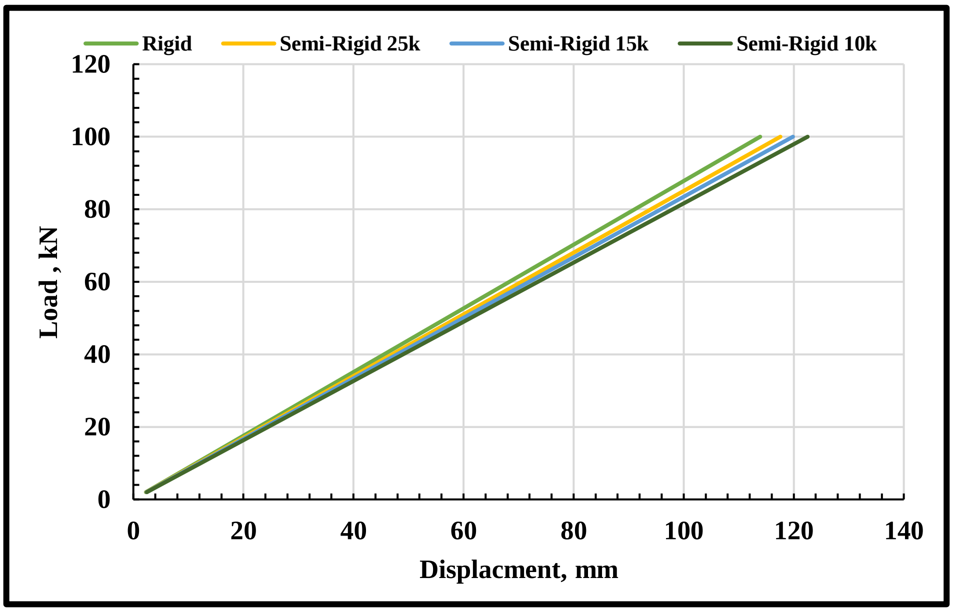

Figure 12. Effect of rotational joint stiffness value on load-vertical displacement at node 3 pinned-pinned support type

The bending moment values with rotational stiffness of 10EI/L, 15EI/L, 25EI/L and rigid case are listed in Table 5 for different nodes on the frame. As can be shown, the maximum bending moment values increased when the stiffness of beam-column connection is increased at the joint. This is relative to the influence of large stiffness at the beam-column connection which can behave as fixed point on the frame, which will increase in the maximum capacity of bending moment at beam-column connection area and the whole frame. This will lead to increase the carrying capacity against applied loads of the frame and vice versa.

Moreover, decrease the maximum displacement of the frame at the mid span of the beam is parallel to the increase in the rotational stiffness of the beam-column connection. The semi-rigid connection can increase the flexibility of the frame and behave as pinned connection at the joints. This will lead to decrease the moment capacity at the joint area. Moreover, changing the support type from fixed to pinned support with rotational stiffness of 10EI/L can decrease the moment value at the joints by 9 % as listed in Table 3 and 5. For the shear force values of pinned-pinned support type case are also not listed in Table 5, this is due to the shear force values at the beam is almost not affected by the changes of the beam-column connection stiffness values. Figure 13 and 14 show the bending moment diagram and the shear force diagram of the frame respectively with rotational stiffness of 10EI/L.

On the other hand, the load-horizontal displacement curve of the frame is shown in Figure 15. This figure shows the effect of different rotational stiffness on the behavior of the frame in the horizontal displacement. The results of this figure was taken from finite element analysis at node 4 in Figure 3.

Figure 15 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (25EI/L, 15EI/L and 10EI/L) leads to increase the maximum horizontal displacement with percentages (6.82%, 10.87% and 15.47%).

It can be noted from the above results that changing the beam-column connection from the rigid case to semi-rigid connection has a greater effect on the horizontal displacement as compared with vertical displacement, which is differ from fixed-fixed support type by about 63%, this indicate that changing from fixed-fixed support to pinned-pinned support can affect the horizontal displacement, more than the vertical displacement of the frame this is relative to the effect of support type of the frame on the stability of the frame conjugated with the effect of semi-rigid beam-column connection. Figure 16 shows the moment-rotation curve of the frame at node with different beam-column connection stiffness (10EI/L, 15EI/L and 25EI/L). Figure 16 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (25EI/L, 15EI/L and 10EI/L) leads to increase the maximum moment with percentages (5.53%, 7.46% and 8.09%).

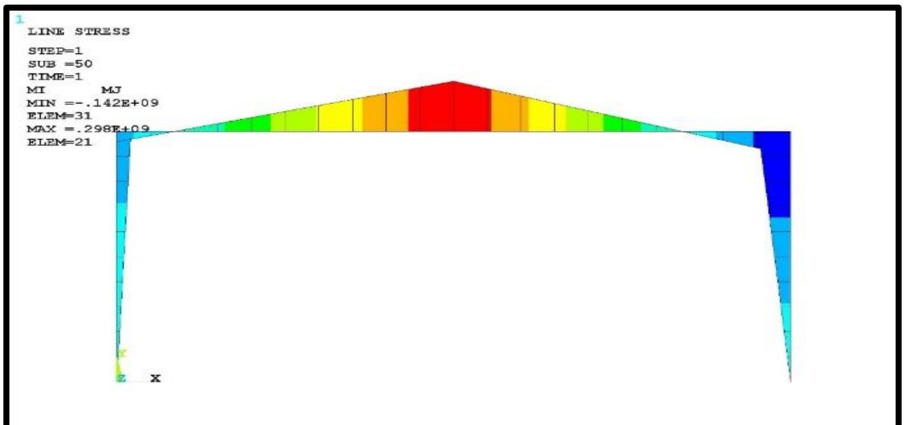

Figure 13. Bending moment diagram with semi-rigid connection of rotational stiffness 10EI/L with pinned-pinned support type

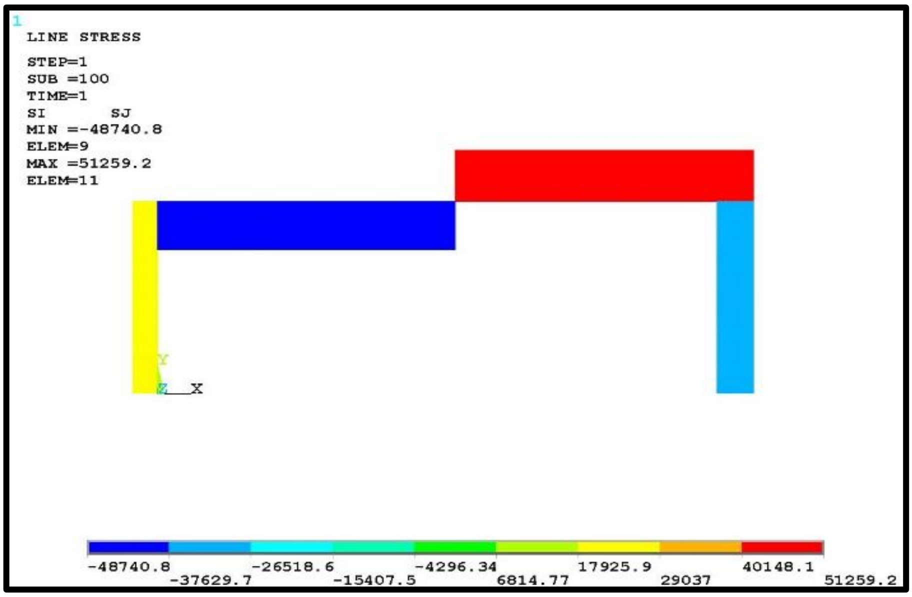

Figure 14. Shear Force diagram with semi-rigid connection of rotational stiffness 10EI/L (pinned –pinned case)

Table 5: Effect of rotational joint stiffness on bending moment values on different nodes of pinned-pinned frame

Node	Bending Moment, kN.m			
	10EI/L	15EI/L	25EI/L	RIGID
1	0	0	0	0
2 (column)	-62	-64	-70	-68
2 (beam)	-61	-66	-69	-65
3	298	294	291	286
4 (beam)	-122	-126	-128	-132
4 (column)	-121	-127	-129	-131
5	0	0	0	0

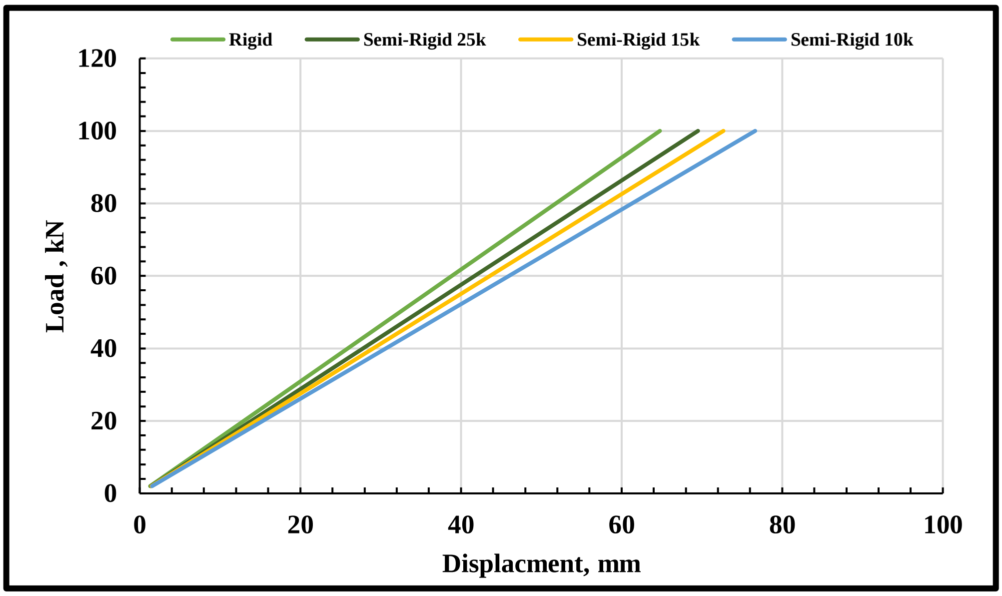

Figure 15. Effect of rotational joint stiffness value on load-horizontal displacement at node 4 pinned-pinned support type

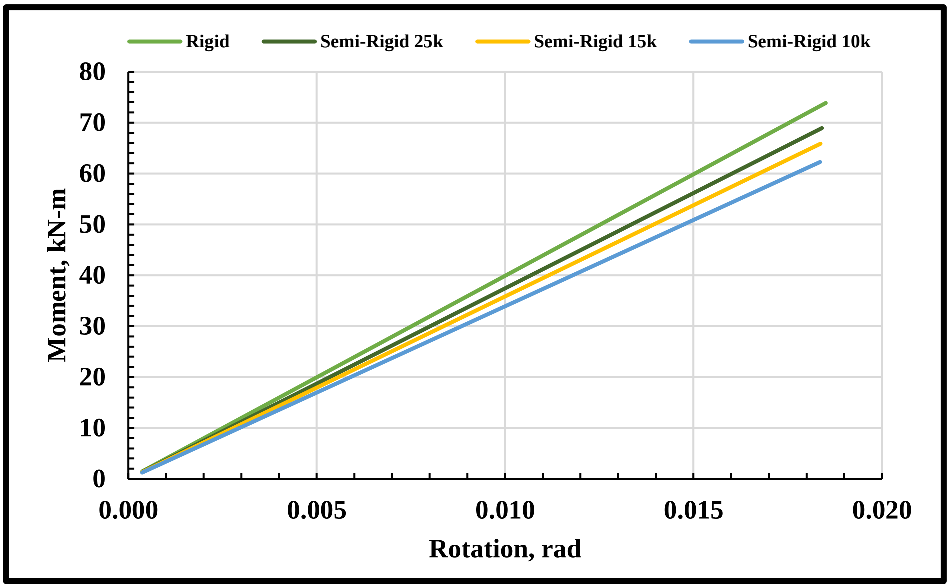

Figure 16. Moment-Rotation curve of semi-rigid beam-column connection at node 2, with different stiffness values for pinned-pinned support type

4.2 Effect of Semi-Rigid Beam-Column Connection on one-bay three-story frame

The effect of semi-rigid beam-column connection on the frame in terms of different number of stories was studied in this article. The model mentioned in section 5.1.1 [18] was considered for multi-story study of semi-rigid beam-column connection of linear behavior. To represent the effect of semi-rigid beam-column connection, three rotational stiffness were used (4EI/L, 7EI/L, 10EI/L as well as the fully rigid case).

The geometry, loading condition and the location of the semi-rigid beam-column connection are illustrated in Figure 17. The frame was modeled in finite element method in ANSYS software using BEAM3 for the modeling of beams and columns and COMBIN14 for modeling the beam-column connection area. The ANSYS model used in this study is shown in Figure 18.

The load-vertical displacement curve of the frame is shown in Figure 19. This figure shows the effect of changing the beam-column connection stiffness on the behavior of multi-story frame. The data of this curve was extracted from the finite element analysis at node 10 as shown in Figure 17. This figure shows the increase in the displacement with the increase of the applied load on the frame until reaching maximum load value. Figure 19 and Table 6 show the changing in the beam-column connection from fully rigid to semi-rigid case with different rotational stiffness values. As can be shown from Table 6 the maximum load is applied on the frame is decreased when the rotational stiffness of the frame is decreased this is conjugated with the increase of the vertical displacement of the frame. This can indicate the decrease of the strength capacity of the frame with the decrease of the rotational stiffness of the frame due to the decrease of the stability of the frame.

Table 6 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (10EI/L, 7EI/L and 4EI/L) leads to increase the maximum vertical displacement with percentages (11.71%, 14.78% and 20.33%) respectively.

The bending moment diagram of the numerical models with different rotational stiffness (4EI/L, 7EI/L, 10EI/L and rigid case) respectively are listed in Table 7 in various nodes of the frame. As can be shown, the maximum bending moment values increased when the stiffness of beam-column connection is increased at the joint area. This is relative to the influence of large stiffness at the beam-column connection which can behave as fixed point of the frame, this will lead to increase in the maximum bending moment at beam-column connection area. The results showed that the maximum bending moment at the mid span of the second and third story is decreased when the stiffness of the beam-column connection is 4EI/L, while in the rigid case the maximum bending moment is increased at mid the span. This is indicating the influence of the beam-column connection on the moment bending diagram distribution on the frame. Moreover, the maximum bending moment at the mid of the third story is increased when the stiffness of the beam-column connection is increased.

Figure 20 and 21 show the bending moment and shear force diagrams respectively for the three story frame with rotational stiffness of 4EI/L.

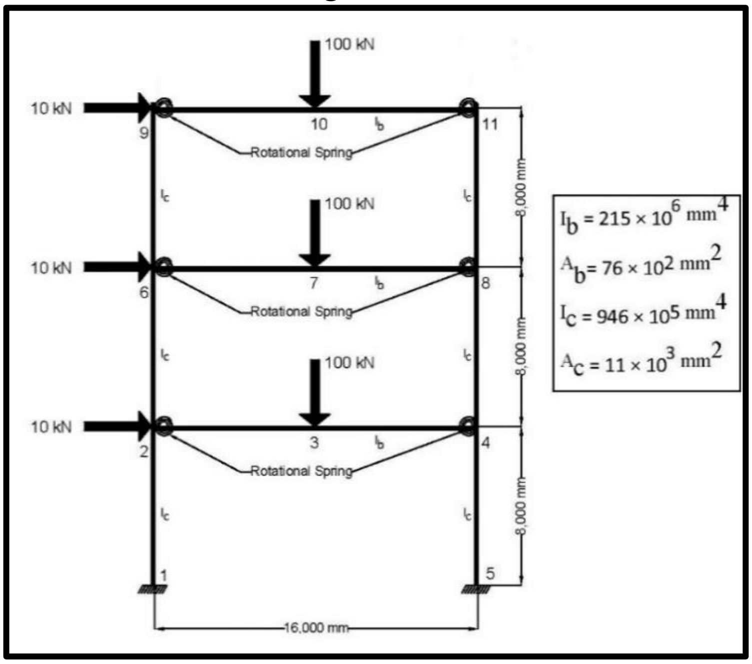

Figure 17. Geometry and loading of braced one-bay three-story frame

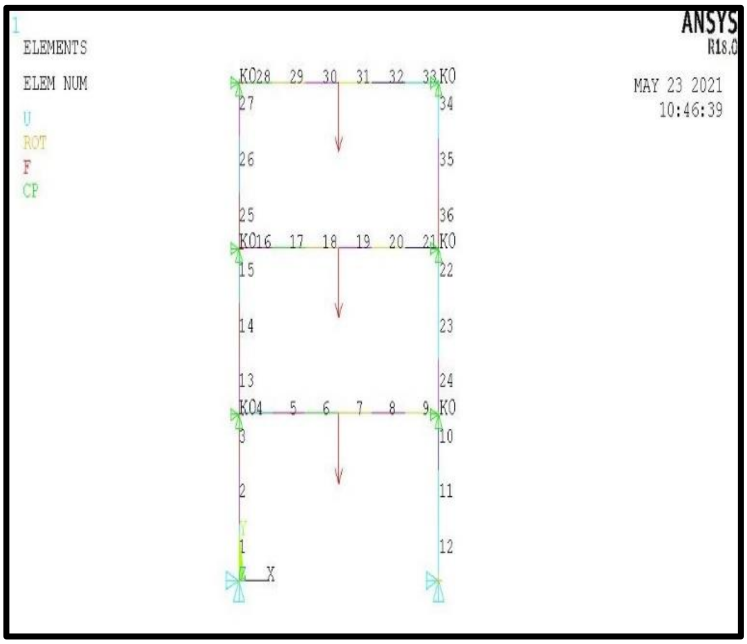

Figure 18. Modelling of one-bay three-story frame in ANSYS

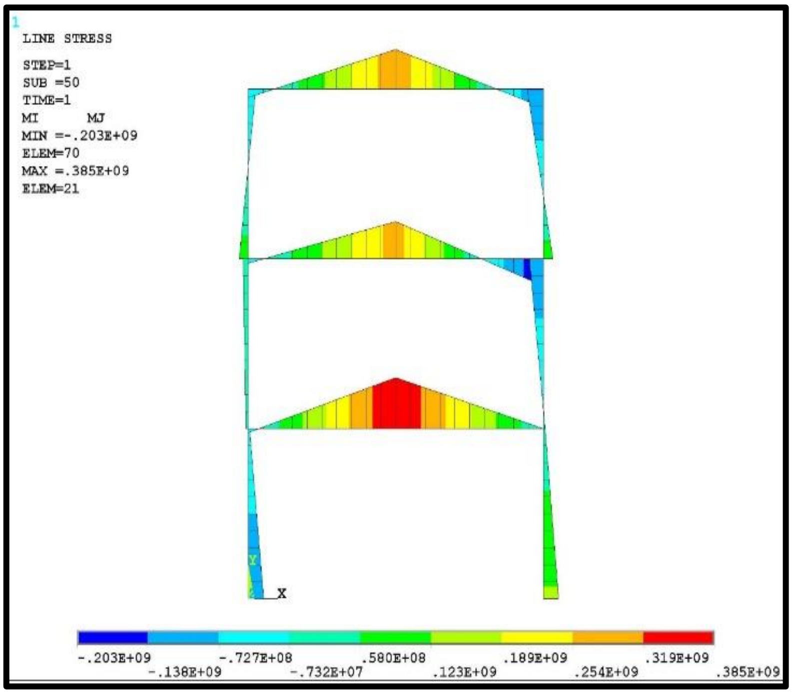

Figure 20. Bending moment diagram with semi-rigid connection of rotational stiffness 4EI/L for one-bay three-story frame

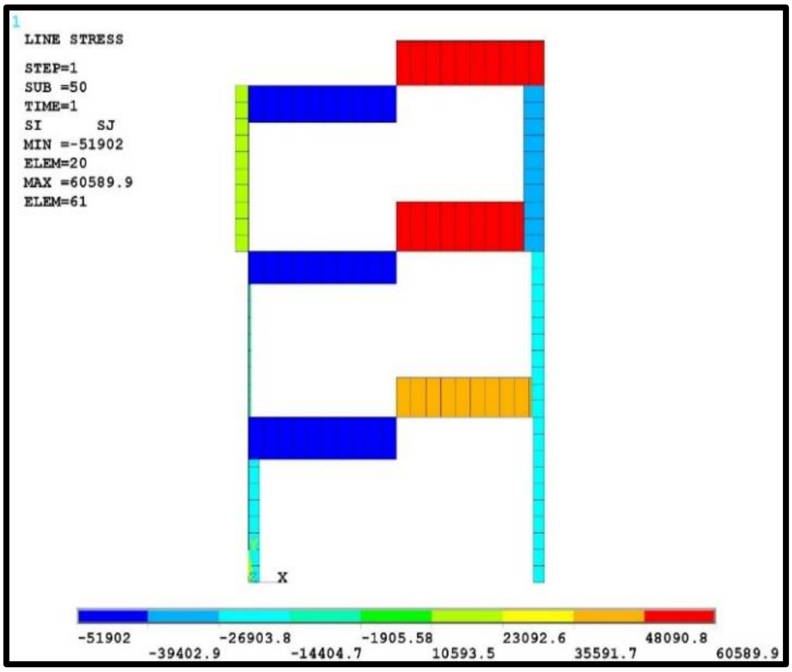

Figure 21. Shear force diagram with semi-rigid connection of rotational stiffness 4EI/L for one-bay three-story frame

Table 6: Effect of rotational joint stiffness on vertical and horizontal displacement and on the maximum moment of three-story frame

Stiffness	Rigid	10EI/L	7EI/L	4EI/L
Maximum Load (kN)	173	171	170	164
Percentage Decrease (%)	-	1.16	1.73	4.05
Ultimate vertical displacement (mm) at node 10	98	111	115	123
Percentage increase (%)	-	11.71	14.78	20.33
Ultimate horizontal displacement (mm) at node 11	144	185	201	442
Percentage increase (%)	-	22.16	28.36	67.42
Maximum Bending Moment kN-m at node 9	110	91.6	84	64
Percentage Decrease (%)	-	17.30	23.64	41.82

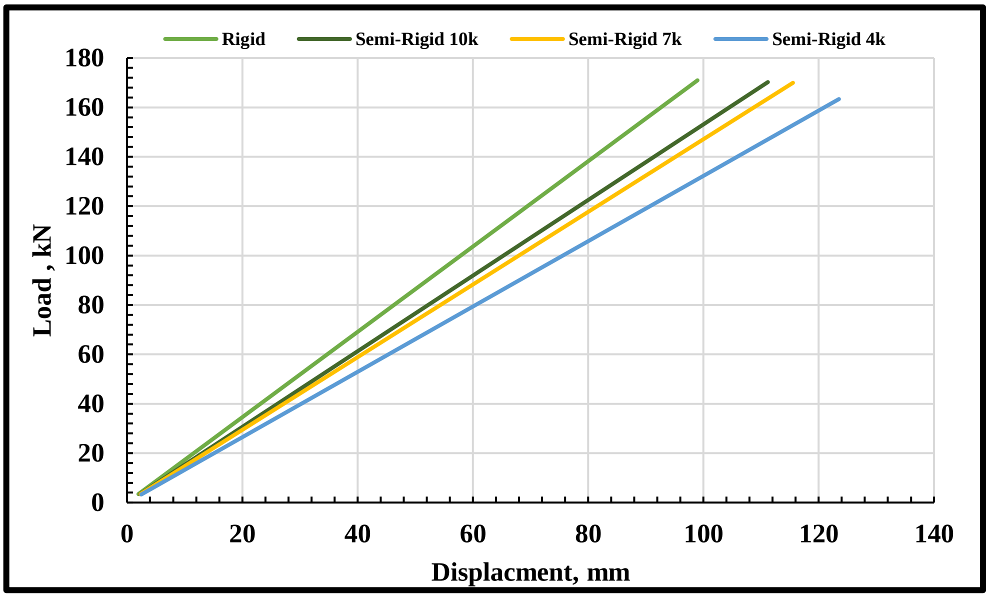

Figure 19. Load-displacement curve in y-direction at node 10 with different stiffness values of one-bay three-story frame

Table 7: Effect of rotational joint stiffness on bending moment values on different nodes of three-story frame

Node	Bending Moment, kN.m			
	4EI/L	7EI/L	10EI/L	RIGID
11	-121	-126	-129	-142
10	254	287	281	285
9	-65	-82	-94	-131
8	-182	-186	-185	-188
7	223	261	269	265
6	-66	-86	-94	-118

Figure 22 shows the effect of rotational stiffness on the load-displacement curve in the horizontal direction which was taken from the finite element analysis at node 11 in Figure 36. Figure 22 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (10EI/L, 7EI/L and 4EI/L) leads to increase the maximum horizontal displacement with percentages (22.16%, 28.36% and 67.42%).

It can be noted from the above results that the semi-rigid beam-column connection has a great influence on the horizontal displacement of the frame if compared with vertical displacement. This indicate the effect of the semi-rigid beam-column connection with the increase of stories of the frame.

Figure 23 shows the moment-rotation curve of the frame at node 9 with different beam-column connection stiffness (4EI/L, 7EI/L and 10EI/L). Figure 23 shows that changing the beam-column connection from rigid to semi-rigid connection of rotational stiffness value (10EI/L, 7EI/L and 4EI/L) leads to increase the maximum horizontal displacement with percentages (15.87%, 22.70% and 45.60%).

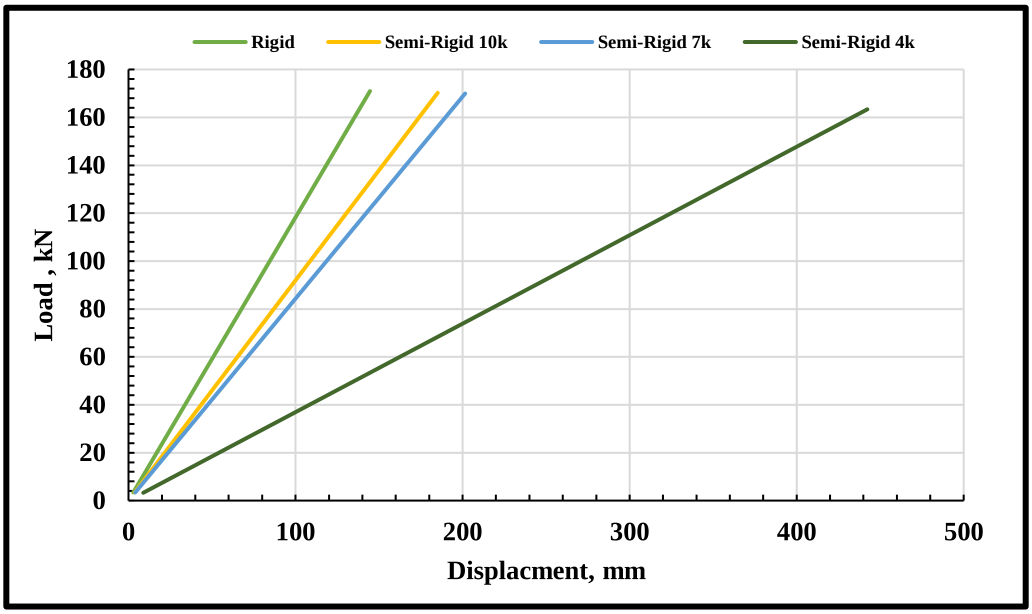

Figure 22. Load-displacement curve in x-direction at node 11 with different stiffness values of one-bay three-story frame

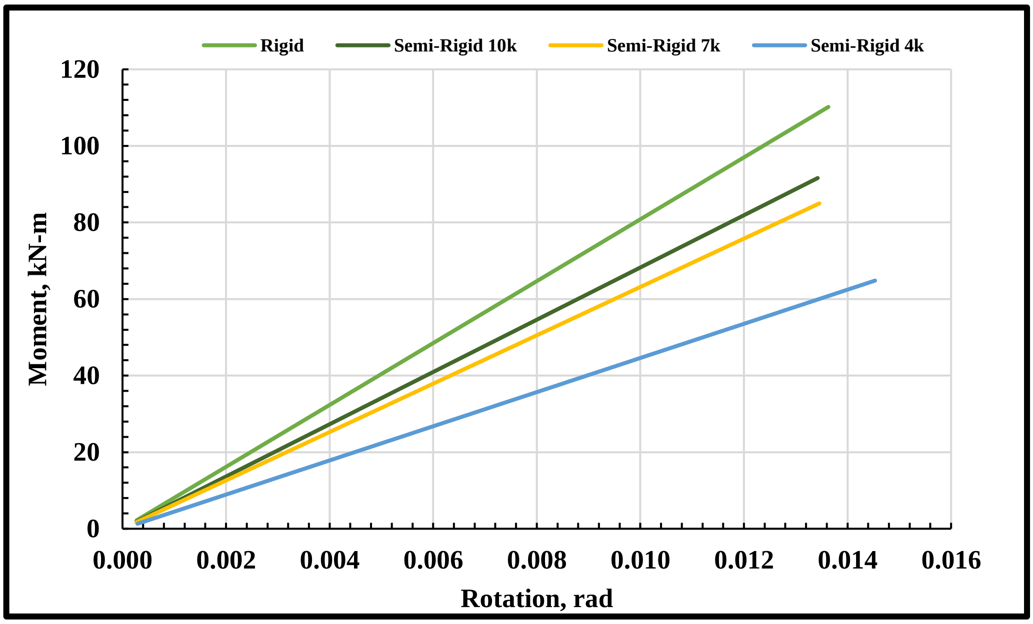

Figure 23. Moment-Rotation curve of semi-rigid beam-column connection at node 9, with different stiffness values for one-bay three-story frame of Chan and Chui model

5. Conclusion

According to the numerical analysis presented in the study the following were concluded:

1- The behavior of frames with semi-rigid beam-column connection analyzed using finite element method can be with a good agreement with the results of previous studies.
2- In general, the increase in the stiffness of the semi-rigid beam-column connection can increase the stiffness of the frame and increase the strength capacity of the frame.
3- The results of the numerical models showed that, changing the connection from rigid to semi-rigid connection with linear rotational stiffness of (25EI/L, 15EI/L and 10EI/L) can increase the maximum vertical displacement with a percentage of (4.23, 6.64 and 9.34) % respectively for fixed-fixed support type while a percentage of (3.13, 4.96 and 7.04) % respectively for pinned-pinned support type.
4- In three story frame, changing the rotational stiffness from rigid to semi-rigid connection can increase the horizontal displacement of the frame be a percentage of (22.16, 28.36 and 67.42) % for rotational stiffness of 10EI/L, 7EI/L and 4EI/L respectively.
5- Changing the number of stories from one story to three stories can decrease the vertical displacement of the top story by a percentage of 2.70 %, if the rotational stiffness of the beam-column connection is 10EI/L.
6- In multistory frame, the bending moment of the last and the first floor are the most affected by the changes in the stiffness value of the beam-column connection.

References

[1] U.V.Dave, and G.M. Savaliya, “Analysis and design of semi-rigid steel frames,” in Structures Congress 2010 (pp. 3240-3251), 2010.

[2] J. A. Khalifa, “Design optimization of semi rigid steel framed structures to AISC-LRFD using Harmony search algorithm,” M.Sc. Thesis, The Islamic University of Gaza, Gaza, Palestine, 2011.

[3] AISC Manual of steel construction-Load and resistance factor design. American Institute of Steel Construction, (2010).

[4] S. W. Jones, P. A. Kirby, and D. A. Nethercot, “Effects of semi-rigid connections on steel column strength,” Journal of Constructional Steel Research, vol. 2, no. 1, pp. 44–45, Jan. 1982.

[5] S. O. Degertekin, and M. S. Hayalioglu, M. S., “Design of Non-linear Semi-Rigid Steel Frames with Semi-Rigid Column Bases,” Electronic Journal of Structural Engineering, Vol. 4, pp 1- 16, 2004.

[6] A. Öztürk and M. Seçer, “An Investigation for Semi-Rigid Frames by Different Connection Models,” Mathematical and Computational Applications, vol. 10, no. 1, pp. 35–44, Apr. 2005.

[7] Ibrahim, Amer M., and Murtada A. Ismael. "Post buckling behavior of prismatic structural steel members with semi rigid connections," Engineering and Technology Journal, 34, no. 6, pp. 1116-1130, 2016.

[8] Mohammed, Douaa Raheem, and Murtada A. Ismael, "Effect of Semi-Rigid Connection on Post-Buckling Behaviour of Frames using Finite Element Method," Civil Engineering Journal 5, no. 7, pp. 1619-1630, 2019.

[9] S. L. Chan and S. H. Cho, “SECOND-ORDER P-Δ-δ ANALYSIS AND DESIGN OF ANGLE TRUSSES ALLOWING FOR IMPERFECTIONS AND SEMI-RIGID CONNECTIONS,” Volume 1 Number 1, pp. 157–172, 2005.

[10] S. O. Degertekin, and M. S. Hayalioglu, M. S., “Design of Non-linear Semi-Rigid Steel Frames with Semi-Rigid Column Bases,” Electronic Journal of Structural Engineering, Vol. 4, pp 1- 16, 2004.

[11] M. Brognoli, P. Gelfi, R. Zandonini, and M. Zanella, “Optimal design of semi-rigid braced frames via knowledge-based approach,” Journal of Constructional Steel Research, vol. 46, no. 1–3, pp. 365–366, Apr. 1998.

[12] Del Savio, Alexandre A., S. A. L. Andrade, P. C. G. S. Vellasco, and Luiz Fernando Martha. "Genetic algorithm optimization of semi-rigid steel structures." In Proceedings of 8th International Conference on the Application of Artificial Intelligence to Civil, Structural and Environmental Engineering, AICC, Roma, pp. VIII-24.1–VIII-24.16. 2005.

[13] A. Csébfalvi, and G. Csébfalvi, "Effect of semi-rigid connection in optimal design of frame structures," in Proceedings of the 6th World Congress of Structural and Multidisciplinary Optimization (WCSMO-6), Rio de Janeiro, vol. 30. 2005.

[14] A. Csébfalvi, "Optimal design of frame structures with semi-rigid joints," Periodica Polytechnica Civil Engineering, vol. 51, no. 1, p. 9, 2007.

[15] S. Hernández, A. N. Fontán, J. C. Perezzán, and P. Loscos, "Design optimization of steel portal frames," Advances in Engineering Software, vol. 36, no. 9, pp. 626–633, Sep. 2005.

[16] V. D. Kapgate, and K. N. Kadam, "Response of semi rigid connections on frame behaviour," Int. J. Recent Innov. Trends Comput. Commun. 3, no. 2, pp. 37-40, 2015.

[17] Ansys," ANSYS Structural Analysis Guide", Release 12.0, U.S.A., Copyright 2012.

[18] Chan, Siu-Lai, and Pui-Tak Chui, eds. Non-linear static and cyclic analysis of steel frames with semi-rigid connections. Elsevier, 2000.