EFFECT OF COLUMN BASE FLEXIBILITY ON DEMANDS OF PIPES OF LOCATED ON PIPE SUPPORTING STRUCTURES

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ABSTRACT

The effect of column-base flexibility on the response of pipes in steel piperacks is assessed through analysis. The response of pipes in two piperacks with 4 and 8 span lengths is investigated through linear time history analysis. Each structure is modeled with seven types of column base flexibility including fixed, pinned and the values of zero, 450, 5000, 25000, 45000, 64000 kN.m/rad of the rotational stiffness of linear springs that represent the base flexibility. Linear time history analysis show that increasing base fixity generally reduces pipe stress but does not reduce responses from rotational stiffness of 25000 kN.m/rad to fully fixed by more than 5%. This limit of rotational stiffness correspond to boundry of 30EI/H of Eurocode3 in which do not change the column ultimate strength by more than 5% or column lateral displacement under service load by more than 10% from the fixed base case. Hence, it has been suggested that Eurocode3 recommendation can be considered for fixed-base case for this structures.

Keywords: Pipe; Piperack; Column base; Flexibility

1. INTRODUCTION

Steel piperack are structures that support pipes used in refiners and petrochemical plants in order to enhance their reach to site's different parts. One of the most important connections in this structures are column base plate connections. The rotational stiffness of these connections at the base of a column affects the force and displacement demands on frame elements during an earthquake. A many studies have been conducted to evaluate the effect of base flexibility. Maan and Osman [1] modelled five and ten story buildings with different column base flexibility values. They showed that while frame displacements increased with increasing base flexibility, the frame displacement capacity also increased. The location of inelasticity could change with base flexibility and could increase at some levels. Aviram et al. [2] showed that increasing base flexibility increased displacement demands and concentrated deformations in the first story of a three story building. Ruiz-Garcia and Kanvinde [3] showed that ideal pinned based connection leads to larger interstory drift demands but smaller residual drift demands compared to the fixed base condition. Zareian and Kanvinde [4] found that increasing base flexibility results in the collapse mechanism with large deformations concentrated in a fewer stories in 2-, 4-, 8-, and 12-story steel moment resisting frames. Borzouie et al. [5] evaluated the effects of column base rotational stiffness on the seismic demand of single storey frames with a range of periods using linear and nonlinear time history analysis. Linear and nonlinear spectral analyses showed that increasing base flexibility generally increases frame lateral displacement and top moment of the column. Furthermore, moments at the top of the columns and the nonlinear base rotation may also increase with increasing base flexibility, especially for shorter period structures. This paper assesses the effect of changing of rotational stiffnesses on stress response of pipes in defferent cases of U-bolt rings in steel piperacks with span lengths of 4 and 8 meter. Stress response is expressed to form of average of von mises stress of pipe elements to allowable stress of pipe material.

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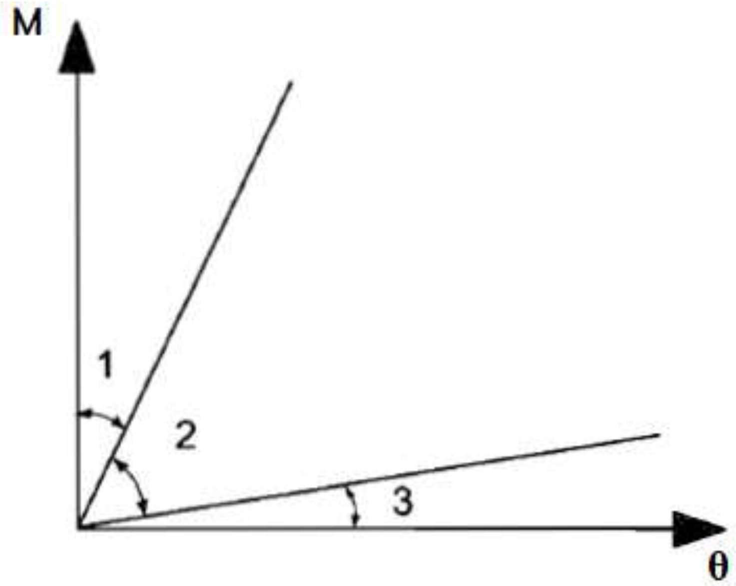
2. CLASSIFICATION BY STIFFNESS OF COLUMN BASE CONNECTION

Eurocode3 [6] defines base connections into categories depending on k_θ (k_θ may be defined as the base moment, M, divided by the base rotation,)as shown in Figure 1. Here, k_θ is normalized by EI/H, where EI is the flexural stiffness of the column section and H is the height of the column to the point of inflection. according to Jaspart et al. [7] Column bases in sway frames with rotational stiffness (k_θ) of $30EI/H$ or more do not change the column ultimate strength by more than 5% or column lateral displacement under service load by more than 10% from the fixed base case. In this case, the connection may be considered to be fully rigid. Base connection stiffness values lower than 0.5 EI/H capture the fully pinned condition and connections may be modelled as being fully pinned. It is suggested that if the real rotational stiffness is between these two boundaries, then rotational stiffness should be explicitly considered in the analyses.



Zone 1: Rigid, $k_\theta \geq 30\ (\frac{EI}{H})_{col}$

Zone 2: Semi rigid, $0.5\ (\frac{EI}{H})_{col} < k_\theta < 30(\frac{EI}{H})_{col}$

Zone 3: Pinned, $k_\theta \leq 0.5(\frac{EI}{H})_{col}$

Figure 1. Eurocode 3 [6] column base rotational stiffness boundaries

3. PIPE SUPPORTING STRUCTURES CONSIDERED IN THIS STUDY

3.1 Building Discription

Two structures models having different span lengths (4 and 8 meter) are shown in Figures 2 and 3. The piperack structure have beams at two levels for carrying more pipes. The structure for which the results of analyses are presented in this paper includes two main lateral frames at 4.0 and 8.0 m spacing, giving a total length of 48.0 m for the whole piperack structure. The structure supports a set of pipes at two levels with 4.0m and 5.2 m heights. There is no bracing in longitudinal and transverse directions.

The pipes cross-sectional dimensions were considered as 70.0*2.6 mm, 102.0*2.9 mm, 159.0*4.0 mm, 194.0*4.5 mm, 245.0*5.0 mm, 324.0*5.6 and 419.0*6.3 mm. Because of numerous number of pipes, in this study it was decided to develop the structural models in two group. In half of them pipes with diameters of 70.0 mm 102.0mm, 159.0 mm and 324.0 mm were used, and in the other half pipes with diameters of 194.0 mm 245.0mm and 419.0 mm were used with Approximately equal weight ratio. just one branch line of large diameter pipes were supported on upper level of frame structures. Also to find out the effects of the rotational stiffness, result were derivated for four U bolt links including the rods of 4.0 mm, 8.0 mm, 12.0 mm and 16.0 mm diameters. It was assumed that the end conditions of all pipes supported on frame structure both ends are fixed. The total length of the piping supported by the 48.0 m piperack was assumed to be 52.0 m, letting the pipe to pass 2.0 m over with respect to each of the end frames of the piperack structure.

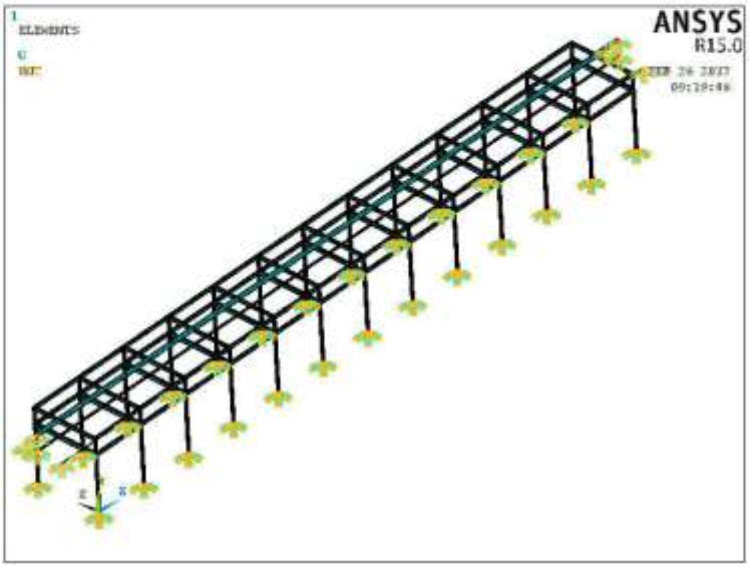


Figure 2. Steel pipe supporting structure with span lengths 4 meter and pipes 70-102-159-324 located on it.

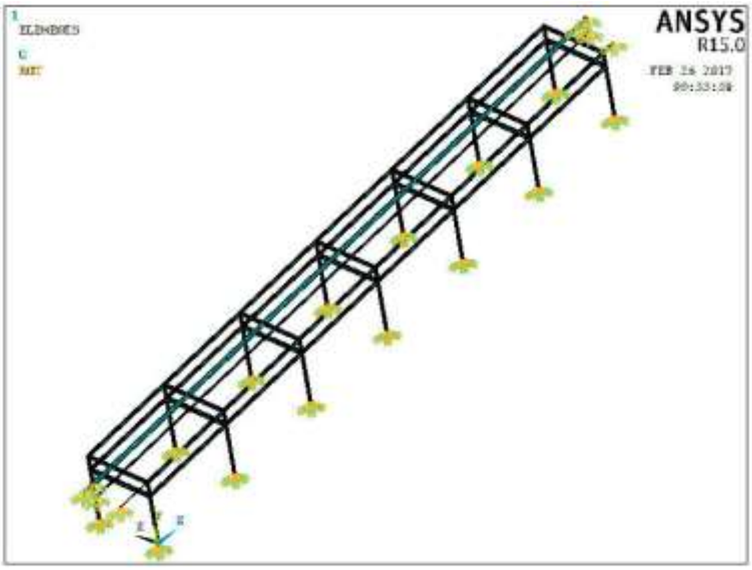


Figure 3. Steel pipe supporting structure with span lengths 8 meter and pipes 70-102-159-324 located on it.

3.2 Modeling of Column Base Connection

Column base flexibility was incorporated in the numerical models through rotational springs at the column base. The rotational springs are modelled as linear springs with seven different levels of stiffness fully pinned and fully fixed base conditions as well as the rotational stiffnesses of 450, 5000, 25000, 45000 and 64000 kN.m/rad.

3.3 Modeling of Pipes to Structure Connection

Pipes are connected to structure by U-bolt rings in steel piperacks of this study. For considering of rings in structure, initially lateral stiffness of rings are obtained by finite element analysis and therefore linear spring is connected to pipe laterally. Finite element model as which pipe and ring are modelled in together as is shown in figure 4. The length of pipes is considered 2.0 meter because of prevention of effectness of end condition of pipe on stiffness resultant. The side of connection of pipe to ring is applied under lateral displacement and other side of pipe are fixed. The both of ends of ring are considered fixed. The lateral stiffness of ring is considered equal to sum of reaction forces of both ends of ring.

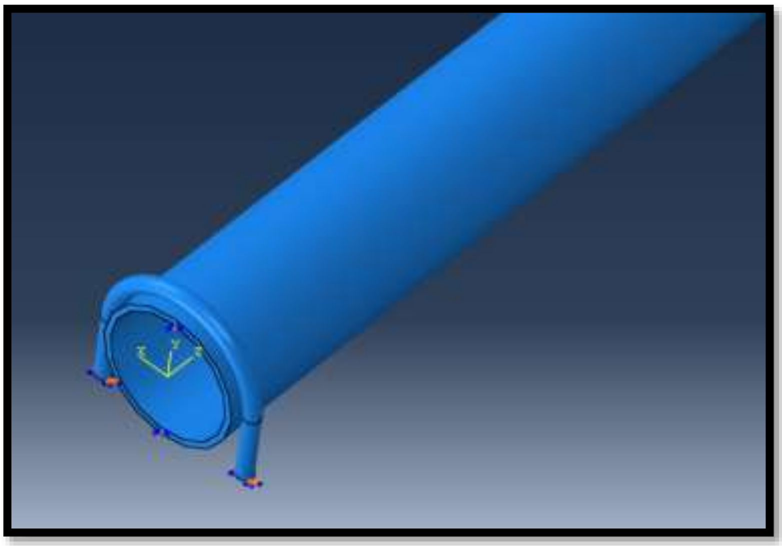


Figure 4. Modeling of pipe and ring

4. EARTHQUAKES RECORDS FOR THE TIME HISTORY ANALYSES

The acceleration records of two earthquakes including kobe and tabas were used for time history analyses this study. A sample of these records, which is related to the KJM-000 component of the Kobe earthquake, is shown in Figure 5.

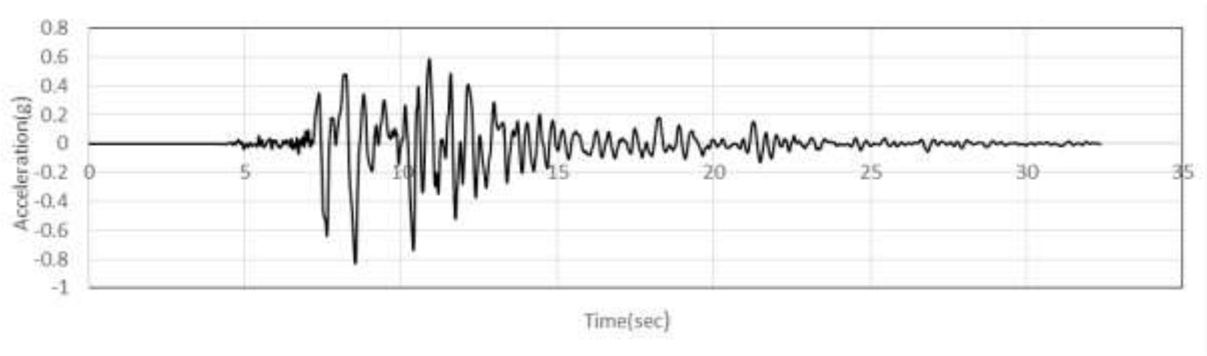


Figure 5. Acceleration time history of KJM-000 component of Kobe earthquake

5. EFFECT OF COLUMN BASE FLEXIBILITY ON PERIOD VALUES

Table 1 reports the fundamental period of vibration (T1), the second-mode period of vibration (T2) and third-mode period of vibration(T_3) corresponding to steel piperack with span lengths of 4 meter and U-bolt rings of 4.0 mm in both group of pipes.

Table 1. Periods of vibration corresponding to steel piperack span lengths of 4 meter and U-bolt rings of 4.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness of column base (kN.m/rad)	Ring of pipe	Period (s) 1	2	3
Structure with pipes of 70-102-159-324	4	Pinned	Ring-4.0mm	0.40	0.60	0.36
Structure with pipes of 70-102-159-324	4	450	Ring-4.0mm	0.34	0.58	0.31
Structure with pipes of 70-102-159-324	4	5000	Ring-4.0mm	0.25	0.57	0.24
Structure with pipes of 70-102-159-324	4	25000	Ring-4.0mm	0.23	0.57	0.21
Structure with pipes of 70-102-159-324	4	45000	Ring-4.0mm	0.23	0.57	0.22
Structure with pipes of 70-102-159-324	4	64000	Ring-4.0mm	0.23	0.57	0.22
Structure with pipes of 70-102-159-324	4	Fixed	Ring-4.0mm	0.23	0.57	0.21
Structure with pipes of 194-245-419	4	Pinned	Ring-4.0mm	0.46	0.80	0.35
Structure with pipes of 194-245-419	4	450	Ring-4.0mm	0.39	0.80	0.31
Structure with pipes of 194-245-419	4	5000	Ring-4.0mm	0.32	0.80	0.24
Structure with pipes of 194-245-419	4	25000	Ring-4.0mm	0.31	0.80	0.22
Structure with pipes of 194-245-419	4	45000	Ring-4.0mm	0.31	0.80	0.22
Structure with pipes of 194-245-419	4	64000	Ring-4.0mm	0.31	0.80	0.22
Structure with pipes of 194-245-419	4	Fixed	Ring-4.0mm	0.30	0.80	0.22

From the table, it can be seen that period values are reduced by changing of the rotational stiffness from fully pinned to 450 and 5000 kN.m/rad but are remained constant from the stiffness of 25000 kN.m/rad to fully fixed approximately. This results also are obtained for other cases including U-bolt rings of 8.0, 12.0 and 16.0 mm and structures with span lengths of 8 meter that is given in the Appendix A.

6. NUMERICAL RESULTS OF THE TIME HISTORY ANALYSES

The effect of the column base flexibility on responses of pipes was assessed in the analyzed frames under selected earthquake ground motions. Fig. 6 shows a comparison of the ratio of von mises stress to allowable stress of pipe elements for any pipe and U-bolt ring diameter with change of rotational stiffness of column base connection in structure with span lengths of 4 meter. The average of response values of figures of 6-a to 6-d is obtained that is shown in Fig.7. From Fig. 7, it can be seen that the ratio of von mises stress to allowable stress of pipe elements significantly are reduced by changing of rotational stiffness from fully pinned condition to stiffnesses of 450 and 5000 kN.m/rad. The differential is by lower than 5% just for pipe 70.0 mm but it is considerable that the response values are not reduced from rotational stiffness of 25000 kN.m/rad to fully fixed condition by more than 5%. A similar comparison corresponding to the structure with span lengths of 8 meter is shown in Figures 8 and 9. Again, from Fig. 9, it is seen that the response values significantly are reduced by changing of rotational stiffness from fully pinned condition to stiffnesses of 450 and 5000 kN.m/rad. The differential is by lower than 5% just for pipes 70.0 and 102.0 mm. Also the values are not reduced from rotational stiffness of 25000 kN.m/rad to fully fixed condition.

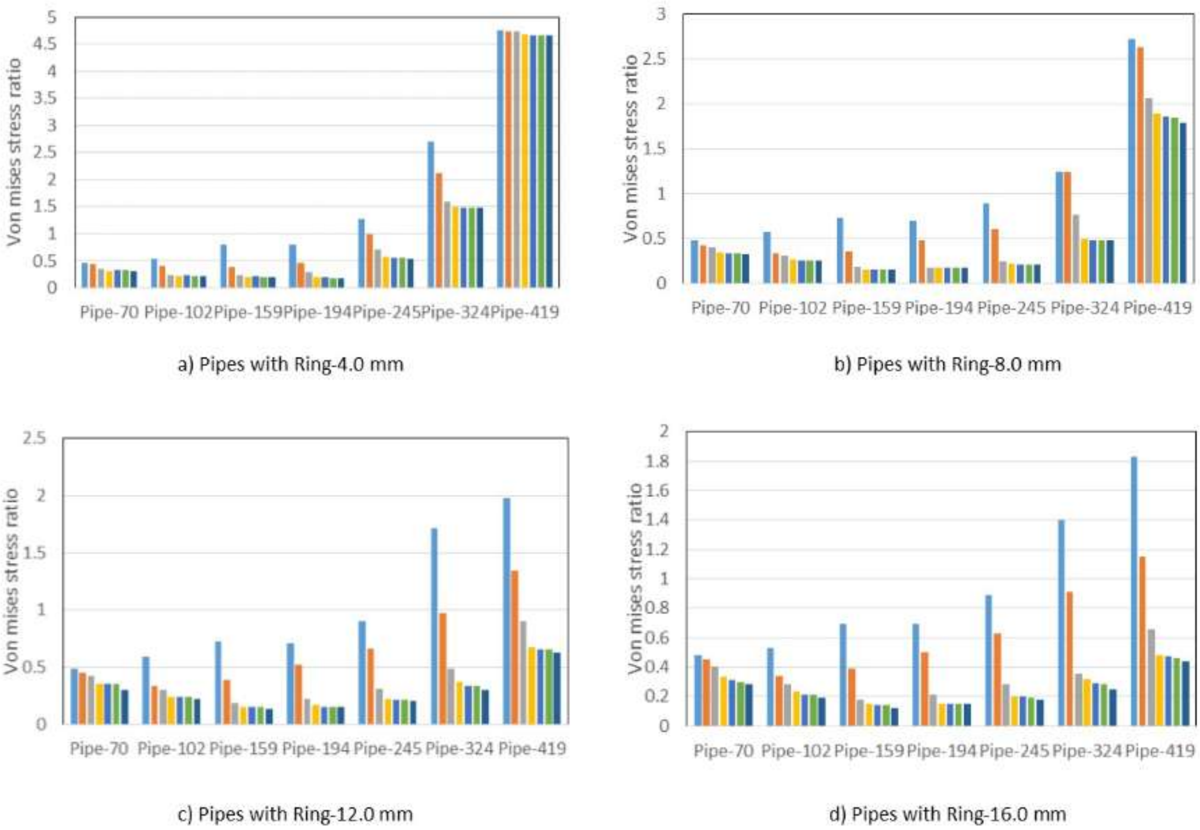


Figure 6. The comparison of ratio of von mises stress to allowable stress of pipe elements with the change of rotational stiffness of column base in structure with span lengths of 4 meter in different cases of rings. a) pipes with ring-4.0 mm, b) pipes with ring-8.0 mm, pipes with ring-12.0 mm, pipes with ring-16.0 mm

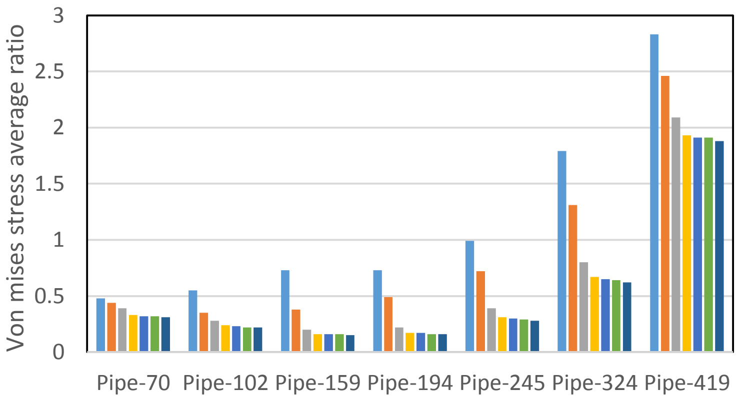


Figure 7. The average of values of figures of 5-a to 5-d

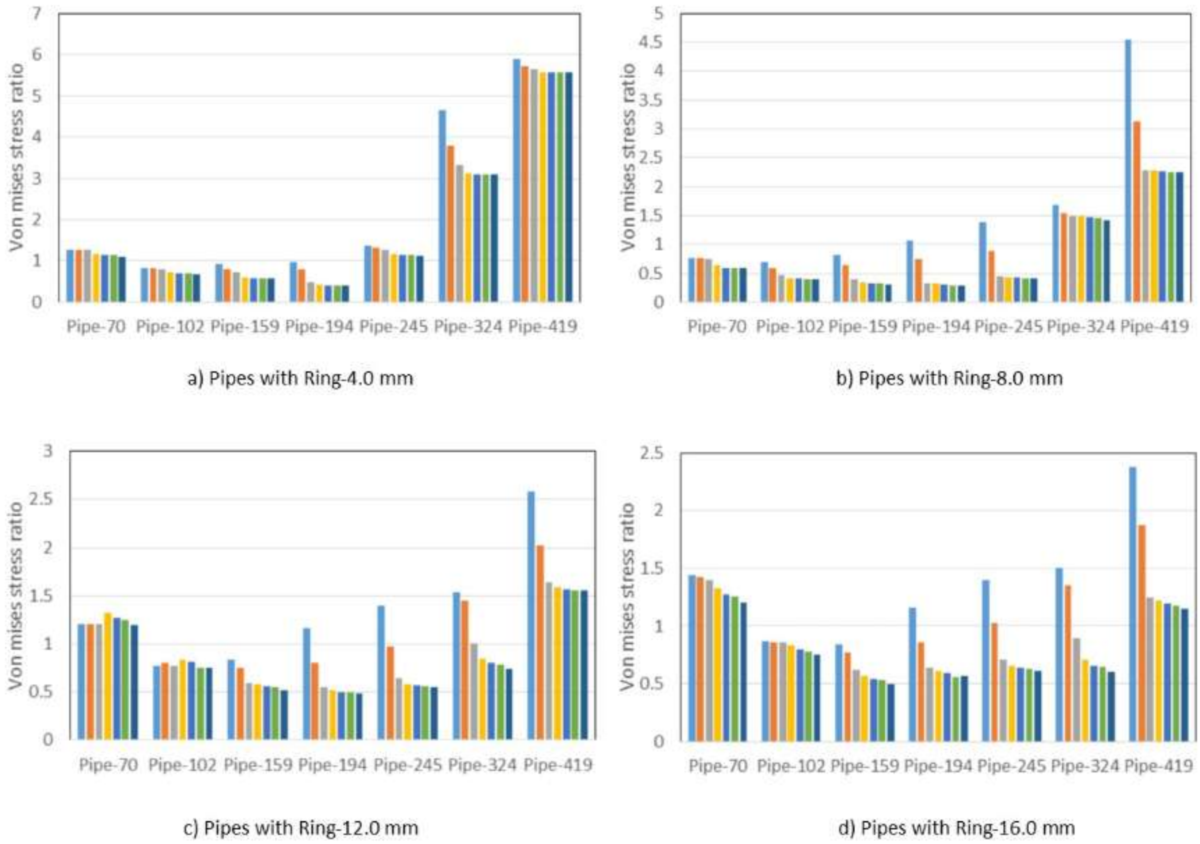


Figure 8. The comparison of ratio of von mises stress to allowable stress of pipe elements with the change of rotational stiffness of column base in structure with span lengths of 8 meter in different cases of rings. a) pipes with ring-4.0 mm, b) pipes with ring-8.0 mm, pipes with ring-12.0 mm, pipes with ring-16.0 mm

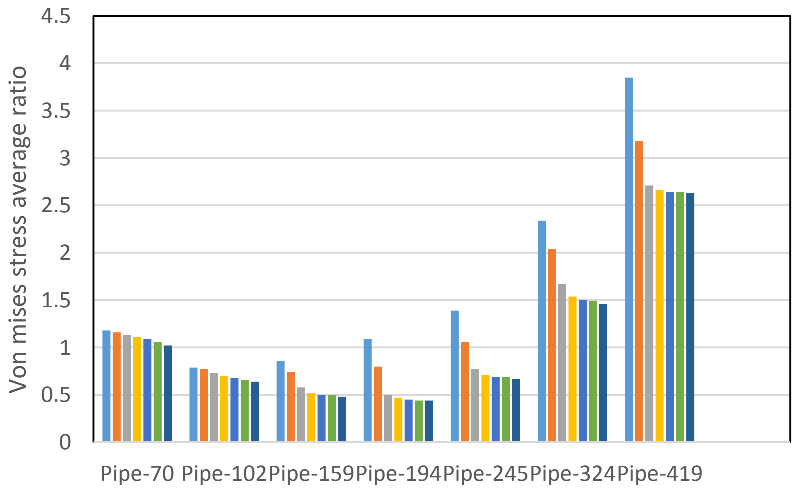


Figure 9. The average of values of figures of 7-a to 7-d

2. ASSESSMENT OF THE EUROCODE3 RECOMMENDATION FOR THE CONSIDERATION OF FIXED OR PIPNNED BASES FOR STEEL PIPERACKS

The initialy, in order to the comparison of boundries of Eurocod3 with rotational stiffnesses in this study, these values should be normalized by EI/H. As regards the height of column (H), moment inertia of column (I) and elasticity modul (E) is 4 m, 0.16e-4 m^4 and 2.1e11 N/m^2 respectively, values of rotational stiffnesses as the following table have been normalized.

Table 2. values of rotational stiffnesses normalized by EI/H

The rotational stiffness (kN.m/rad)	The rotational stiffness (EI/H)
450	0.53
5000	5.90
25000	29.7
45000	53.6
64000	76.0

According to Eurocod3 for column bases with rotational stiffness of 30 EI/H or more, the connection may be considered to be fully rigid and beside the normalized value of stiffness of 25000 kN.m/rad is 29.7(~ 30) EI/H which in this stiffness was seen that do not change the values of period and ratio of von mises stress to allowable stress pipe elements by more than 5% from the fixed base case. It can be suggested that be used the Eurocod3 recommendation for these structures for pipes demands.

8. CONCLUSIONS

This paper presents modal and linear time history analysises of the effect of base flexibility on pipe demands over two level ground motions of kobe and tabas in steel piperack with different analysis conditions including four U-bolt ring diameters of 4.0, 8.0, 12.0 and 16.0 mm and seven rotational stiffnesses of zero, 450, 5000, 25000, 45000, 64000 kN.m/rad and fixed base, two span lengths of 4 and 8 meter and two pipe groups of 70-102-159-324 and 194-245-419. The following were found:

(1) Period values considerably reduced by changing of rotational stiffness from fully pinned base to stiffnesses of 450 and 5000 kN.m/rad but these values not change from the rotational stiffness 25000 kN.m/rad to fully fixed base approximately

(2) Pipe stress response that is expressed as ratio of von mises stress of pipe elements to allowable stress of material pipe, was evaluated by changing of base flexibility under linear time history analysis. It was shown that pipe responses significantly were reduced by changing of rotational stiffness from fully pinned base to stiffnesses 450 and 5000 except for small pipes such as pipe of 70.0 mm in which responses is reduced lower than by 5% but response values were not reduced from stiffness of 25000 kN.m/rad to fully fixed base by more than 5%.

(3) by normalizing of rotational stiffnesses in this stydy by EI/H, it was seen that the stiffness of 25000 kN,m/rad approximately equal to 30 EI/H in which pipe responses were not reduced than fixed base condition by more than 5%. On the other hand, Eurocode3 suggests that column bases with rotational stiffness $30EI/H$ or more in which do not change the column ultimate strength by more than 5% or column lateral displacement under service load by more than 10% from the fixed base case, connection may be considered to be fully rigid. So, it was suggested that the Eurocade3 recommendation regarding fixed base condition to be used for pipe demands in steel piperack.

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APPENDIX

Table A.1. Periods of vibration corresponding to steel piperack span lengths of 4 meter and U-bolt rings of 8.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness(kN.m/rad)	Ring of pipe	Period (s) 1	2	3
Structure with pipes of 70-102-159-324	4	Pinned	Ring-8.0mm	0.47	0.34	0.25
Structure with pipes of 70-102-159-324	4	450	Ring-8.0mm	0.40	0.30	0.23
Structure with pipes of 70-102-159-324	4	5000	Ring-8.0mm	0.30	0.24	0.19
Structure with pipes of 70-102-159-324	4	25000	Ring-8.0mm	0.28	0.22	0.19
Structure with pipes of 70-102-159-324	4	45000	Ring-8.0mm	0.28	0.22	0.19
Structure with pipes of 70-102-159-324	4	64000	Ring-8.0mm	0.28	0.22	0.19
Structure with pipes of 70-102-159-324	4	Fixed	Ring-8.0mm	0.28	0.21	0.19
Structure with pipes of 194-245-419	4	Pinned	Ring-8.0mm	0.35	0.53	0.33
Structure with pipes of 194-245-419	4	450	Ring-8.0mm	0.32	0.48	0.30
Structure with pipes of 194-245-419	4	5000	Ring-8.0mm	0.26	0.43	0.24
Structure with pipes of 194-245-419	4	25000	Ring-8.0mm	0.23	0.43	0.22
Structure with pipes of 194-245-419	4	45000	Ring-8.0mm	0.23	0.43	0.21
Structure with pipes of 194-245-419	4	64000	Ring-8.0mm	0.23	0.43	0.21
Structure with pipes of 194-245-419	4	Fixed	Ring-8.0mm	0.23	0.43	0.21

Table A.2. Periods of vibration corresponding to steel piperack span lengths of 4 meter and U-bolt rings of 12.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness(kN.m/rad)	Ring of pipe	Period (s)		
				1	2	3
Structure with pipes of 70-102-159-324	4	Pinned	Ring-12.0mm	0.47	0.33	0.22
Structure with pipes of 70-102-159-324	4	450	Ring-12.0mm	0.40	0.30	0.21
Structure with pipes of 70-102-159-324	4	5000	Ring-12.0mm	0.28	0.24	0.19
Structure with pipes of 70-102-159-324	4	25000	Ring-12.0mm	0.26	0.22	0.17
Structure with pipes of 70-102-159-324	4	45000	Ring-12.0mm	0.25	0.22	0.17
Structure with pipes of 70-102-159-324	4	64000	Ring-12.0mm	0.25	0.21	0.17
Structure with pipes of 70-102-159-324	4	Fixed	Ring-12.0mm	0.24	0.21	0.16
Structure with pipes of 194-245-419	4	Pinned	Ring-12.0mm	0.49	0.30	0.20
Structure with pipes of 194-245-419	4	450	Ring-12.0mm	0.42	0.28	0.19
Structure with pipes of 194-245-419	4	5000	Ring-12.0mm	0.31	0.23	0.17
Structure with pipes of 194-245-419	4	25000	Ring-12.0mm	0.28	0.21	0.16
Structure with pipes of 194-245-419	4	45000	Ring-12.0mm	0.28	0.21	0.16
Structure with pipes of 194-245-419	4	64000	Ring-12.0mm	0.28	0.21	0.16
Structure with pipes of 194-245-419	4	Fixed	Ring-12.0mm	0.28	0.21	0.16

Table A.3. Periods of vibration corresponding to steel piperack span lengths of 4 meter and U-bolt rings of 16.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness(kN.m/rad)	Ring of pipe	Period (s)		
				1	2	3
Structure with pipes of 70-102-159-324	4	Pinned	Ring-16.0mm	0.47	0.33	0.20
Structure with pipes of 70-102-159-324	4	450	Ring-16.0mm	0.39	0.30	0.20
Structure with pipes of 70-102-159-324	4	5000	Ring-16.0mm	0.28	0.24	0.17
Structure with pipes of 70-102-159-324	4	25000	Ring-16.0mm	0.25	0.22	0.16
Structure with pipes of 70-102-159-324	4	45000	Ring-16.0mm	0.25	0.22	0.16
Structure with pipes of 70-102-159-324	4	64000	Ring-16.0mm	0.25	0.21	0.16
Structure with pipes of 70-102-159-324	4	Fixed	Ring-16.0mm	0.24	0.21	0.16
Structure with pipes of 194-245-419	4	Pinned	Ring-16.0mm	0.49	0.29	0.18
Structure with pipes of 194-245-419	4	450	Ring-16.0mm	0.41	0.27	0.17
Structure with pipes of 194-245-419	4	5000	Ring-16.0mm	0.30	0.23	0.15
Structure with pipes of 194-245-419	4	25000	Ring-16.0mm	0.27	0.21	0.15
Structure with pipes of 194-245-419	4	45000	Ring-16.0mm	0.27	0.21	0.15
Structure with pipes of 194-245-419	4	64000	Ring-16.0mm	0.27	0.21	0.15
Structure with pipes of 194-245-419	4	Fixed	Ring-16.0mm	0.27	0.21	0.15

Table A.4. Periods of vibration corresponding to steel piperack span lengths of 8 meter and U-bolt rings of 4.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness(kN.m/rad)	Ring of pipe	Period (s) 1	2	3
Structure with pipes of 70-102-159-324	8	Pinned	Ring-4.0mm	0.5	0.77	0.43
Structure with pipes of 70-102-159-324	8	450	Ring-4.0mm	0.43	0.75	0.38
Structure with pipes of 70-102-159-324	8	5000	Ring-4.0mm	0.32	0.74	0.30
Structure with pipes of 70-102-159-324	8	25000	Ring-4.0mm	0.30	0.74	0.27
Structure with pipes of 70-102-159-324	8	45000	Ring-4.0mm	0.29	0.74	0.27
Structure with pipes of 70-102-159-324	8	64000	Ring-4.0mm	0.29	0.74	0.27
Structure with pipes of 70-102-159-324	8	Fixed	Ring-4.0mm	0.29	0.74	0.26
Structure with pipes of 194-245-419	8	Pinned	Ring-4.0mm	0.58	0.89	0.41
Structure with pipes of 194-245-419	8	450	Ring-4.0mm	0.51	0.89	0.36
Structure with pipes of 194-245-419	8	5000	Ring-4.0mm	0.44	0.89	0.32
Structure with pipes of 194-245-419	8	25000	Ring-4.0mm	0.43	0.89	0.30
Structure with pipes of 194-245-419	8	45000	Ring-4.0mm	0.42	0.89	0.30
Structure with pipes of 194-245-419	8	64000	Ring-4.0mm	0.42	0.89	0.30
Structure with pipes of 194-245-419	8	Fixed	Ring-4.0mm	0.42	0.89	0.30

Table A.5. Periods of vibration corresponding to steel piperack span lengths of 8 meter and U-bolt rings of 8.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness(kN.m/rad)	Ring of pipe	Period (s) 1	2	3
Structure with pipes of 70-102-159-324	8	Pinned	Ring-8.0mm	0.60	0.40	0.21
Structure with pipes of 70-102-159-324	8	450	Ring-8.0mm	0.51	0.36	0.28
Structure with pipes of 70-102-159-324	8	5000	Ring-8.0mm	0.40	0.29	0.26
Structure with pipes of 70-102-159-324	8	25000	Ring-8.0mm	0.38	0.26	0.25
Structure with pipes of 70-102-159-324	8	45000	Ring-8.0mm	0.38	0.26	0.25
Structure with pipes of 70-102-159-324	8	64000	Ring-8.0mm	0.38	0.26	0.25
Structure with pipes of 70-102-159-324	8	Fixed	Ring-8.0mm	0.37	0.26	0.25
Structure with pipes of 194-245-419	8	Pinned	Ring-8.0mm	0.66	0.45	0.38
Structure with pipes of 194-245-419	8	450	Ring-8.0mm	0.60	0.40	0.34
Structure with pipes of 194-245-419	8	5000	Ring-8.0mm	0.30	0.56	0.26
Structure with pipes of 194-245-419	8	25000	Ring-8.0mm	0.30	0.56	0.26
Structure with pipes of 194-245-419	8	45000	Ring-8.0mm	0.30	0.56	0.26
Structure with pipes of 194-245-419	8	64000	Ring-8.0mm	0.30	0.56	0.26
Structure with pipes of 194-245-419	8	Fixed	Ring-8.0mm	0.30	0.56	0.26

Table A.6. Periods of vibration corresponding to steel piperack span lengths of 8 meter and U-bolt rings of 12.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness(kN.m/rad)	Ring of pipe	Period (s)		
				1	2	3
Structure with pipes of 70-102-159-324	8	Pinned	Ring-12.0mm	0.58	0.38	0.24
Structure with pipes of 70-102-159-324	8	450	Ring-12.0mm	0.49	0.34	0.27
Structure with pipes of 70-102-159-324	8	5000	Ring-12.0mm	0.37	0.28	0.21
Structure with pipes of 70-102-159-324	8	25000	Ring-12.0mm	0.33	0.26	0.20
Structure with pipes of 70-102-159-324	8	45000	Ring-12.0mm	0.33	0.26	0.20
Structure with pipes of 70-102-159-324	8	64000	Ring-12.0mm	0.32	0.26	0.20
Structure with pipes of 70-102-159-324	8	Fixed	Ring-12.0mm	0.32	0.26	0.20
Structure with pipes of 194-245-419	8	Pinned	Ring-12.0mm	0.62	0.34	0.22
Structure with pipes of 194-245-419	8	450	Ring-12.0mm	0.53	0.31	0.23
Structure with pipes of 194-245-419	8	5000	Ring-12.0mm	0.41	0.27	0.19
Structure with pipes of 194-245-419	8	25000	Ring-12.0mm	0.37	0.25	0.22
Structure with pipes of 194-245-419	8	45000	Ring-12.0mm	0.37	0.25	0.22
Structure with pipes of 194-245-419	8	64000	Ring-12.0mm	0.37	0.25	0.22
Structure with pipes of 194-245-419	8	Fixed	Ring-12.0mm	0.37	0.25	0.22

Table A.7. Periods of vibration corresponding to steel piperack span lengths of 8 meter and U-bolt rings of 16.0 mm in both group of pipes

Group of pipes	Span length(m)	Rotational Stiffness(kN.m/rad)	Ring of pipe	Period (s)		
				1	2	3
Structure with pipes of 70-102-159-324	8	Pinned	Ring-16.0mm	0.58	0.37	0.22
Structure with pipes of 70-102-159-324	8	450	Ring-16.0mm	0.49	0.34	0.27
Structure with pipes of 70-102-159-324	8	5000	Ring-16.0mm	0.36	0.28	0.2
Structure with pipes of 70-102-159-324	8	25000	Ring-16.0mm	0.32	0.26	0.2
Structure with pipes of 70-102-159-324	8	45000	Ring-16.0mm	0.32	0.26	0.2
Structure with pipes of 70-102-159-324	8	64000	Ring-16.0mm	0.32	0.26	0.2
Structure with pipes of 70-102-159-324	8	Fixed	Ring-16.0mm	0.32	0.25	0.2
Structure with pipes of 194-245-419	8	Pinned	Ring-16.0mm	0.61	0.32	0.19
Structure with pipes of 194-245-419	8	450	Ring-16.0mm	0.52	0.3	0.19
Structure with pipes of 194-245-419	8	5000	Ring-16.0mm	0.39	0.26	0.18
Structure with pipes of 194-245-419	8	25000	Ring-16.0mm	0.35	0.25	0.18
Structure with pipes of 194-245-419	8	45000	Ring-16.0mm	0.35	0.24	0.18
Structure with pipes of 194-245-419	8	64000	Ring-16.0mm	0.35	0.24	0.18
Structure with pipes of 194-245-419	8	Fixed	Ring-16.0mm	0.35	0.24	0.18