# Pipe and Pipe Rack Interaction

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## Abstract

*In current method of pipe and pipe rack design, first pipe is designed, and then pipe supports reactions are imposed on pipe rack. After that, pipe rack is designed according to the addressed loading. There are some ambiguities and problems in this pipe and pipe rack design method due to not modeling pipe in pipe rack design. The experienced damages in previous earthquakes confirm the mentioned claim. This study aims to propose a new method for considering pipe and pipe rack interaction instead of current method in order to solve current problems. In the proposed method, pipe is framed to pipe rack in all points and then pipe and supporting structure are design simultaneously. The proposed method is assessed by modeling in Sap and Caesar programs with nonlinear static analysis which results confirm our claims. In our suggested method, current problems are solved and the amount of used materials is reduced up to 29%.*

## *Introduction*

Pipe networks are considered as main components of industrial complexes like refineries and petrochemicals that transfer fluid and gas and any damage in their structures may be dangerous. Pipes are supported by the usage of pipe steel rack as it is seen in picture 1. So pipe rack behavior influences pipe behavior directly. According to recent studies, pipe damages in earthquake are mainly caused by pipe rack which is one of the most important reported reasons of pipe damages [1, 2].

Picture1: Picture of pipe and pipe rack

This study aims to assess pipe and pipe rack interaction. Nowadays, pipe and pipe rack are designed separately. According to available codes, the possibility of release of stress caused by temperature is obligatory in pipe design owing to high operating temperature [3, 4]. And that’s why the connections between pipe and its support are just seated in most points.

So there is friction between pipe and its supports mostly, and the connections between pipe and its support are framed in some points. According to Japanese code, simultaneous modeling is intricate; therefore pipe and pipe rack should be modeled separately [5]. And no direct proposing of separate modeling is mentioned in American codes like ASCE, but interaction should be considered by designers [6]. The mentioned problems cause that designers model pipe and pipe rack separately and apply some methods for considering the interaction between pipe and pipe rack.

The current method which designers apply has some problems, which are going to be discussed later. The main objective behind this research is to solve the mentioned problems of current method. Our proposed method is simultaneous modeling of pipe and pipe rack. A static nonlinear modeling in Sap and Caesar is used to measure our proposed method and evaluate it with current method.

## *Materials and Methods*

### Current method of considering pipe and pipe rack interaction

In this part of the study, the way one can consider pipe and pipe rack interaction is going to be discussed. At first, pipe is modeled and designed in Caesar according to pipe loading with specifying pipe supports places [7]. Vertical supports are assumed rigid in downward directions. Then pipes supports reactions are imposed on pipe rack and supporting structure are designed according to these reactions in the used software like Sap. Implemented loads just imposed on structure design and pipe modeling is ignored as seen in figure1 [6, 8, 9].

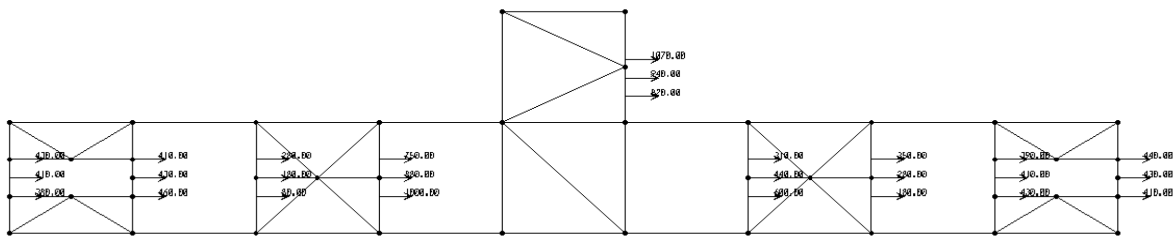

Figure1: pipe rack plan. A continuous structure which some forces are imposed on pipe rack and pipe modeling is ignored.

The imposed loads of pipe supports on pipe rack for considering interaction are as the fallowing [6, 9]:

Operating load: Vertical reactions of supports in load combinations of pipe operating conditions are calculated in pipe design. So the mentioned vertical reactions are imposed on pipe rack in corresponding points as operating load.

Thermal load: The existence of contraction and expansion is lead to thermal load production. Horizontal reactions of supports in load combinations of pipe operating conditions as thermal load are calculated in two orthogonal directions and the mentioned reactions are imposed on pipe rack in corresponding points.

Friction load: Vertical reactions of pipe supports in load combinations of pipe operating conditions are calculated in pipe design and 30% of calculated reactions are imposed on pipe rack as friction load (if we assume that friction factor between pipe and pipe rack is 30%) in two orthogonal positive directions of coordinate axes in corresponding points. Figure1 shows the imposed friction load in a plan.

Test load: Gravity load during hydrostatic test of tanks, pipes and equipment are calculated in pipe design and imposed on pipe rack in corresponding points as test load.

Earthquake load: Earthquake load is imposed on pipe and the horizontal components of pipe supports calculated reactions are imposed on pipe rack in two orthogonal directions.

Dead load: It is composed of weight of empty pipe equipment and weight of pipe rack.

Then in order to design pipe rack, its elements are divided into two groups. The first group contains elements which have no contact with pipe like columns, braces and some of the beams. And the second group contains those beams which act as a support for pipes [9]. In the second group's elements, friction and thermal loads cause torsion in supporting beams, as it is seen in figure2.

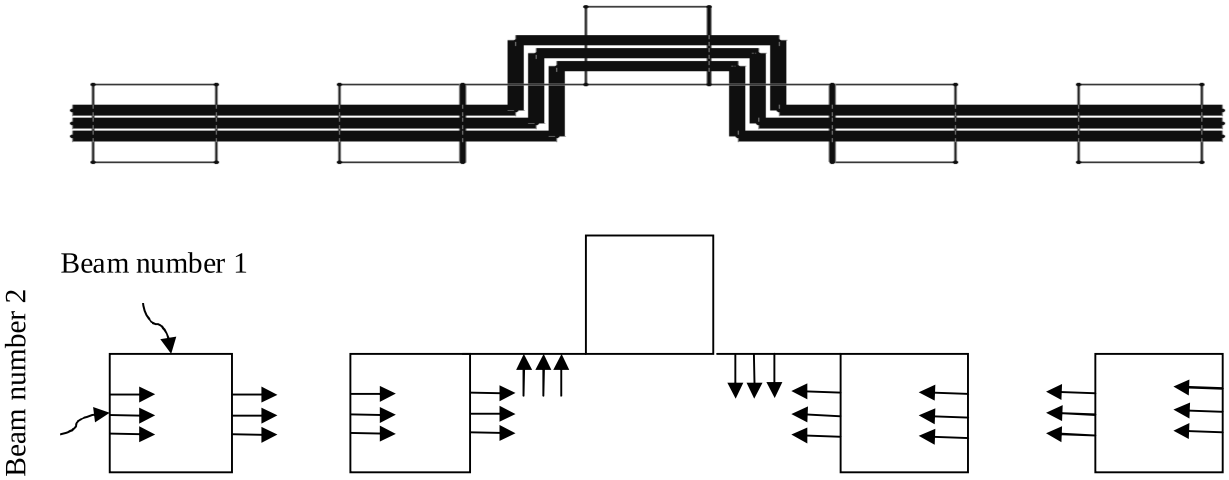


Figure2: two groups of supporting beams

Pipes and pipe rack are shown in upper part. And in the lower part pipes are omitted and their supports reactions are imposed on pipes racks. Beam number 1 is related to the first group and beam number 2 is related to the second group. The elements of the first groups are designed according to the first group of load combinations and the elements of the second group are design according to the second group of load combinations. Two groups of load combinations are as following:

First group of load combinations:

1. 1.4D+ 1.4Operp±1.4Therx±1.4Thery
2. 1.4D+ 1.4Testp
3. 1.2D + 1.2Emptyp+ 1.2T+ 0.5S
4. 1.2D + 1.2Operp±1.2Therx±1.2Thery+ 1.2T+ 0.5S
5. 1.2D + 1.2Operp±1.2Therx±1.2Thery+ E+ 0.2S
6. 0.9D + 0.9Emptyp

Second group of load combinations:

1. 1.4D + 1.4Operp±2.8Therx±1.4Thery±2.8Fricx±1.4Fricy
2. 1.4D + 1.4Testp
3. 1.2D + 1.2Emptyp+ 1.2T+ 0.5S

S is snow load and T is ambient temperature and emptyp is weight of empty pipe. Number 4 to 6 Load combinations are the same for both groups. In the second group of load combinations, load factors are doubled which cause torsion. The doubled thermal and friction load is explained in following:

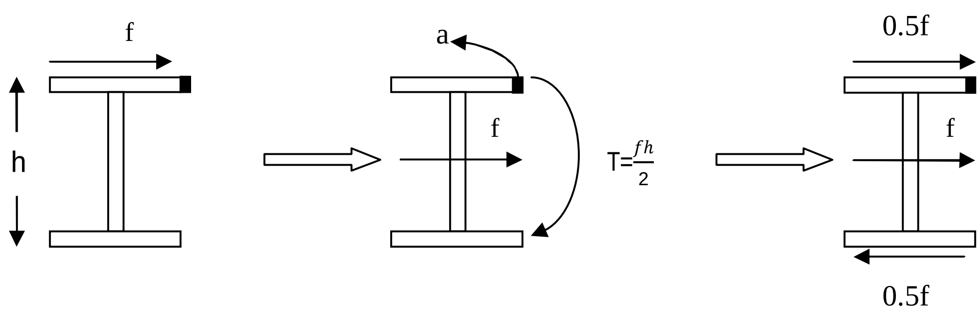


Figure3: eccentric force f is transformed to a load f which is imposed on the center of the section and a torsion T.

As it is seen in figure3, the eccentric force f is transformed into a load f which is imposed on the center of the section and a torsion T. Then torsion T is transformed into two loads 0.5 f which are imposed on the top and bottom of the section. So the stress is calculated in figure3 which is marked as "a".

$$\sigma_a = \frac{f}{s_y} + \frac{0.5f}{s_f} = \frac{f}{s_y} + \frac{0.5f}{0.5s_y} = \frac{2f}{s_y}$$

**Ambiguities and problems in the current method of considering pipe and pipe rack interaction**

The method of how to consider pipe and pipe rack interaction in current design method was discussed. Now problems and ambiguities of this method are explained in the fallowing.

1. In the current method, friction loads are imposed on pipe rack in the positive direction of coordinate system [2, 9]. But friction loads are produced in the direction opposite to the movement of moving factor .In other words, friction loads direction is related to pipe movement direction and in the earthquake, friction forces are useful and imposed on structure in the direction opposite to the earthquake direction.

2. All separated pipe racks have a related behavior in bearing gravity and seismic loads, because long pipes lines have restrained these separated structures from free movement. Thus the response of each pipe rack to seismic load affects the behavior of adjacent structures in the earthquake as well.

3. Two separated adjacent pipe rack structures have different geometric shapes and pipes supports places are different. And the mentioned adjacent pipe racks have different behaviors during earthquake. Thus they may have unequal drifts or even drifts in opposite directions [5]. So the mentioned point should be considered in pipe and pipe rack design. However this point is ignored in current method of design.

4. In beams design, thermal load and friction load are used in some load combinations simultaneously [9], although they are the same. In other words, $Fricx^2 = Fricy^2 = Therx^2 + Thery^2$.

5. 30% of friction load plus earthquake load are imposed on pipe rack simultaneously [9, 2]. In this case, the forces which are imposed on pipe rack are more than actual amount.

6. Since pipe is not modeled, horizontal braces are used in storey level. These braces bear horizontal friction load. Weight of these braces is about 10% of pipe rack weight.

7. Since pipe is not modeled and there is not rigid diaphragm in storey level, the main modes of dynamic analysis of pipe rack are not actual modes. The main modes are transmission modes because of framed connections between pipe and pipe rack. Whereas, in many of designed pipe racks, vibrations of some of beams are seen in the first mode.

8. In current method of design, connections between pipe and pipe rack are framed in some points but are seated in most points. So pipe seismic load is just transmitted to pipe rack from framed connections. But lateral load resisting system of pipe rack is placed in some spans regardless of this point. Therefore, there is no determined load transmission path because of having no rigid diaphragm.

9. When the connection between pipe and its supports is seated, pipes have considerable different displacements and vibrations in lateral unrestrained directions in earthquake. Thus unintended collision between pipes and between pipe and other structural elements, like columns, is probable [1, 10].

10. When the connection between pipe and its supports is seated, pipe falling down in earthquake in the last storey is probable [1].

11. In pipe design, it is assumed that pipe has no displacement in the framed supports. In other words, in the mentioned supports, pipe has no displacement due to expansion. Therefore pipes have no interaction during expansion. Of course, it is obvious that this is incorrect.

12. In load combinations, loads which cause torsion in beams become doubled. The reason of factor 2 is shown in figure3. As it is seen in figure3, pipes are omitted and substituted just by forces which cause torsion in supporting beams. It should be mentioned that big pipes prevent torsion in beam.

**Suggestions for solving problems and ambiguities**

Ambiguities and problems which are mentioned earlier prove that the method of considering pipe and pipe rack interaction should be modified. So for solving the discussed problems the following suggestions are proposed by the authors.

1. The connections between pipe and pipe rack are suggested to be framed in more pints and in all points if possible. Thermal and friction loads will totally be omitted accordingly.

2. Pipe and pipe rack simultaneous modeling for pipe and pipe rack design is proposed and pipes interaction should be considered as well [11]. By modeling pipe in Sap, there is no need to impose pipe supports reactions on pipe rack and pipe acts as a structural member.

However, pipe thermal stress doesn't increase when all connections between pipe and supporting beams are framed as a result of weak axis bending stiffness of beam is small in comparison with pipe axial stiffness. The advantageous of framed connections between pipe and its supports in all points are as following.

1. Pipe and pipe rack can be modeled in Sap easily. Hence the problems of considering pipe and pipe rack interaction will be totally omitted

2. Pipe can be considered as a structural element which acts as a load transmission path. So there is no need for horizontal braces to transmit loads. Therefore the weight of pipe rack reduces up to 10%.

3. Continuous multi span pipe racks can be substituted by several single pipe racks when connections between pipes and supporting beams are framed in all points. Each single span frame has itself a moment frame system, as seen in figure4. Load transmission path is a secure path accordingly. Because each supporting beam is a part of lateral load resisting system which receives seismic load of the framed pipe directly. These single span structures allow some beam to be omitted. Consequently the number of beams and the amount of materials which are used in beams reduce.

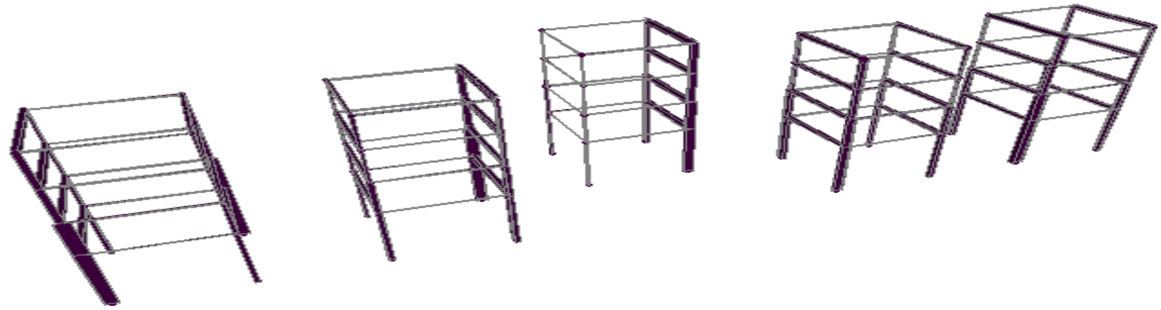

Figure 4: Separated single span structure

4. When all connections between pipe and pipe rack are framed, pipe and pipe rack act together. Thus factor 2 of loads for considering torsion is omitted. Of course, when all connections between pipe and pipe rack are framed, some restrictions are caused as following:

1. When all connections between pipe and pipe rack are framed, the assessment of pipes interaction in asynchronous operation is essential. Because when several pipes are framed to a common supporting beam and just one of these pipes is under operating condition, the pipes which are in non-operating condition, act as displacement constraint for under operating pipes which cause increase in pipe thermal stress and beam flexural stress [11].

2. In pipe rack design, all different states of operating conditions should be considered. In order to get to this point, close cooperation between pipe designers and pipe rack designers is necessary [11].

## *Results and Discussion*

### Modeling

The current method and the proposed method were discussed earlier, now some pipes and pipe racks are modeled and static linear and nonlinear analysis is run to assess the proposed method of design. At first, 12 lines of pipes with 80cm diameter and 56m length which are supported at 6-meter intervals are designed. Pipes supports are assumed rigid in vertical downward direction. Operating pressure and temperature are considered 3000MPa and 150C respectively. Pipe rack structure is a 4-storey steel structure which has 5, 3, 3 and 3 meters height from first to fourth storey, respectively. And also, there are three pipes lines in each storey.

Then pipes lines are designed and pipes reactions forces are imposed on pipes racks and a 54 length continuous structure is designed according to current method of design. Weight of the designed structure is 54ton. The lateral load resisting system in two orthogonal directions are moment frame [9]. Figure1 shows a plan of designed pipe rack. After that, pipe rack and pipe are modeled simultaneously in Sap program. In pipe modeling, pipe bend is modeled like a torsion spring [3, 10]. Then pipe rack is modeled. In pipe rack modeling, several separated single-span structures are designed instead of a continuous structure. Lateral load resisting system is considered as a moment frame system in two orthogonal directions. Weight of pipe rack is 41.95ton.

**Analysis of results**

The amount of used materials in the proposed method is reduced up to 24% compared to the current method of design. Of course, using frame with knee brace connections reduces the amount of used materials up to 29% [12]. The reduction of the amount of used materials is caused by some reasons as following:

1. In current method of design, pipe is seated on supporting beams, thus horizontal braces are used to transmit load which their weigh are up to10%
2. In current method, load combinations are conservative [9].
3. Factor 2 which is used in some loads to consider torsion effect.
4. Continuous pipe rack is used in current design method [9].

At the end, following suggestions are made for pipe and pipe rack simultaneously:

1. Framed connections between pipe and pipe rack are suggested in all supports.
2. Single span structures with knee brace connections is suggested to be used instead of a continuous pipe rack.
3. In single span structures, sections of half of columns are rotated 90 thus bending strength of strong axisof half of column acts in each direction
4. Bending stiffness of pipe bend should be modeled correctly in Sap.
5. The assessment of pipes interaction in asynchronous operating condition should be considered a must.

## *Conclusion*

The following results are achieved by doing the mentioned suggestions.

1. Pipe and pipe rack interaction will be considered in a correct way
2. The amount of used material reduces up to 29%.
3. Transmission path of seismic load is a secure path.

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