DESIGN OF OPTIMUM PIPE RACK FOR VARIOUS BAYS

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ABSTRACT

Pipe rack are common structures in industries like Oil & gas. Pipe racks are most common structures in industries like Oil & Gas, Petrochemical, refinery, etc. It carries various pipes from one Equipment to another or from one unit to another unit. Pipe racks should be designed for various loads like primary essential loads and pipe loads. The study aims to compare the effect of increasing the column to column distance in pipe rack using STAAD Pro V8i. The pipe rack members has been designed by using Indian Standard codes. The Members of the Pipe racks should be verified for Strength, Vertical Horizontal Deflection. The utility ratios of the Pipe racks has to be maintained within the desired limit. At the end, conclusions are drawn about the comparison of the three pipe racks with different lengths.

Keywords: Pipe rack, pipe Loadings, Cross bracings, support, design, STAAD Pro V8i.

I. INTRODUCTION

A. General

Pipe networks are considered as main components of industrial complexes like refineries and petrochemicals that transfer fluid and gas. Pipe rack is concrete or steel structure (better fire resistant) which carries multiple pipes carrying liquid or gas in different tiers and also carries Electrical/Instrument/Telecom Cable trays for supporting auxiliary Equipment like Pressure release valves etc. with walkways and service platforms. Structural steel pipe racks support pipes, power cables and instrument cable trays. They also carry large diameter to small bore lines with liquid or gas from one Equipment to another Equipment or from one unit to another unit. These are necessary for carrying large number of Process lines, Utility lines, Flare lines etc. Pipe racks have a series of transverse bents which run along the length. These are spaced at uniform intervals of the pipe system around 20 ft. The transverse bents are typically moment frames and connected with longitudinal struts for maintenance access.

Different types of pipes are used in the pipe rack. Utility pipes include steam, cooling water, fuel oil, extinguishing water, etc. They are mostly located in the middle of a one-level pipe rack or on the top level. Also there are the

Process pipes. Process pipes carry product which is a part of chemical reactions. When there are multiple pipes, process pipes are heavy weighted or placed on the bottom level, they are placed outside of the utility pipes. At last there are relief pipes and flare pipes that fulfill a safety goal. They are always located on the outside of the rack to protect the installation against too much pressure. A complete structure of pipe rack system and its structural elements should perform their function adequately and safely, with appropriate degree of reliability during design life. It should be constructed before it becomes obstruction for other structures.

B. Objective

The main objective of this project is to design optimum pipe rack. The following are also the objective behind our project

• To analyze steel pipe rack.
• To design steel pipe rack of 3 various span lengths as per codes specifications.
• To compare of 3 models of pipe rack with different span lengths.
• To determine the optimum pipe rack model.

II. METHODOLOGY

The design of the pipe rack is done on the basis of the standard load data. The design is followed as per the Is 800:2007.
• Data collection: Following data should be collected before designing a pipe rack
  • Unit plot plan / overall plot plan.
  • Instrumentation and piping diagrams.
  • Plant layout specification.
  • Specification of clients
  • Material of construction.
  • Fireproofing requirements
  • The loads of pipes has been considered.
  • After collecting the data, 3 various spans of different lengths has been considered.
  • The pipe rack bridges are designed by using STAAD Pro v8i software.
  • All the three designs are compared and figured out the outcomes.

III. MODELING AND ANALYSIS

Three types of pipe rack structures are considered for the study. The pipe rack of 30m, 35m and 40m lengths are considered having column to column spacing as 6m, 7m and 8m respectively. The loadings and design parameters are kept constant for all the three cases.

Model 1

Column to column spacing is 6m c/c. Tier spacing is 3m. 1 tier is placed at the centre of main beams. X type of bracings are provided in longitudinal direction at 1st grid and at 4th grid. X type of bracings are provided in lateral direction.

• Length of pipe rack : 30.00m
• Height of pipe rack : 08.00m
• Width of pipe rack : 06.00m
• Column to column spacing : 06.00m
• Tier spacing : 03.00m

The general dimensions of pipe rack are as below:

Model 2

Column to column spacing is 7m c/c. Tier spacing is 2.33m. 2 tiers are placed at the equal distances of 2.33m from main beams. X type of bracings are provided in longitudinal direction at 1st grid and at 4th grid. X type of bracings are provided in lateral direction.

The general dimensions of pipe rack are as below:

• Length of pipe rack : 35.00m
• Height of pipe rack : 08.00m
• Width of pipe rack : 06.00m
• Column to column spacing : 07.00m
• Tier spacing : 02.33m
Model 3

Column to column spacing is 8m c/c. Tier spacing is 2m. 3 tiers are placed at the equal distances of 2m from main beams. X type of bracings are provided in longitudinal direction at 1<sup>st</sup> grid and at 4<sup>th</sup> grid. X type of bracings are provided in lateral direction.

The general dimensions of pipe rack are as below:

- Length of pipe rack : 40:00m
- Height of pipe rack : 08:00m
- Width of pipe rack : 06.00m
- Column to column spacing : 08.00m
- Tier spacing : 02.00m

A. Section Property

In this design various sections of beams and columns are assigned up to which utilization is less than unity and deflection limits should satisfy by the structure. Following sections are assigned to the structure.

- Columns : ISMB 400
- Main Beam : ISMB 300
- Tier : ISMB 200
- Bracings : ISA 75 X 75 X 10

B. Specification of structure

As bracings are provided in longitudinal (X) direction, beams in longitudinal direction are provided releases at supports. Due to which longitudinal frames are not moment-resisting. As transverse frames are modeled is moment-resisting frames, the beams in transverse (Z) direction are not released

C. Supports

Fixed supports are considered for all columns.

D. Loads Considered to design pipe rack

The design of the pipe rack is done on the basis of standard data.

1. Dead Load (DL)
   
   Self-weight for all beams and columns are considered.
   
   Floor Load of pressure = 0.1 kN/m<sup>2</sup>is taken.

2. Live Load
   
   Pipe carrying water loads are considered.
   
   Live Load of 7kN/m<sup>2</sup>has been taken.

3. Seismic Load
   
   As per IS 1893:2002, Zone II is considered for the design. Following parameters are considered,
   
   a) Type of soil = Type II, Medium soil
   b) Seismic zone factor (II) Z = 0.10 (Clause no.6.4.2, Table no.2, Page no.16)
c) Response reduction factor = 5 (Clause no.7.2 Table no.7, Page no. 23)
d) Importance factor = 1 (Clause no.7.2 Table no.6, Page no. 18)
e) Damping Ratio = 5%
f) Medium soil factor = 1.00 (Clause no.7.2.3 Table no.3, Page no. 17)
4. Fu = 450kN/m²
5. Fyld = 345kN/m²
6. Effective length \( E_{ff} \) length = 1.2 \( X \) L
7. All the common parameters are considered as per IS 800:2007.

**Load Combinations:**

Load Combinations as per Indian codes are taken.

1. \((1.5 \times DL) + (1.5 \times LL)\)
2. \((1.2 \times DL) + (1.2 \times LL)\)
3. \((1.2 \times DL) + (1.2 \times LL) + (1.2 \times EX)\)
4. \((1.2 \times DL) + (1.2 \times LL) + (1.2 \times E-X)\)
5. \((1.2 \times DL) + (1.2 \times LL) + (1.2 \times EZ)\)
6. \((1.2 \times DL) + (1.2 \times LL) + (1.2 \times E-Z)\)
7. \((1.2 \times DL) + (1.2 \times LL) + (-1.2 \times EX)\)
8. \((1.2 \times DL) + (1.2 \times LL) + (-1.2 \times E-X)\)
9. \((1.2 \times DL) + (1.2 \times LL) + (-1.2 \times EZ)\)
10. \((1.2 \times DL) + (1.2 \times LL) + (-1.2 \times E-Z)\)
11. \((1.5 \times DL)\)
12. \((1.5 \times DL) + (1.5 \times EX)\)
13. \((1.5 \times DL) + (1.5 \times E-X)\)
14. \((1.5 \times DL) + (1.5 \times EZ)\)
15. \((1.5 \times DL) + (1.5 \times E-Z)\)
16. \((1.5 \times DL) + (-1.5 \times EX)\)
17. \((1.5 \times DL) + (-1.5 \times E-X)\)
18. \((1.5 \times DL) + (-1.5 \times EZ)\)
19. \((1.5 \times DL) + (-1.5 \times E-Z)\)
20. \((0.9 \times DL) + (1.5 \times EX)\)
21. \((0.9 \times DL) + (1.5 \times E-X)\)
22. \((0.9 \times DL) + (1.5 \times EZ)\)
23. \((0.9 \times DL) + (1.5 \times E-Z)\)
24. \((0.9 \times DL) + (-1.5 \times EX)\)
25. \((0.9 \times DL) + (-1.5 \times E-X)\)
26. \((0.9 \times DL) + (-1.5 \times EZ)\)
27. \((0.9 \times DL) + (-1.5 \times E-Z)\)

**IV. RESULTS AND DISCUSSION**

**Displacement**

Displacement diagram of model 1, model 2 and model 3 are as follows:
Figure 4: Displacement Diagram of 30m length Pipe rack

Figure 5: Displacement Diagram of 35m length pipe rack

Figure 6: Displacement Diagram of 40m length pipe rack

Maximum displacement for model 1, model 2 and model 3 are as follow:

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max X</td>
<td>0.888</td>
<td>8.291</td>
<td>11.912</td>
</tr>
<tr>
<td>Max Y</td>
<td>0.159</td>
<td>23.097</td>
<td>25.086</td>
</tr>
<tr>
<td>Max Z</td>
<td>39.845</td>
<td>39.479</td>
<td>38.133</td>
</tr>
</tbody>
</table>

Comparison of displacements of all the 3 models is as follows:

- Displacement along X direction and Y-Direction is increasing gradually with the increase in the column to column distance.
- The displacement along Z-Direction is slightly decreasing with the increase in column to column distance.

Graph 1: Maximum Displacement

Maximum Displacement
Axial Force

Axial Force diagram of model 1, model 2 and model 3 are as follows:

![Axial Force Diagram of Model 1](image1)

![Axial Force Diagram of Model 2](image2)

![Axial Force Diagram of Model 3](image3)

**Figure 7:** Axial Force of 30m length pipe rack

**Figure 8:** Axial Force of 35m length pipe rack

**Figure 9:** Axial Force of 40m length pipe rack

Maximum Axial force for model 1, model 2 and model 3 are as follows:

<table>
<thead>
<tr>
<th>Model</th>
<th>Maximum Axial Force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>58.842</td>
</tr>
<tr>
<td>Model 2</td>
<td>91.381</td>
</tr>
<tr>
<td>Model 3</td>
<td>119.533</td>
</tr>
</tbody>
</table>

Comparison of Axial Force of all the 3 models is as follows:

- Axial force in case 1 is 35.61% less than axial force in case 2. Axial force in case 2 is 23.55% less than axial force in case 3.

**Graph 2:** Maximum Axial Force
Shear Force

Shear Force diagram of model 1, model 2 and model 3 are as follows:

**Figure 10**: Shear Force of 30m length pipe rack

**Figure 11**: Shear Force of 35m length pipe rack

**Figure 12**: Shear Force of 40m length pipe rack

Maximum Shear Force for model 1, model 2 and model 3 are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Shear Force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>33.913</td>
</tr>
<tr>
<td>Model 2</td>
<td>53.361</td>
</tr>
<tr>
<td>Model 3</td>
<td>54.881</td>
</tr>
</tbody>
</table>

Comparison of Shear Force of all the 3 models is as follows:

- Shear force in case 1 is 36.45% less than shear force in case 2. Shear force in case 2 is 2.77% less than shear force in case 3.

**Graph 3**: Maximum Shear Force
Bending Moment

Bending Moment diagram of model 1, model 2 and model 3 are as follows:

**Figure 13**: Bending Moment of 30m length pipe rack

**Figure 14**: Bending Moment of 35m length pipe rack

**Figure 15**: Bending Moment of 40m length pipe rack

Maximum Bending Moment for model 1, model 2 and model 3 are as follows:

<table>
<thead>
<tr>
<th>Model</th>
<th>Bending Moment (kNm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>94.185</td>
</tr>
<tr>
<td>Model 2</td>
<td>120.361</td>
</tr>
<tr>
<td>Model 3</td>
<td>141.659</td>
</tr>
</tbody>
</table>

Comparison of Bending Moment of all the 3 models is as follows:

- Bending moment of case 1 is 21.75% less than bending moment of case 2. Bending moment of case 2 is 15.03% less than bending moment in case 3.
Support Reaction

Support reaction of 30m length pipe rack is as follows:

<table>
<thead>
<tr>
<th>Node</th>
<th>L/C</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fx kN</td>
<td>Fy kN</td>
<td>Fz kN</td>
</tr>
<tr>
<td>Max Fx</td>
<td>(1.2 X DL) + (1.2 X LL) + (1.2 X E-X)</td>
<td>11.889</td>
<td>51.172</td>
<td>-1.778</td>
</tr>
<tr>
<td>Max Fy</td>
<td>(1.5 X DL) + (1.5 X LL)</td>
<td>-10.670</td>
<td>65.499</td>
<td>1.756</td>
</tr>
<tr>
<td>Max Fz</td>
<td>(1.2 X DL) + (1.2 X LL) + (1.2 X E-Z)</td>
<td>9.921</td>
<td>48.618</td>
<td>4.396</td>
</tr>
</tbody>
</table>

Support reaction of 35m length pipe rack is as follows:

<table>
<thead>
<tr>
<th>Node</th>
<th>L/C</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fx kN</td>
<td>Fy kN</td>
<td>Fz kN</td>
</tr>
<tr>
<td>Max Fx</td>
<td>(1.2 X DL) + (1.2 X LL) + (1.2 X E-Z)</td>
<td>17.718</td>
<td>83.199</td>
<td>-2.769</td>
</tr>
<tr>
<td>Max Fy</td>
<td>(1.5 X DL) + (1.5 X LL)</td>
<td>-13.135</td>
<td>105.046</td>
<td>2.016</td>
</tr>
<tr>
<td>Max Fz</td>
<td>(1.2 X DL) + (1.2 X LL) + (1.2 X E-Z)</td>
<td>13.632</td>
<td>58.451</td>
<td>6.429</td>
</tr>
</tbody>
</table>

Support reaction of 40m length pipe rack is as follows:

<table>
<thead>
<tr>
<th>Node</th>
<th>L/C</th>
<th>Horizontal</th>
<th>Vertical</th>
<th>Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Fx kN</td>
<td>Fy kN</td>
<td>Fz kN</td>
</tr>
<tr>
<td>Max Fx</td>
<td>(1.2 X DL) + (1.5 X LL)</td>
<td>28.605</td>
<td>95.520</td>
<td>-3.600</td>
</tr>
<tr>
<td>Max Fy</td>
<td>(1.2 X DL) + (1.5 X LL) + (1.2 X E-Z)</td>
<td>-17.639</td>
<td>133.541</td>
<td>4.054</td>
</tr>
<tr>
<td>Max Fz</td>
<td>(1.2 X DL) + (1.2 X LL) + (1.2 X E-Z)</td>
<td>21.412</td>
<td>71.978</td>
<td>6.339</td>
</tr>
</tbody>
</table>

V. CONCLUSION

- As utilization ratio for all members is less than one, and deflection of all members is within permissible limit the design is safe for all three cases.
- Cross vertical bracings are used to transmit transverse and longitudinal forces to the foundation.
- Vertical deflection of structural members is more in case 3 as compared to case 1 and case 2 but found to be within limit.
- This helps to reduce the number of columns.
- Tried to maximize the distance between supports by keeping the value of stresses and deflection within safe limits.
- Tonnage of model 1 is found to be 10.06 Tonnes. Tonnage of model 2 is found to be 12.73 Tonnes and tonnage of model 3 is found to be 15.75 Tonnes.
- For the deflection check: Height of pipe rack = 8000mm. Allowable deflection= H/150=53.33mm. As per Indian code criteria. Actual deflection<53.33mm. So structure is safe in deflection.
- All the utility ratios are less than 1 which is an allowable ratio.
- So the design and analysis has been followed as per the codes IS 800:2007.
VI. REFERENCES


[4] “Minimum design loads for buildings and other structures (ASCE 7-10).” American Society of Civil Engineers (ASCE), (2010)


[16] Siyu Xua, Yufei Wanga, Xiao Feng, “Plant Layout Optimization with Pipe Rack and Frames,” CHEMICAL ENGINEERING TRANSACTIONS(Cet) VOL. 81, 2020
