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Optimization of Pipe Rack by Study of Braced Bay

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***Abstract*: Steel pipe racks are commonly used in oil and gas industry to support pipes and cables. They are very complex and long structures. The real common problem in industry is taken and an attempt is made for optimization by changing the position and pattern of bracing. Three cases were considered for study. In this, first case is pipe rack with bracings are provided at 6th bay from either side, second is pipe rack with bracings at center and third is pipe rack same as case I with split at center. The use of software STAAD-Pro is done for analysis and design. IS 800:2007 along with other relevant codes is used. It is observed that the most optimized design is obtained when bracing is provided at the center.**

***Keywords*: non-building structures, pipe, transverse, racks, support, design, optimization**

1. Introduction

Pipe networks are considered as main components of industrial complexes like refineries and petrochemicals that transfer fluid and gas. Main pipe racks generally transfer material between equipment and storage. A pipe rack is the main artery of a process unit. Pipe racks carry process and utility piping and may also include instrument and cable trays as well as equipment mounted over all of these. Pipe racks consist of a series of transverse bents that run along the length of the pipe system, spaced at uniform intervals typically around 20 ft. To allow maintenance access under the pipe rack, the transverse bents are typically moment frames. Transverse bents are typically connected with longitudinal struts.

Three types of pipe racks are designed for similar loading. In first case the bracings in longitudinal direction are provided at two bays at 6 m from both sides. In second case bracings are provided at center of pipe rack. In third case bracings are similar to first case but pipe rack is split at center.

- The general dimensions of pipe rack are as below:
- Total length of pipe rack: 138 m
- Each longitudinal span: 6 m
- Transverse span: 6 m
- Elevation of first tier: 12 m
- Elevation of second tier: 9 m
- Elevation of third tier: 6 m

The location of pipe rack is considered as Haldia in West Bengal.

A. Model description

The pipe rack structure is located at Haldia in West Bengal. The total length of structure is 138m having 23 bays and each bay is of 6m.Width of pipe rack is 6m and height is 12m. First case has the anchor bay at 2 sides of rack, 2nd case has anchor bay at middle and 3rd at 2 sides of rack with structure cut at center. Fig.2. shows 2D model of pipe rack and Fig.3. shows 3D model of pipe rack.

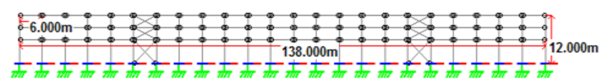

Fig. 1. 2D model of pipe rack

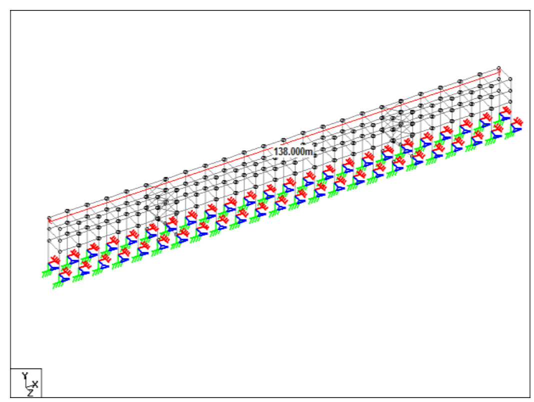

Fig. 2. Isometric view of pipe rack

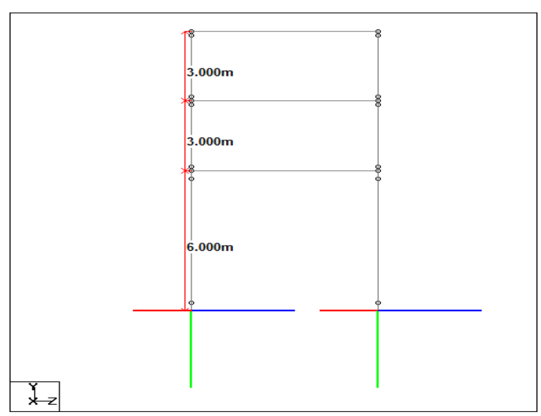

Fig. 3. Front view of pipe rack

B. Case I: pipe rack with bracings are provided at 6th bay from either side

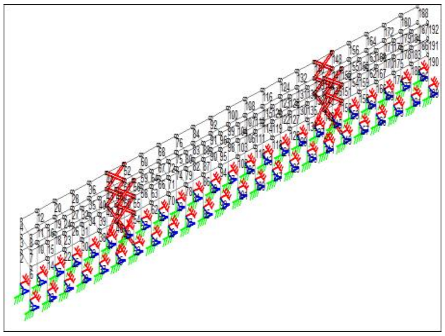

Fig. 4. Geometry of Pipe Rack with Bracings provided at 6th Bay from either Side

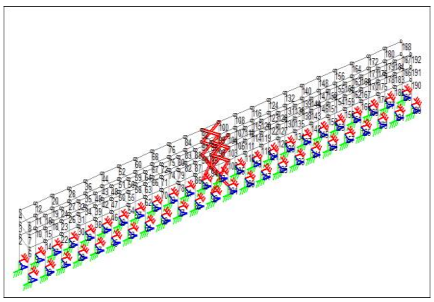

Fig. 5. Geometry of pipe rack with bracings at center

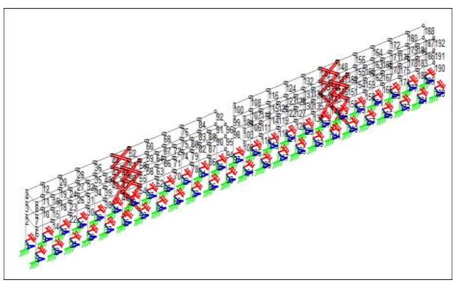

Fig. 6. Geometry of Pipe Rack Same as Case I with Split at Center

a) Section property

In this design of case I, by trial and error method, various sections for beam and column & bracing are assigned up to which utilization faction is less than unity and deflection limits should be satisfied by the structure.

b) Specification of structure

Beams in longitudinal (X) direction are provided releases at supports as bracings are provided in this direction. This mean the longitudinal frames are not moment resisting. Beams in transverse (Z) direction are not released as transverse frames are modeled is moment-resisting frames.

c) Supports

Fixed butt supports are considered for all columns.

d) Loads considered to design pipe rack

1) Dead Load

Dead load shall include the weight of all process equipment, pipes, valves and accessories, electrical and lighting conduits, trays, switchgear, instrumentation, insulation, structural steel plates and shapes, etc.

I. Pipe Empty Load (PEL)

The empty weight of piping, piping insulation, cable tray, process equipment and vessels. When plant is shut down using approximate uniform loads, 60% of the operating dead load for piping levels is typically used. Engineering judgment should be used for cable tray levels.

Table 1
Pipe empty load (Loading data from piping department)

S. No.	Elevation (m)	Dead load (kN/m)
1.	12	6
2.	9	7.5
3.	6	9

II. Pipe Operating Load (POL)

The operating dead load is the weight of piping, piping insulation, cable tray, process equipment and vessels plus their contents (fluid load). When plant is operating the piping and cable tray loads may be based on actual loads or approximated by using uniform loads.

Table 2
Pipe Operating Load (Loading data from piping department)

S. No.	Elevation (m)	Dead load (kN/m)
1.	12	9
2.	9	10.5
3.	6	12

III. Pipe Test Load (PTL)

The test load shall be defined as the gravity load imposed by the liquid (normally water) used to pressure test the piping. Large vapor lines may require hydro testing. If so, it may be possible to test them one at a time while the other lines on the support are empty and thus avoid the heavy pipe support loading. When such procedures are used, special notes should be placed on the structural and piping drawings to specify test procedures. Small vapor lines are normally considered filled with water.

Table 3
Pipe Test Load (Loading data from piping department)

S. No.	Elevation (m)	Pipe test load (kN/m)
1.	12	13.5
2.	9	11.34
3.	6	18

2) Earthquake /Seismic Load (E)

As per IS 1893 (Part 1): 2016, following parameters are considered,

1) Seismic zone factor (III) Z= 0.16 (Clause no.6.4.2, Table no.3, Page no. 10)
2) Response reduction factor = 4 (Clause no.7.2.6 Table no.9, Page no. 20)
3) Importance factor = 1 (Clause no.7.2.3 Table no.8, Page no. 19)
4) Rock and soil site factor = 1

3) Pipe Anchor and Guide Load

Anchor forces may dictate the use of horizontal channels or horizontal bracing as well vertical bracing at anchor bents. This should not occur too frequently since Piping Engineering like to anchor large lines on only a few bents in a pipe way. Anchor and guide forces and locations shall be obtained from the piping stress analysis and piping isometric drawings.

Pipe anchor and guide forces produced from thermal expansion, internal pressure, and surge shall be considered as dead loads. Pipe racks beams, struts, columns, braced anchor frames, and foundations shall be designed to resist actual pipe anchor and guide loads.

Table 4
Pipe anchor and guide load (Loading data from piping department)

S. No.	Elevation (m)	Anchor load (kN/m)	Guide load (kN/m)
1.	12	1.35	0.9
2.	9	1.57	1.05
3.	6	1.8	1.2

4) Temperature load

5) Wind load

Wind load is considered in following directions:

1) Wind Load(+X)
2) Wind Load (-X)
3) Wind Load(+Z)
4) Wind Load(-Z)

Calculation of Wind load

Design Wind Speed (V_z)

Pipe rack location = Haldia, West Bengal

$V_z = V_b k_1 k_2 k_3 k_4$

Where,

V_z = design wind speed at any height z in m/s,

k_1 =1= probability factor (risk coefficient) (IS 875 (Part 3):2015, Clause no.6.3.1, Table no. 1, Page no. 7)

k_2 = terrain roughness and height factor (IS 875 (Part 3):2015, Clause no. 6.3.2.2, Table no. 2, Page no.8)

k_3 =1= topography factor (IS 875 (Part 3):2015, Clause no. 6.3.3.1, Page no. 8)

k_4 =1.15= importance factor for the cyclonic region (IS 875 (Part 3):2015, Clause no. 6.3.4, Page no. 9)

Table 5
Value of k_1, k_2, k_3, k_4

Height (m)	k_1	k_2	k_3	k_4
0	1	1.05	1	1.15
10	1	1.05	1	1.15
15	1	1.09	1	1.15

$V_z = V_b k_1 k_2 k_3 k_4$

V_b = 44 as per, IS 875(Part 3): 2015, Clause no. 6.3.1, Pg. no 7

V_z = 1x1.05x1x1.15x44
= 53.13m/s

Design Wind Pressure

The wind pressure at any height above mean ground level shall be obtained by the following relationship between wind pressure and wind speed

$P_z= 0.6V_z^2$
$= 1.69$ kN/m^2

Where, p_z = wind pressure in kN/m^2

Table 6
Value of V_z and P_z

Height (m)	k_2	V_z (m/s)	P_z (kN/m^2)
0	1.05	53.13	1.69
10	1.05	53.13	1.69
15	1.09	55.15	1.82

C. Load combinations

1) Serviceability Load Combination

i. Plant Empty Condition

A. D.L
B. D.L+0.8W.L
1. DL+0.8WL(X)
2. DL+0.8WL(-X)
3. DL+0.8WL(Z)
4. DL+0.8WL(-Z)
C. D.L+0.8E.L
1. DL+0.8EQX+0.24EQZ
2. DL+0.8EQX-0.24EQZ
3. DL-0.8EQX-0.24EQZ
4. DL-0.8EQX+0.24EQZ
5. DL+0.24EQX+0.8EQZ
6. DL+0.24EQX-0.8EQZ
7. DL-0.24EQX-0.8EQZ
8. DL-0.24EQX+0.8EQZ
D. D.L+W.L
1. DL+PEL+WL(X)
2. DL+PEL+WL(-X)
3. DL+PEL+WL(Z)
4. DL+PEL+WL(-Z)
E. D.L+E.L
1. DL+EQX+0.3EQZ
2. DL+EQX-0.3EQZ
3. DL-EQX-0.3EQZ
4. DL-EQX+0.3EQZ
5. DL+0.3EQX+EQZ
6. DL+0.3EQX-EQZ
7. DL-0.3EQX-EQZ
8. DL-0.3EQX+EQZ

ii. Plant Operating Condition

A. DL
1. DL
B. DL+0.8WL
1. DL+0.8WL(X)
2. DL+0.8WL(-X)
3. DL+0.8WL(Z)
4. DL+0.8WL(-Z)
C. DL+0.8EQ
1. DL+0.8EQX+0.24EQZ
2. DL+0.8EQX-0.24EQZ
3. DL-0.8EQX-0.24EQZ

4. DL-0.8EQX+0.24EQZ
5. DL+0.24EQX+0.8EQZ
6. DL+0.24EQX-0.8EQZ
7. DL-0.24EQX-0.8EQZ
8. DL-0.24EQX+0.8EQZ

D. DL+WL
1. DL+WL(X)
2. DL+WL(-X)
3. DL +WL(Z)
4. DL +WL(-Z)

E. DL+EQ
1. DL+EQX+0.3EQZ
2. DL+EQX-0.3EQZ
3. DL-EQX-0.3EQZ
4. DL-EQX+0.3EQZ
5. DL+0.3EQX+EQZ
6. DL+0.3EQX-EQZ
7. DL+-0.3EQX-EQZ
8. DL-0.3EQX+EQZ

iii. Plant Test Condition

A. DL
1. DL

B. DL+0.8WL
1. DL+0.8WL(X)
2. DL+0.8WL(-X)
3. DL+0.8WL(Z)
4. DL+0.8WL(-Z)

C. DL+0.8EQ
1. DL+0.8EQX+0.24EQZ
2. DL+0.8EQX-0.24EQZ
3. DL-0.8EQX-0.24EQZ
4. DL-0.8EQX+0.24EQZ
5. DL+0.24EQX+0.8EQZ
6. DL+0.24EQX-0.8EQZ
7. DL-0.24EQX-0.8EQZ
8. DL+-0.24EQX+0.8EQZ

D. DL+WL
1. DL+WL(X)
2. DL+WL(-X)
3. DL+WL(Z)
4. DL+WL(-Z)

E. DL+EQ
1. DL+EQX+0.3EQZ
2. DL+EQX-0.3EQZ
3. DL-EQX-0.3EQZ
4. DL-EQX+0.3EQZ
5. DL+0.3EQX+EQZ
6. DL+0.3EQX-EQZ
7. DL-0.3EQX-EQZ
8. DL-0.3EQX+EQZ

2) Strength Load Combination

i. Empty Condition

1. 1.5DL
2. 1.2DL + 0.6WL
3. 1.2DL + 0.6EL
4. 1.5DL + 1.5WL
5. 0.9DL + 1.5WL
6. 1.5DL + 1.5EL
7. 0.9DL + 1.5EL

ii. Operating Condition

1. 1.5DL
2. 1.2DL+ 0.6WL
3. 1.2DL+ 0.6EL
4. 1.5DL+ 1.5WL
5. 0.9DL+1.5WL
6. 1.5DL+1.5EL
7. 0.9DL+1.5EL

iii. Test Condition

1. DL
2. DL + 0.6WL
3. DL + 0.6EL
4. DL + 1.5WL
5. 0.9DL + 1.5WL
6. 1.5DL + 1.5EL
7. 0.9DL + 1.5EL

2. Result and discusions

Results of maximum deflection, maximum utilization ratio and tonnage for three cases are given below:

Table 7
Result of maximum deflection

Cases	Max. X(mm)	Max. Y(mm)	Max. Z(mm)
Pipe rack with bracings are at 6th bay from either side	4.29	1.36	15.91
Pipe rack with central bracing	7.11	1.67	14.17
Pipe rack same as case 1with split at center	4.1	1.37	16.22

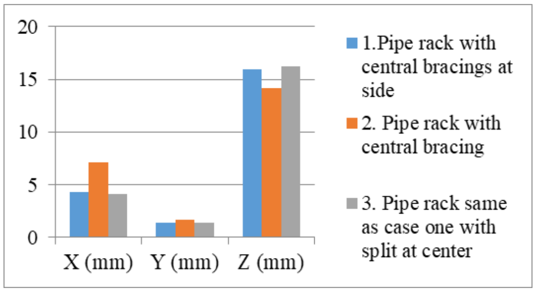

Fig. 7. Deflection of Beam (X & Z) and Column(Y)

Table 8
Result of strength for maximum utility ratio

Cases	Column	Beam	Bracing
Pipe rack with bracings at 6th bay from either side	0.96	0.84	0.57
Pipe rack with central braced bay	0.96	0.89	0.66
Pipe rack same as case 1 with split at center	0.96	0.94	0.56

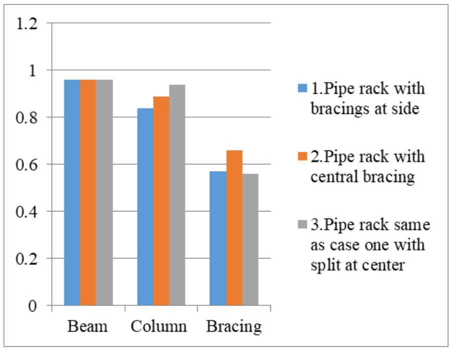

Fig. 8. Utilization of beam, column and bracing

Table 9
Result of tonnage

Cases	Steel quantity in tones (T)
Pipe rack with two braced bay at side	102.01
Pipe rack with central braced bay	97.96
Pipe rack same as case 1 with split at center	101.58

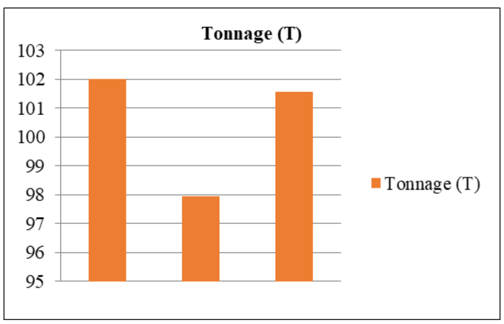

Fig. 9. Graph of tonnage

3. Conclusion

From the results it can be concluded that,

- 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.
- Vertical deflection of structural members is less in case two i.e. pipe rack with bracing at center than case one i.e. pipe rack with bracings at 6th bay from either side and case three i.e. pipe rack same as case one but split at center.
- Steel quantity for case one i.e. pipe rack with bracings are provided at 6 m from either side is 102.01 tones, for case two i.e. pipe rack with bracings at center is 97.96 tones and for case three i.e. pipe rack same as case one with split at center is 101.58 tones i.e. steel required is more by 5% and 4% in case one and case three respectively, as compared to case two.
- So, case two i.e. pipe rack with bracing at center is economical than case one and case three i.e. pipe rack with bracing at two sides and pipe rack same as case one but split at center.
- The structural arrangement in case two i.e. pipe rack with bracings at center is optimum solution.

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