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Optimization in Design and Construction of Pipe Rack based on Location of Braced bay and introduction of loops in piping system

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Abstract*—A pipe support is a steel structure which is used to support pipes inside a plant. It is used to transfer liquid between production equipment to storage facility. Optimization of steel pipe supporting structures in an oil & gas industry is complex and one of the important parts of structural systems for safe production processes. In this work steel pipe rack is designed for four different case i.e. one and two loops in the piping system and two different locations of braced bays. The results are further compared for the most optimized design.

***Keywords*— Pipe rack, pipe frame, braced bay, design, construction optimization**

I. INTRODUCTION

Pipes carrying fluids like chemicals, steam, oil, water and many more, are usually laid between numerous components in any petrochemical, power or chemical and processing plants. It is not always feasible to support them on ground but at an elevated structure in order to avoid any obstruction and enable easy accessibility for maintenance. A pipe rack is the main channel of a process unit. Pipe racks carry process and utility pipes and also support cable trays. Pipe support design is an imperative module of process engineering. Model piping support design should take into consideration the thought of cost of installation, consideration of pressure loss on production, concern of stress level, effects of support and anchor, stability, maintenance ease, capacity of expansion etc. It should be least expensive over a long term. A pipe support is an element that transfers the load from a pipe to the supporting structure. The load includes the self-weight of the pipe, the content of the pipe fluid, all the pipe connections attached to pipe, and the pipe covering like insulation around the pipe. The key role of a pipe support is to anchor, guide, absorb shock, and sustain the load. The overall design configuration of a pipe support is dependent on the loading as well as operating conditions. If the piping system is not appropriately supported, many problems may rise. Mainly, the problems that generally occur are due to bending in the flange joints, bending of pipes, vibration, undue movement, higher deflection, line overstress and equipment nozzle overload and faulty piping support design. To avoid all these glitches, it is very important that your pipe support design is proper. Piping supports analysis and designs and the choosing of support material help improve the value of piping. There are ASME standards to ensure proper piping support.

Four cases are taken into consideration for design. Pipe stress analysis results for one expansion loop and two expansion loops are taken and its reactions are applied to the pipe rack structure. Also two different location of braced bay, one at two second last bays and one at middle bay are considered.

The geometry of the pipe rack is as below

- Total length of pipe rack is 63 m
- Each longitudinal span is 7 m
- Transverse span is 2 m
- Elevation of first tier is at 4 m
- Elevation of second tier is at 6 m
- Location of pipe rack is considered at Pune, Maharashtra.

II. MODEL GEOMETRY AND LOADING

A. STAAD model and Piping description

The pipe rack is considered to be located at Pune, Maharashtra. The Overall length of pipe rack is 63m. It has 9 bays each of length 7m. The width of pipe rack is 2 m and height is 6 m. First tier is at 4 m and second tier is at 6m. For single loop piping system two cases are considered. In case one the braced bay is considered in the middle part of the pipe rack i.e. the 5th bay. In second case two braced bays are considered one at 2nd bay and one at 8th bay. Same two cases are considered for two loops in the pipe system. Fig.1 shows piping with one loop, Fig.2 shows piping with two loops, Fig.6 Shows Case 1 geometry of pipe rack i.e. bracing at central bay and Fig.7 shows case 2 geometry of the pipe rack i.e. two braced bays.

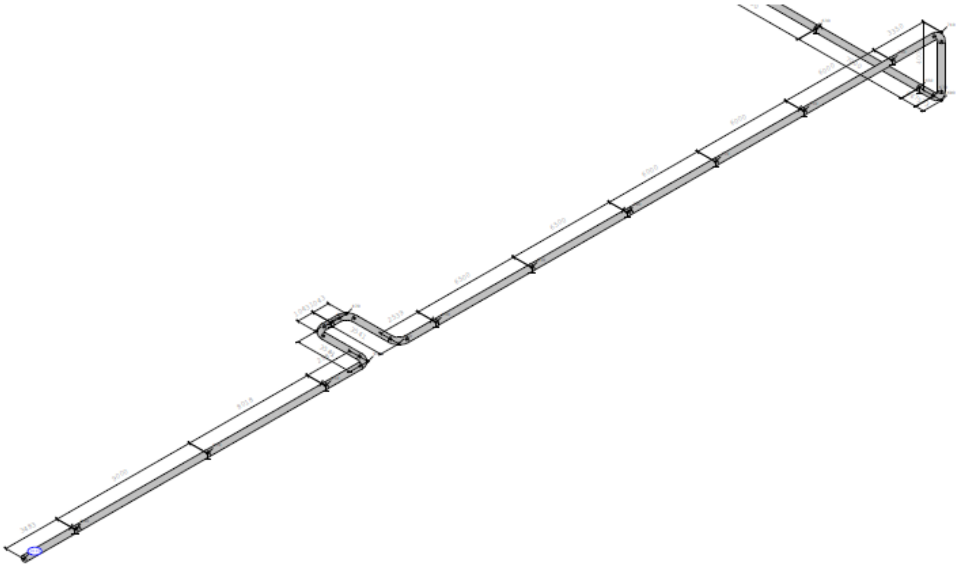


Fig. 1 One loop piping system

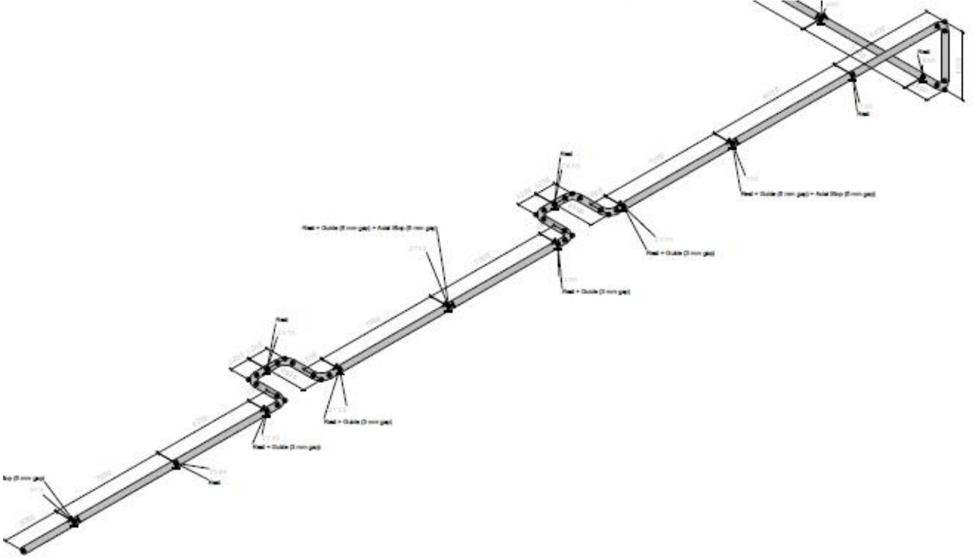


Fig. 2 Two loop piping system

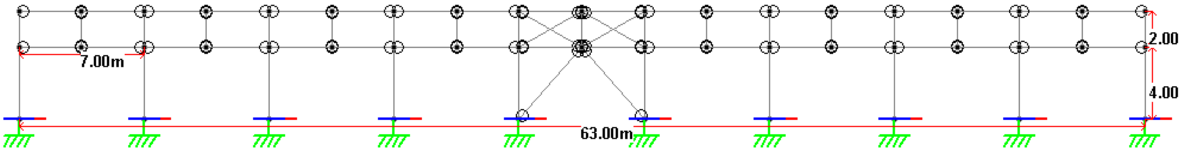


Fig. 3 Two dimensional model of Pipe Rack

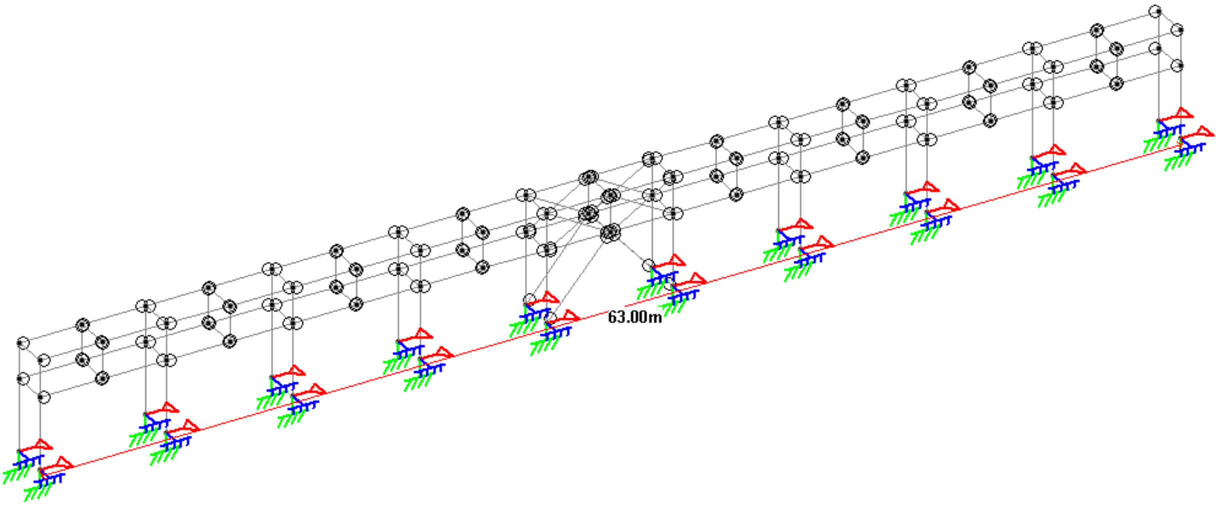


Fig. 4 Isometric view of Pipe Rack

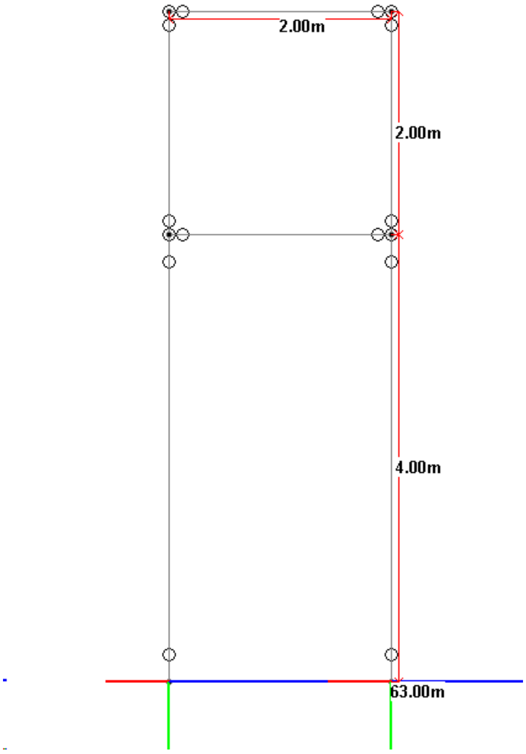


Fig. 5 Front View if Pipe rack

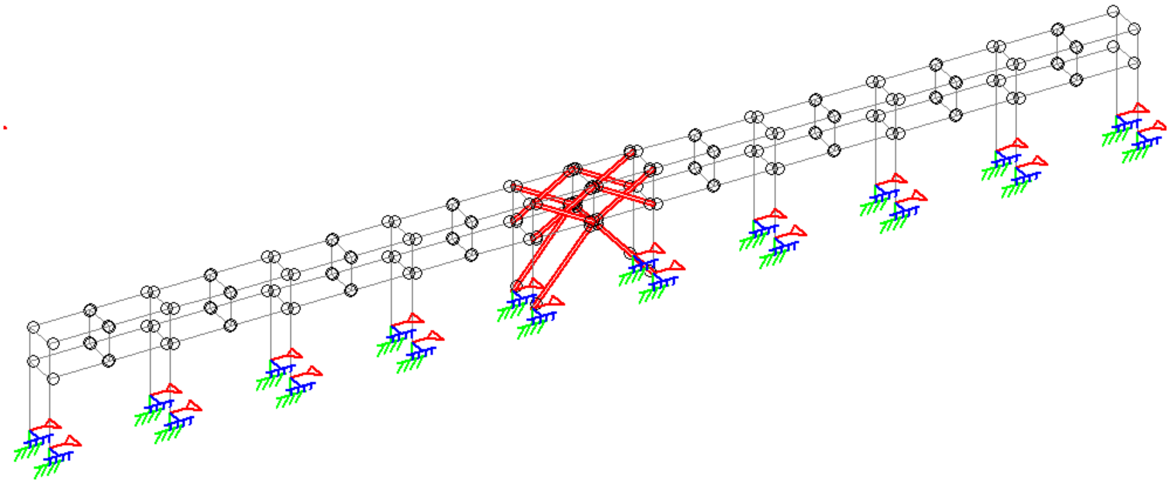


Fig. 6 Pipe rack with central braced bay

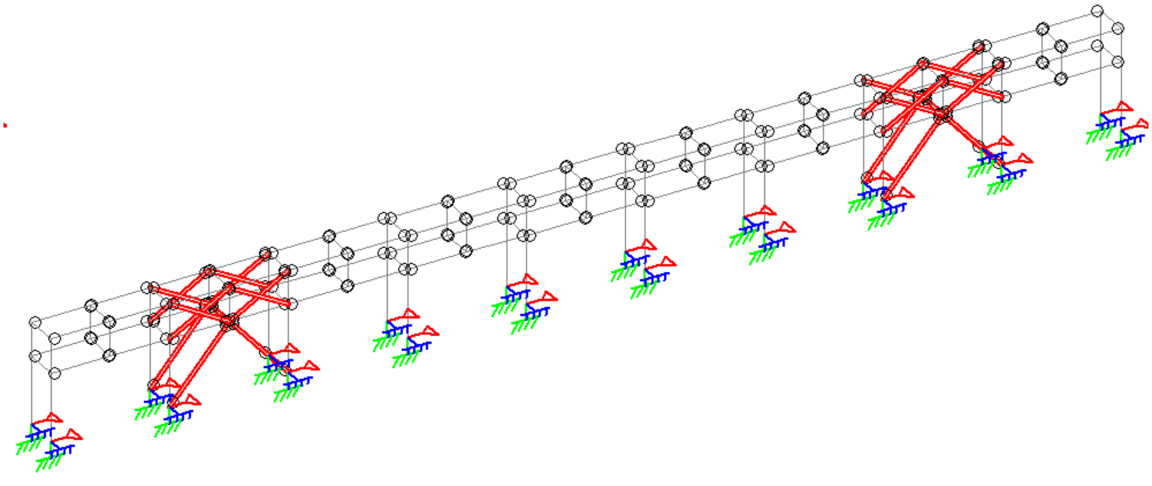


Fig. 7 Pipe rack with 2nd and 8th braced bay

B. Section Properties

Section properties are assigned to different elements like column, beam and bracings of the structure by trial and error method so that the utilization ratio of the elements is within permissible limit of 1. Also serviceability checks such as deflection are within the permissible limits.

C. Specifications of the structure

In STAAD model, the beams in longitudinal (X) direction are released at the column junction and bracings are provided in this direction. The connections in longitudinal directions are shear connections. In transverse (Z) direction the frame is modeled as moment resisting and bracings are not provided in transverse direction. The connections in transverse directions are moment connections.

D. Supports

Fixed But supports are considered for all columns. The supports are released in transverse direction as moment connections are provided.

E. Load Considered for Pipe rack design

1) *Dead Load*: Dead Loads will include the total self-weight of the structural materials/ components, platforms, all permanent externally applied loads for fixed loads and other equipment including their content. Following load cases are included under dead load.

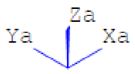
I. Pipe Empty Load – Pipe Empty load case consists of the pipe's dead weight, weight of the insulation and other sustained working primary loads.

II. Pipe Operating Load –This load case includes the weight of pipe including the contents of the pipe. This includes pipe operation condition means, Friction, anchor and temperature loads on pipe.

III. Equipment test Load - This load case includes the weight of piping during hydrostatic testing after erection/ installation, including the weight of water within pipe. This load is as input from piping analysis

Below are the reactions for piping loads considering two cases i.e. with one and two loops. Piping stress analysis is performed in ROHR software. The reactions are applied as load in STAAD model of pipe rack. Below are the comparison of directions of ROHR and STAAD.

ROHR axis



STAAD axis

TABLE I
PIPE REACTION TABLE

1-Loop					**2-Loop**		
		Forces			**Forces**		
ROHR Directions		**Aqx**	**Aqy**	**Aqz**	**Aqx**	**Aqy**	**Aqz**
STAAD directions		**Fx**	**Fz**	**Fy**	**Fx**	**Fz**	**Fy**
Node	**Load Case**	**kN**	**kN**	**kN**	**kN**	**kN**	**kN**
990	Dead	0.003494	-0.00046	-13.654	0.00014	-6E-06	-12.585
	Empty	0.00168	-0.00023	-6.342	0.000065	-3E-06	-5.842
	Operation	-23.3057	-0.19969	-13.654	-27.612	-0.70978	-12.585
	Wind x	0	0	0.000	0.877	0.0092	0.000
	Wind y	0	0	0.000	-0.65138	3.84859	0.001
	Equipment Test	0.003074	-0.00038	-11.114	0.000123	-5E-06	-10.245
	Friction			-4.779			-4.405
970	Dead	0	0	-14.187	0	0	-11.061
	Empty	0	0	-6.546	0	0	-5.116
	Operation	3.949	-1.583	-14.183	2.777	-1.816	-11.061
	Wind x	0	0	0.000	0	0	0.000
	Wind y	0	0	0.000	0	0	-0.004
	Equipment Test	0	0	-11.551	0	0	-8.997
	Friction			-4.965			-3.871
950	Dead	0	0.005165	-14.691	0	0.000157	-8.817
	Empty	0	0.00253	-6.945	0	0.000073	-4.206
	Operation	4.398	0.109	-14.667	2.97	1.079	-8.821
	Wind x	0	0	0.000	0	0.275	-0.001
	Wind y	0	0	0.000	0	4.189	-0.012
	Equipment Test	0	0.00439	-11.979	0	0.000137	-7.207
	Friction			-5.142			-3.086
830	Dead	0	-0.01591	-13.764	0	-0.00082	-9.664
	Empty	0	-0.0078	-6.533	0	-0.00039	-4.594
	Operation	-4.384	1.011	-13.604	-3.489	1.94	-9.689
	Wind x	0	0	0.000	0	-0.266	-0.005
	Wind y	0	0	0.000	0	1.465	-0.065
	Equipment Test	0	-0.01345	-11.231	0	-0.00069	-7.906
	Friction			-4.817			-3.382
810	Dead	0	0	-9.997	-0.044	0.0034	-14.607
	Empty	0	0	-4.587	-0.0205	0.00166	-6.757
	Operation	-2.807	-1.114	-10.069	5.56	-5.016	-14.570
	Wind x	0	0	0.000	1.774	0.01325	0.004
	Wind y	0	0	0.000	0.784	3.374	0.061
	Equipment Test	0	0	-8.139	-0.038	0.00288	-11.871
	Friction			-3.499			-5.112
790	Dead	-0.00028	0.05977	-10.970	0	-0.05198	-9.101
	Empty	0.00006	0.02958	-5.103	0	-0.024	-4.334
	Operation	8.236	-0.749	-10.919	2.706	0.355	-9.097
	Wind x	0	0	0.000	0	0.247	0.028
	Wind y	0	0	0.000	0	2.349	0.237
	Equipment Test	0.00116	0.05	-8.929	0	-0.044	-7.446
	Friction			-3.840			-3.185

770	Dead	0	0	-10.121	0	0.257	-9.392
	Empty	0	0	-4.699	0	0.123	-4.471
	Operation	3.054	0.346	-10.247	-3.342	2.541	-8.598
	Wind x	0	0	0.000	0	-0.238	0.017
	Wind y	0	0	0.000	0	0.437	0.928
	Equipment Test	0	0	-8.239	0	0.212	-7.683
	Friction			-3.542			-3.287
750	Dead	0	-0.126	-9.885	-0.12	-0.356	-14.192
	Empty	0	-0.062	-4.563	-0.057	-0.171	-6.569
	Operation	4.009	-2.151	-11.213	12.186	3.636	-16.174
	Wind x	0	0	0.000	3.021	-0.097	0.179
	Wind y	0	0	0.000	-0.263	6.515	-0.491
	Equipment Test	0	-0.105	-8.045	-0.096	-0.292	-11.541
	Friction			-3.460			-4.967
730	Dead	0	0	-10.536	0	0	-14.186
	Empty	0	0	-4.946	0	0	-6.602
	Operation	0	0	0.000	2.365	-0.939	-8.484
	Wind x	0	0	0.000	0	0	-1.023
	Wind y	0	0	0.000	0	0	0.689
	Equipment Test	0	0	-8.589	0	0	-11.554
	Friction			-3.688			-4.965
710	Dead	0	0	-10.536	0	0	-14.186
	Empty	0	0	-4.946	0	0	-6.602
	Operation	0	0	0.000	2.365	-0.939	-8.484
	Wind x	0	0	0.000	0	0	-1.023
	Wind y	0	0	0.000	0	0	0.689
	Equipment Test	0	0	-8.589	0	0	-11.554
	Friction			-3.688			-4.965

2) *Seismic Load*: As per IS1893(Part 1) : 2016 following parameters are considered.

- Seismic zone factor (III) Z= 0.16
- Response reduction factor = 4
- Importance factor = 1
- Rock and soil site factor = 2
- Damping Ratio = 0.02

3) *Temperature Load:* Temperature load Thermal/Temperature load consist of Self-straining force arising from contraction or expansion resulting from temperature change, shrinkage, moisture change, creep in component materials, movement due to differential settlement or combinations thereof. Thermal load is applied as variation of temperature with respect to ambient temperature. Thermal variation increase, $+\Delta T = 20\ ^{0}C$

4) *Wind Load:* Wind load is applied in X and Z directions and is calculated as per IS875- Part 3 as below.

Pipe rack location = Pune, Maharashtra.
Vz = Vb k1 k2 k3 k4
Where, Vz = design wind speed at any height z in m/s,
k1 =1= probability factor (risk coefficient)
k2 =1.05=terrain roughness and height factor
k3 =1= topography factor
k4 =1 = importance factor for the cyclonic region
Vb= 39 m/s= Basic wind speed in Pune
Vz= 39x1x1.05x1x1= 40.95 m/s
Pz=0.6xVz2 = 0.6x40.952 = 1.1 kN/m2
Where Pz= Wind Pressure in kN/m2

F. Load Combinations

Load combinations are applied as per standards for pipe rack design. All the Pipe Empty, Operation, Wind and Seismic cases are taken into consideration for design. Serviceability combinations as well as Strength combinations were applied to the model.

III. RESULT AND DISCUSSION

Results comparison for deflection, Utility ratio and Tonnage are as below.

TABLE III
DEFLECTION COMPARISON TABLE

Case	**Maximum X(mm)**	**Maximum Y(mm)**	**Maximum Z(mm)**
1 loop Central braced bay	8.157	1.98	13.167
1 loop 2nd and 6th braced bay	4.323	2.005	12.286
2 loop Central braced bay	8.277	2.006	15.155
2 loop 2nd and 6th braced bay	4.356	2.006	15.246

TABLE IIIII
UTILITY RATIO COMPARISON TABLE

Case	**Column**	**Beam**	**Bracing**
1 loop Central bay	0.553	0.635	0.728
1 loop 2nd and 6th braced bay	0.553	0.635	0.759
2 loop Central braced bay	0.582	0.714	0.728
2 loop 2nd and 6th braced bay	0.581	0.714	0.768

TABLE IVV
TONNAGE COMPARISON TABLE

Case	**Tonnage (kN)**
1 loop Central bay	260.47
1 loop 2nd and 6th braced bay	295.43
2 loop Central braced bay	260.47
2 loop 2nd and 6th braced bay	295.43

IV. CONCLUSIONS

Based on above comparison we can conclude as follows.

- Though expansion loops are introduced in piping system to reduce expansion stresses in pipe, it introduces longitudinal and transverse forces in piping system at the loop location due to change in direction of flow in the operating condition.
- Horizontal deflection in longitudinal direction is minimum in case of 1 loop, 2nd and 6th braced bay.
- Horizontal deflection in transverse direction is minimum in case of 1 loop, 2nd and 6th braced bay.
- Vertical deflection is almost same in all cases.
- Utility ratio is minimum in 1 loop system in Columns and Beams.
- Tonnage wise central braces bay is economical.
- Over all it can be concluded that the single loop system with 2nd and 6th braced bay is the most optimized option for pipe rack.

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