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Comparative Study of Pipe Rack Structure with Modular Concept and Normal Stick-built Approach using ASCE 7-02

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Abstract—*Pipe rack structure is the most important structure in the field of liquid production industries and petrochemical refineries and so it is necessary to analyze and design in order to satisfy the different parameters of safety and economy. In this study, the location of pipe rack structure is taken at 100 miles away from the costal line in Whiting, Indiana of the North America. The height of the pipe rack structure is 25.0 m having 6.0 m tier width and 6.0 m bay spacing. Modular Pipe rack structure having seven tiers of piping load assembly is designed for its land transportation analysis, water transportation analysis and lifting analysis to ensure safety of the individual members of the structure. The critical load combination in which maximum deflection of the tiers occurs is pipe operating condition in the dominance of the wind. The aim of the study is to carry out the check of the behavior of structure in each approach and cost comparison in terms of design results and material usage. The further study is to compare both the structures by applying knee bracing system.*

Keywords*: Pipe rack structure, Modular pipe rack structure, Land Transportation Analysis, Water Transportation Analysis, Lifting Analysis, Knee bracing system*

1. INTRODUCTION

21th century is the "Century of Speed", means people want to work as fast as possible. In construction sector, more technologies and innovative techniques are being explored for a faster and economical work. As a better option to this, "modularization" technique proves a lucrative option in the field of industrial sector.

Modularization is fabricating and pre-assembling plant elements far from the actual plant location. A module is a product resulting from a series of remote assembly operations, the largest transportable unit or component of a facility and a volume fitted with all structural elements, finishes and process components which are designed to occupy that space. It imparts many benefits in the construction process. It is useful when the location of site does not have sufficient work space. Also it is a better option when there is a lack of skilled labors at the site. Construction activities are not placed particularly when inhospitable work conditions due to bad weather like storm, hurricane or heavy rain/snow fall occurs; modularization is helpful in all those situations. Each and every competitor seeks for faster and economical procedure in order to start their plant activities as soon as possible, module strategy satisfies this demand.

Pipe rack is a structure whose basic geometry is like a portal frame having multi-tiers which are provided to support piping assembly, cable trays and (with) fin-fan coolers or without coolers. Pipe rack is the main artery of a process unit. It connects all equipment with lines that cannot run through adjacent areas. Because it is located in the middle of the most plants, the pipe rack must be erected first, before it becomes obstructed by rows of equipment [1]. Pipe racks carry process, utility piping and also include instrument and electrical cable trays as well as equipment mounted over all of these.

2. PROBLEM DEFINITION

The pipe rack structure taken is the actual project located in Whiting, Indiana in North America. It is a petrochemical production plant. It is 100 miles away from the coastal line of North America. The structure is analyzed first for the static analysis with normal site condition. During this analysis, there are no transportation loads taken in the structure [2].Table 1 shows the problem data used in the analysis. Fig. 1 shows the drawing of the pipe rack structure taken for the analysis purpose.

Table 1: Problem Data

Sr. No.	Data	value
1	Height from the G.L.	25.0 m
2	Rack width	6.0 m

3	C/c spacing of columns	6.0 m
4	Ground level	100.0 m
5	1st Tier level	106.5 m
6	2nd Tier level	111.5 m
7	3rd Tier level	113.5 m
8	4th Tier level	115.0 m
9	5th Tier level	119.5 m
10	6th Tier level	122.5 m
11	7th Tier level	125.0 m

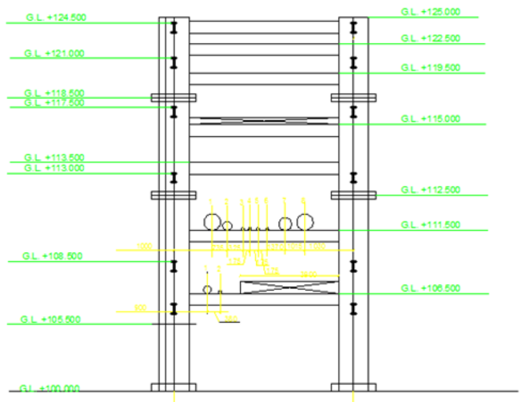

Fig. 1 Pipe rack Problem

2.1 Pipe rack loadings

1. Self weight - It is the dead weight of the structure.
2. Pipe operating load - A uniformly distributed load of 40 psf (190 kg/ m^2) for piping, product and insulation is taken. For any pipe larger than 12" dia., a concentrated load, including the weight of piping, product, valves, fittings and insulation are used as 40 psf (Cl. 4.1.2.5)[3,4].
3. Pipe empty load - For checking uplift and components controlled by minimum loading, 60 % the estimated piping operating loads are taken if combined with wind or earthquake unless the actual conditions require a different percentage (Cl. 4.1.2.5)[3,4].
4. Cable tray operating load - A uniformly distributed dead load of 20 psf (1.0 kPa) is taken for a single level of cable tray and 40 psf for a double level of cable trays (Cl. 4.1.2.6)[3,4].
5. Pipe friction loads – It is load caused by friction forces generated during working condition of pipes when they are sliding in lateral directions and it is applied in both lateral directions as 10 % of the operating pipe loads (Cl. 4.1.7)[3,4].
6. Pipe restraint / thermal anchor loads – These are self-straining thermal forces caused by the restrained expansion of structural members. Thermal loads are included with operating loads in the appropriate load combinations.

Fig. 2 shows the geometry of the problem prepared in the staad pro software.

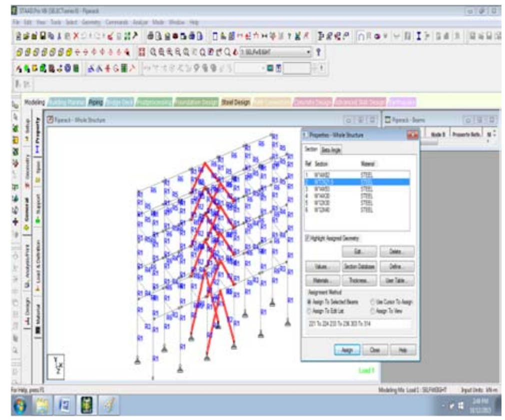

Fig. 2 Geometry in Staad

3. WIND ANALYSIS

Table 2 Calculation of Design wind load [5]

Height (ft)	Kz	Velocity pressure (Qz) (psf)	Design wind load (psf)	Design wind load (kN/m2)
0-15	1.03	20.88	31.94	1.53
20	1.08	21.89	33.49	1.60
25	1.12	2.70	34.73	1.66
30	1.16	23.51	35.97	1.72
40	1.22	24.73	37.83	1.81
50	1.27	25.74	39.39	1.88
60	1.31	26.55	40.63	1.94
70	1.34	27.16	41.56	1.98
80	1.38	27.97	42.80	2.05
90	1.40	28.38	43.42	2.07

Calculation of the design wind load acting on the structure can be shown in table 2.Wind load acting on the pipes and cable trays are shown in staad in Fig. 3.Wind loads on pipes and cable trays are calculated using following equations (Cl. 4.2.2)[5].

1. $F = Q_z \times G \times C_f \times A$
2. $Q_z = 0.00256 \times K_z \times K_{zt} \times V^2 \times I$

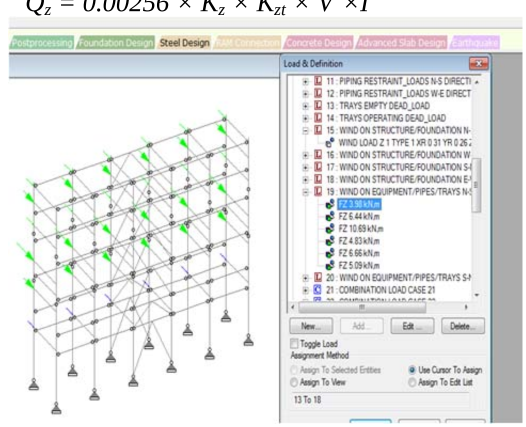

Fig. 3 Wind load on pipes and trays

4. SEISMIC ANALYSIS

For vertical seismic forces,

Seismic load $E_v = 0.2 \times S_{ds} \times F_y$

For horizontal seismic forces,

Seismic load $F_x/F_z = W \times Hi^k$

Fig. 4 shows below the seismic analysis done in staad pro software.

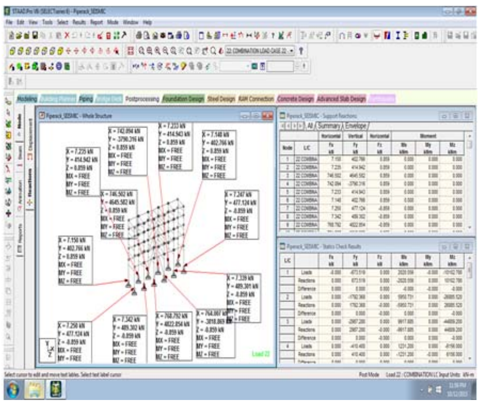

Fig. 4 Seismic Analysis in Staad

5. MODULARIZATION OF PIPE RACK STRUCTURE

The pipe rack structure as per the normal site condition doesn't need to analyze for any additional analysis for the design purpose. So, it is called normal pipe rack structure. At the other side, modularization process involves various phases of construction of the pipe rack structure. Hence, the structure must be analyzed for each phases to ensure the safety during the particular phase.

For modularization of the structure, the whole structure is divided in the three different modules by providing base plate at each joint of the columns of the module at downward side. Table 3 depicts the information of elevations of three modules.

Table 3 Elevations of modules

Module No.	Height (m)`	Top Elevation (m)	Bottom Elevation (m)
1	7.00	112.500	105.500
2	6.00	118.500	112.500
3	6.50	125.000	118.500

5.1 Land Transportation Analysis (LTA)

Each three modules of the pipe rack structure are transported at the site location once they are designed and assembled in the fabrication shop. During its transportation, the structure should be affected with minimum jerks [6].Table 4 shows the transportation load factors taken in analysis. Fig. 5 shows the geometry of the module 1 taken for LTA.

Table 4 Transportation loads taken in analysis [7]

No.	Load Type	Percentage	Factor	Direction
1	Land Transportation Longitudinal Impact	30%	0.3	GZ
2	Land Transportation Transverse Impact	10%	0.1	GX
3	Land Transportation Vertical Impact	5%	0.05	GY
4	Land Transportation Gradient Impact	7%	0.07	GZ
5	Land Transportation Cross Falls	3%	0.03	GX

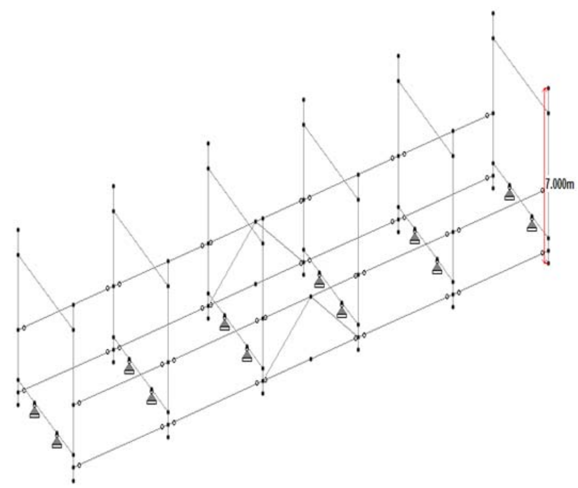

Fig. 5 LTA of module 1 in staad

5.3 Water Transportation Analysis (WTA)

Sometimes module is transported by the ship through the ocean. So, the effect of the water waves causes differential settlement in the structure. Hence the modules are analyzed for the water transportation analysis. During its transportation; the structure should be affected with minimum jerks. Table 5 shows the water transportation loads taken in analysis.

Table 5 Transportation loads taken in analysis [7]

No.	Load Type	Percentage	Factor	Direction
1	Water Transportation Longitudinal Impact	50%	0.5	GZ
2	Water Transportation Transverse Impact	80%	0.8	GX
3	Water Transportation Vertical Impact	30%	0.3	GY

5.4 Lifting Analysis (LFTA)

When the module is arrived at the site by the transporter vehicle, it is lifted up by the crane with the help of hook, sling and shackle, spreader frame and pad eye. Sling angle is set approximately 60 degree to the horizontal beam. Lifting can be done in with or without the use of the spreader frame. Spreader frame is the horizontal frame joining the inclined slingers to give them stability. Fig. 6 shows the lifting assembly with the spreader frame. Fig. 7 gives the idea of the position of hook taken above the center of gravity of the structure. Fig. 8 shows the geometry of the module 3 taken for LFTA.

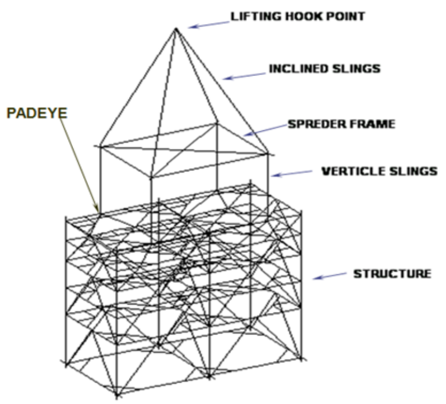

Fig. 6 Lifting of the module with the spreader frame [8]

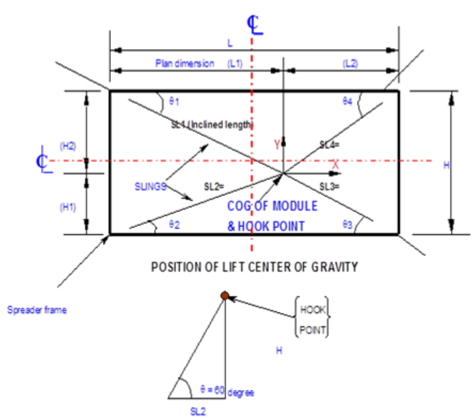

Fig. 7 Position of the hook above the Center of gravity of the module [8]

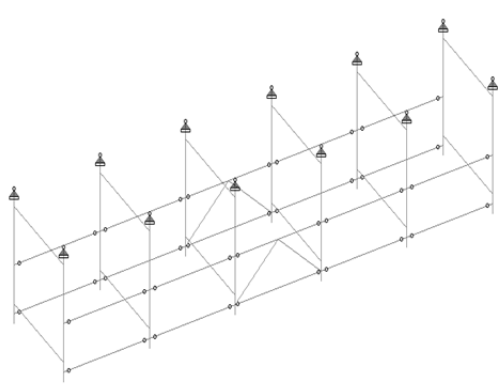

Fig. 8 LFTA pf module 1 in staad

6. RESULTS

Fig. 9 shows the results of normalised ratio found in tiers in normal and modular structure. Fig. 10 shows the bending moment in tiers at different levels in both the structures. Fig. 11 shows comparison of the deflections in tier after providing knee bracing. Fig. 12 shows the comparison of deflections in tiers without providing knee bracing.

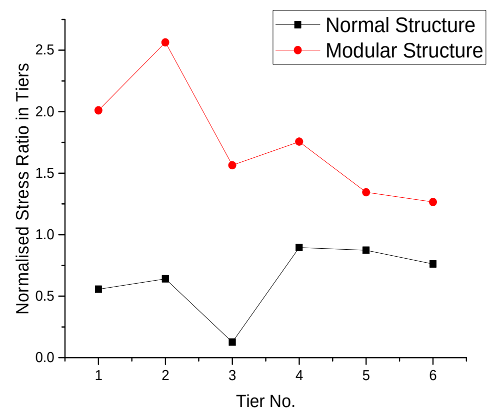

Fig. 9 Normalised Stress Ration in Tiers

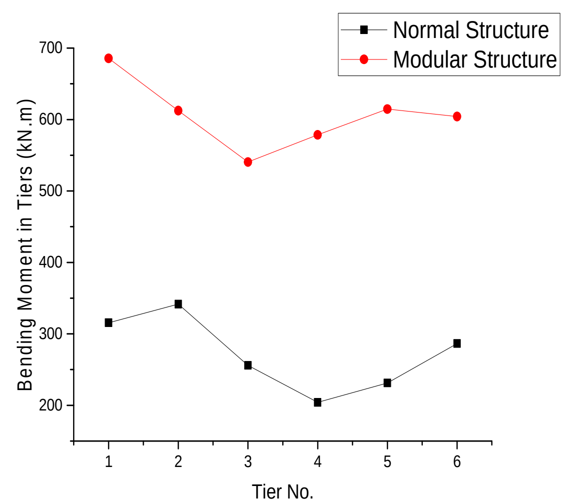

Fig. 10 Bending Moment in Tiers at different level

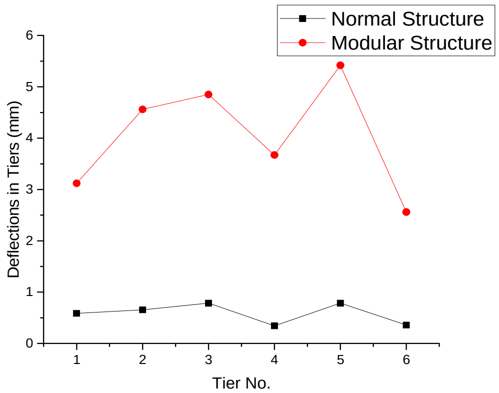

Fig. 11 Deflections in Tiers with Knee Bracing

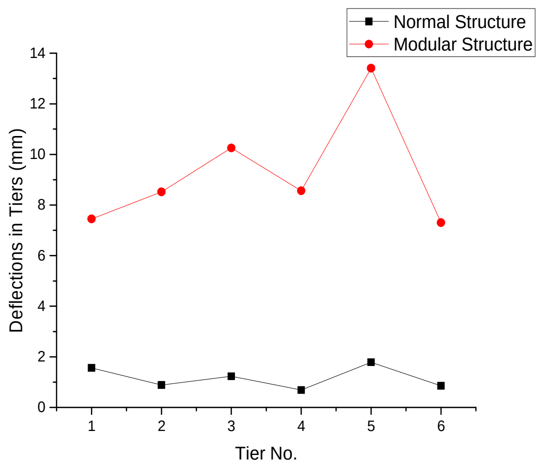

Fig. 12 Deflections in Tiers without Knee Bracing

7. CONCLUSIONS

1. After the staad analysis of both normal and modular structure, it can be concluded that the deflections found in tiers at the different level in modular pipe rack structure are comparatively more in values than that of normal pipe rack structure. It is because of the additional analysis of the structure during transportation phases.
2. During the land transportation of modules, the modules are rested on horizontal beam rather than columns. Hence, larger values of bending moment are generated in beams thus they becomes heavy than those in normal structures.
3. During Lifting of the modules, columns react as tension members and it is designed for heavy sections than those in normal structure to ensure the safety during the lifting operation.
4. Knee bracing at the base of bottom beam lowers overall deflection values in the tiers at different levels. Hence, it should be used in order to make lighter design in modular structure.
5. After carrying out the complete design, the modular structure possesses 7 tonnage of extra steel than those of normal structure. It proves that it is heavier than normal structure.
6. Eventually, though modular structure possesses heavier steel design, it still proves as much economical in aspects of many benefits like saving of time, site constraints, unskilled labours and bad weather condition.

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