ASPECTS OF MODULARIZATION – PARAMETRIC STUDY OF TRUCK MOUNTED MODULE IN OIL AND GAS INDUSTRY

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Abstract: There are two approaches for engineering of this structures: Stick built approach and Modular approach. This paper focuses on the concepts of Modularization which is a Modular type of approach. The major challenge in modularization is understanding that how structure will behave during the different phases of modularization life cycle. That is its behaviour during transportation (Road/Sea), Lifting and operating condition (at site). As there are different stages involved in the modularization, one should have a brief knowledge about additional loads which acts on structure in different phases. The scope of this study is to correctly design a modular process structure of 14 m x 12 m x 10.5 m (tall) structure addressing it precisely in mathematical model. Here entire structure is divided in modules which can be truck mounted (3.45 m x 3.45 m x 12 m) including all the equipment and piping assemblies mounted inside it. P-delta analysis will be performed for deflection and direct analysis method will be carried out for the strength as per AISC 360-05. For the design of module AISC 360-05 shall be used and Similarly ASCE 07-05 will be used for loads and load combination. Here an attempt will be made to develop the procedure for designing the truck mounted modular structure.

IndexTerms – Modularization, Truck mounted modules, Stick-built, Process structure.

I. INTRODUCTION

Modular structure design and construction is recently developed approach, in which entire structure is divided into number of modules which can be prefabricated individually in offsite location and later transported at site location. The transportation of Modular structure can be carried out with Truck transportation, SPMT transportation, and Barge transportation. In case of modularization logistic plays a very important role. It might be possible that more than one type of transportation is required from offsite fabrication facility to installation of modules at site location. The type and amount of modularization is decided earlier as it has direct impact on total cost and schedule of project. Depending upon the layout the modules can be horizontally or vertically stacked. Pipes, platform, Cable tray may be supported on module of process structure during fabrication. It is even possible that they are supported after the process structure modules are installed at site location. For analysis and Design of modular process structure different analysis are required at different stages of modularization i.e. operating condition, Lifting condition and transportation condition. In all the three supporting conditions are different and load resulting in the structures during different conditions are different.

II. OBJECTIVES

- To understand the concept of modularization in process structures.
- To study the impact of operating, lifting and transportation condition for analysis and design of truckable modular process structures.

III. MODELLING OF STRUCTURE

The Plan dimension of Process Structure is 14.4 m (In E-W direction) x 12 m (In N-S direction) and maximum height of the structure is 12.75 m. For strength design direct analysis has been performed and for serviceability design, P-delta analysis has been performed.

The dimension of the typical truck mounted skid on 1st and 2nd tier is 12 m x 3.45 m x 3.45 m. There is 2D frame on 3rd tier which is of dimension 12 m x 3.45 m. Above it there are stick built columns on which the PSV skid is connected. Dimensions of PSV skids are 14.4 m x 3.45 m x 2.54 m. The modules are connected by the rigid links in both the directions.

In case of transportation condition, module is supported on truck deck by bottom transverse beam. So, pinned supports has been considered for analysis of module in transportation condition as shown in below figure 2(a).

For lifting vertical lift has been considered and lifting is done by attaching lug with beam. In case of lifting condition, support condition has been assumed as fixed But MX, MY, MZ are released and springs stiffness of 5.0 kN/m in FX and FZ direction is assigned considering the stiffness of guy rope as shown in figure 2(b).

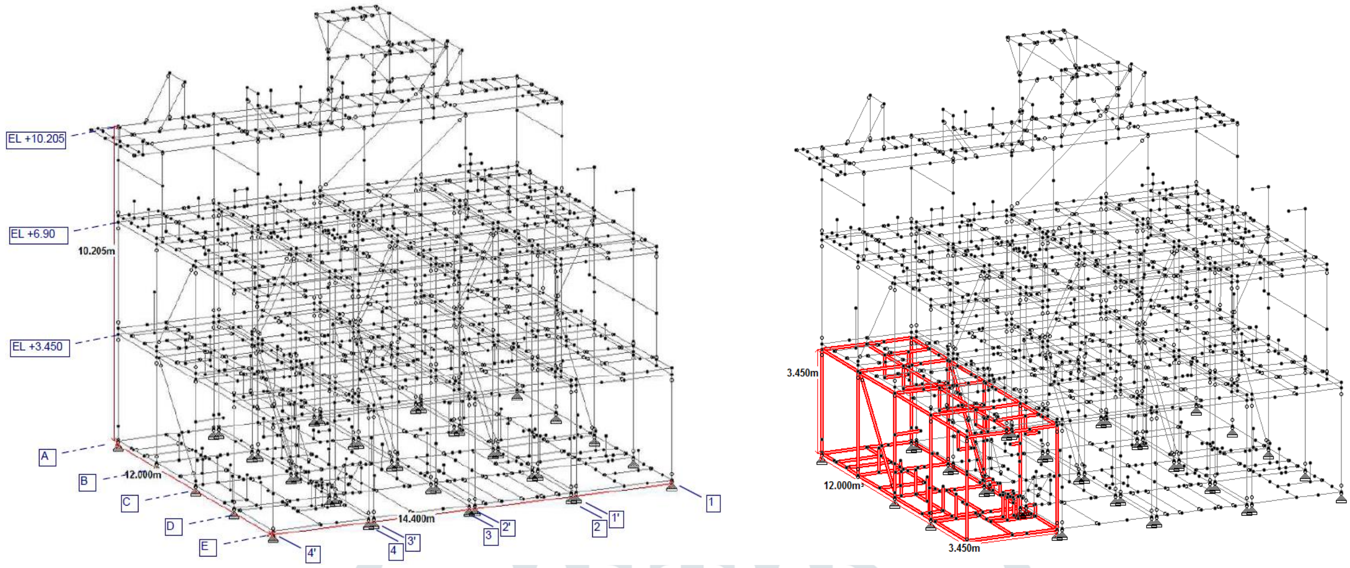

Figure 1: (a) STAAD Geometry of Process Structure in Operating condition (b) Typical Skid in STAAD

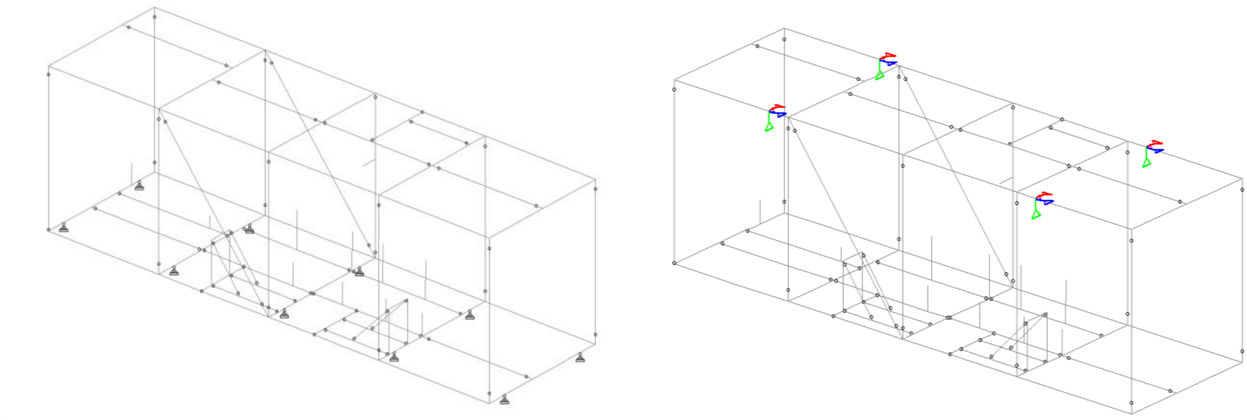

Figure 2: Support condition for typical process module in (a) Transportation condition & (b) Lifting condition

IV. LOADING ON PROCESS STRUCTURE

Dead Load (DL):

Dead load shall be the total weight of material forming the permanent part of structure including self-weight of members, fire proofing, floors, roofs, stairway and fixed services, etc.

Live Load (LL):

Live loads are moving or variable loads and act temporarily. Live load includes loads due to movement of people, the weight of movable loads, tools, movable partitions, dismantled equipment and stored materials.

Empty weight of Piping/Equipment (DL_{DRY}):

It shall be defined as the weight of vessels, equipment cable tray and piping in empty condition. Empty loads are long term loads. Empty load should have the same load factor as dead load.

Operating Weight of Piping / Equipment (DL_{OPR}):

It shall be defined as the weight of any liquids or solid present within the vessel, equipment, or piping during normal operation including empty weight of equipment or piping it also includes weight of cable trays with bundles of cables inside it. Operating loads are long term loads. Operating load should have the same load factor as dead load.

Test Weight of Piping / Equipment (DL_{HYD}):

Test load is defined as the weight of liquid necessary to test equipment or piping including empty weight of equipment or piping. Test weight shall be applied as UDL or concentrated as supplied by piping. Hydro testing shall also be performed on site. In case of modular Process Structure, It might be possible hydro testing shall be performed on fabrication yard. Test loads are short term loads.

Thermal Load (TL):

Thermal Loads are caused by change in temperature. Thermal expansion and contraction is self-restraining forces caused by difference between maximum temperature and minimum temperature of vessel or piping. Thermal forces act at piping restrained supports (i.e. Anchors and guides). While in case of rest piping support there shall be no horizontal load on supporting structure. Thermal loads are not reversible loads. Thermal loads are long term loads and hence shall be combined with Friction, Wind and Seismic loads in load combinations.

Friction Load (FR):

Friction Forces are the forces arising due to friction at contact surface between pipe supports and supporting structure. During start-up/shut down condition, the pipe having higher operating temperature than ambient temperature expands/contracts (respective condition) between the fixed points. Because of pipe expansion/contraction movement, pipe slides at the resting supports and friction force between the contact surfaces counteracts this movement. Also, at fixed points, equal and opposite balance force is generated. Friction loads can positive or negative because of expansion or contraction piping. Friction loads are short term forces and hence shall not be combined with the Wind or Seismic loads in load combinations.

Wind load (WL):

Here, Wind load calculation is in accordance with ASCE 7-05.
Wind load on Process Structure
Design Wind force for the all open framed structures (including Process structure, Equipment supporting structures, Field columns; excludes compressor shelter) is given by
$F = q_z\, G\, C_f\, A_f$ (ASCE 7-05 clause 6.5.15)

Where, q_z = velocity of pressure evaluated at height z above ground, in lb/ft^2
G = gust effect factor
C_f = force coefficient
A_f = area of open building and other structures normal to wind direction

Earthquake Load (Eq):

Here, Earthquake load calculation is in accordance with ASCE 7-05.
The self-weight of the structure and the operating weight of piping, equipment & Cable trays are lumped as mass in STAAD to generate the seismic forces.
Seismic Base Shear
$V = C_s W$
Where, C_S = Seismic Response Coefficient as per 12.8.1.1
W = Seismic Weight as per Clause 12.7.2

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I}\right)}$$

Where, $\boldsymbol{S_{DS}}$ = Design spectrum response acceleration parameter as per Clause 11.4.4
R = Response modification factor as per Table 12.2-1
I = Occupancy importance factor as per Clause 11.5.1

Lifting loads

Wind load shall not be considered during lifting analysis. The Load factors to be considered for lifting analysis of modules are as per section 16 of Noble Denton marine services DNVGL-ST-N001.

Table 1 Load factors for lifting analysis

Load Factor	value
Weight Contingency Factor (WCF)	1.1
Dynamic amplification Factor (DAF)	1.25
Skew Load Factor (SKL)	1.05
CoG Shift Factor (CoG)	1.03
Tilt Factor (TF)	1.03
Yaw Factor (YF)	1.05

Load factor = WCF x DAF x SKL x CoG x TF x YF
= 1.1 x 1.25 x 1.05 x 1.03 x 1.03 x 1.05
= 1.6

Transportation loads

Each module shall be transported by Truck to the site. The module shall be assumed to be supported at the bottom-most beam from the truck deck. In general, this shall be uniformly supported from truck deck by grid of structural elements with wooden planks. It is assumed that only grid beams shall be supported during transportation.

Loads acting during road transportation are taken as per section 9 of Noble Denton marine services DNVGL-ST-N001.

Table 2 gravity loads during transportation

Direction	Requirement
Transverse acceleration	0.5 g
Forward acceleration	0.8 g
Backward acceleration	0.5 g
Vertical acceleration	1.0 g

VI. RESULTS AND COMPARISON

a) Lateral deflection check:

Here for lateral deflection check main structural columns during in place analysis are considered. The results at nodes of each tier level i.e. EL +3.45 m, EL +7.10 m, EL +10.205 are as follows. The allowable lateral deflection shall not be greater than H/200 where H is the height of process structure.

b)Base shear results:

Figure 5 shows the results of base shear for different major lateral loads i.e. wind, earthquake, thermal and friction. This gives idea about the governing load during operating analysis.

Table 3 Lateral Deflection Check

Level (m)	Permissible Deflection (mm)	Actual Deflection (mm)	
		X	Z
3.45	17.25	8.18	5.82
7.1	35.5	14.76	5.31
10.205	51.03	16.09	18.3

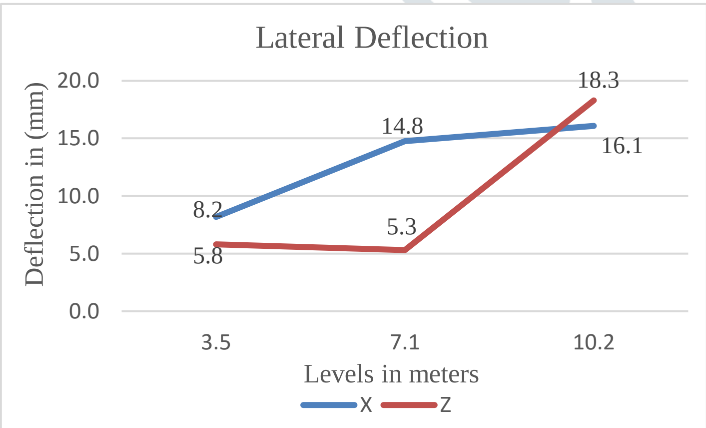

Figure 3 Lateral deflection check for process structure in (a) X-Direction & (b) Z-Direction

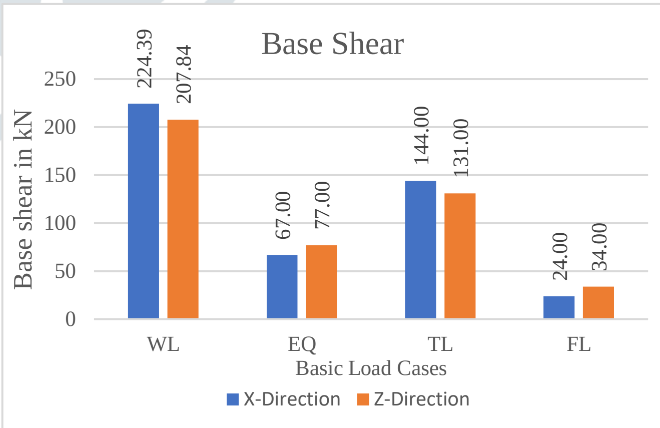

Figure 4 Comparison of base shear in kN

c) Member sizes for standard module

The section sizes of the heaviest module on ground have been computed after performing operating analysis, transportation analysis and lifting analysis. Sections are selected such that they pass in all the conditions. Here operating analysis is referred to in place analysis where entire process structure is analysed considering it is already assembled on the site as shown in figure 2 (a).

Table 4: Section sizes for typical ground level module

Sr. No.	Member	Section Size	U.R. (Strength)	U.R. (Serviceability)	Remark
1	Column	W8x24	0.612	-	ok
2	Primary Longitudinal Beams	W8x24	0.902	0.333	ok
3	Secondary Longitudinal Beams	W6x15	0.576	0.643	ok
4	Primary Transverse Beams	W8x24	0.57	0.433	ok
5	Secondary Transverse Beams	W6x15	0.307	0.545	ok
6	Longitudinal Bracing	W4x13	0.81	-	ok

d) Comparison of typical module in operating, transportation and lifting condition

For comparison of behavior of the module beams i.e. one in transverse and one in longitudinal direction from a skid are selected as shown in snap below. And their utilization ratio's in strength and serviceability criteria for all three types of analysis are expressed in results.

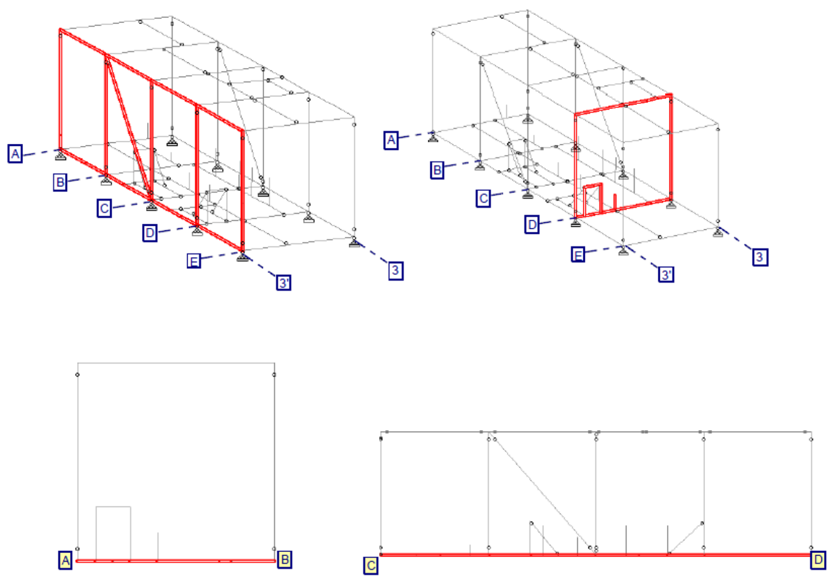

Figure 5 Identification of Beam AB and Beam CD

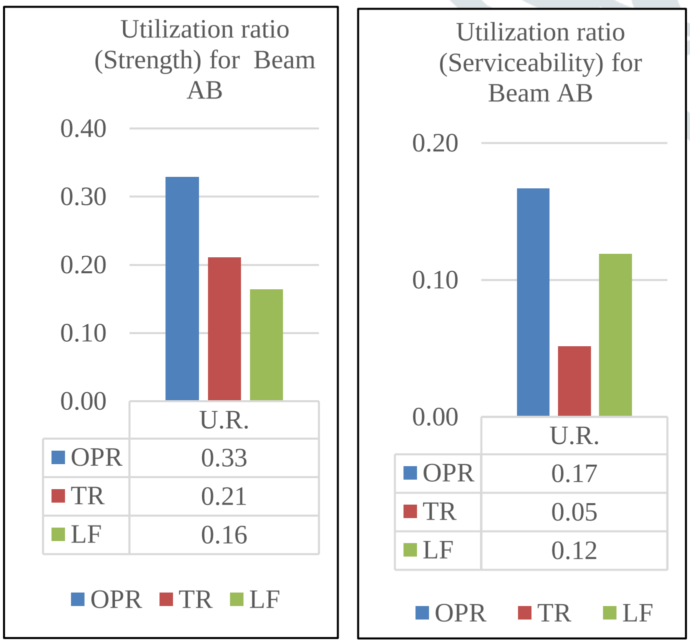

Figure 6 Utilization ratio for Beam AB in strength and serviceability for all three analysis.

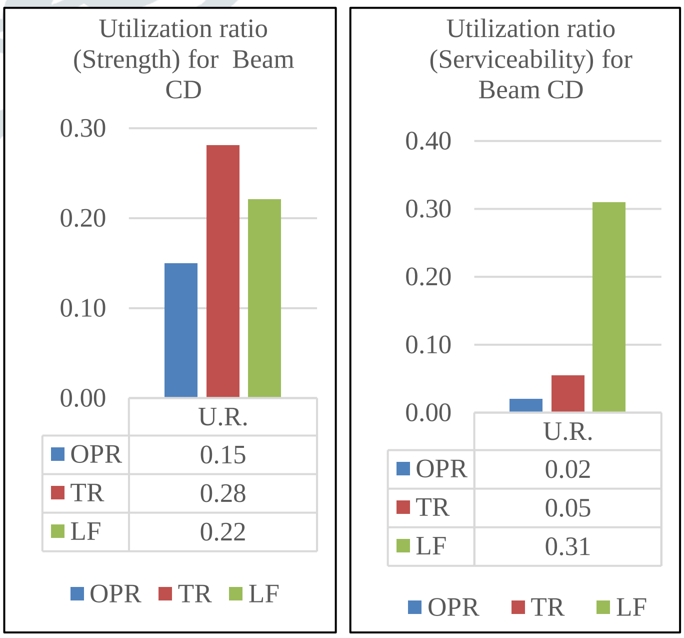

Figure 7 Utilization ratio for Beam AB in strength and serviceability for all three analysis.

V. Conclusion

Modular process structure has been studied in three different conditions i.e. operating, transportation and lifting condition and the results has been shown for the governing beams.

- For the site location which was selected for this project i.e. Laporte, Texas it is a hurricane prone region hence, wind load is governing lateral force in operating condition.
- It is evident from the results that the utilizations of governing beams on which maximum forces are coming are different for all the three types of analysis for both strength as well as serviceability.
- Thus, it can be concluded that all the three analysis i.e. operating, transportation and lifting are necessary for design of modular process structure and the effect of forces on it totally depends on the location of equipment inside the module.
- For both transportation and lifting analysis center of gravity of entire process module including piping equipment and cable tray is necessary to be maintained as low as possible and nearer center of module, to have minimal effect of forces generated due to eccentricity.
- Steel tonnage for modular process structure is higher compared to stick-built process structure of same capacity.

VI. Acknowledgment

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