ANALYSIS OF OFFSHORE PIPE RACK STRUCTURE

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Abstract: The structural analysis reveals distinctive responses among different sections and groups under various conditions. In extreme operating conditions, the Unity Check (UC) surges by 35.6% for the PB5 section PG390B column group and 28.6% for the SA6 column group, yet the TA4 section H194X150 Beam group experiences a 32% decrease, and the SA3 Beam group encounters a 33.3% increase. Wind impact analysis under normal conditions demonstrates a significant 30% UC decrease for the PB5 section PG390B column group without wind, contrasting with an 11% increase for the TA4 section H194X150 Beam group. Meanwhile, the V08 section H250X250 Bracing group sees a 17.4% decrease without wind, and the V06 Bracing group experiences a 7.1% decrease. Under extreme conditions without wind, the PB5 section PG390B column group and SA6 column group show 26.1% and 15.2% UC decreases, respectively. Conversely, the TA4 section H194X150 Beam group exhibits an 11% increase, while the SA3 Beam group encounters a 23.2% decrease. In this scenario, the V08 section H250X250 Bracing group sees a substantial 31.6% UC decrease, and the V06 Bracing group experiences a 30% decrease. Lastly, under normal conditions with wind, joint displacements show no significant difference in X-direction but a notable 50% increase in Y-direction, emphasizing the vertical influence of wind on structural behavior.

Keywords- Offshore Structure, pipe rack structure, Normal operating condition, Extreme operating condition, Unity Ratio check, Wind consideration, Joint Displacement, SACS.

I. INTRODUCTION.

Offshore construction involves installing structures in marine environments for energy production. The exploration of oil began in 1900, initially focusing on shore areas. Over time, offshore drilling expanded, with the first fixed platform drilled in 1947. Today, offshore structures play a crucial role in meeting the world's energy demands.

1.1. Types of Offshore Structures:

- Floating Platforms: Designed to float on water, including semi-submersibles, SPAR platforms, drill-ships, and FPSO vessels.
- Fixed Platforms: Stationary structures permanently anchored, such as Concrete/Gravity Platforms, Jacket Platforms, Tension-leg Platforms (TLPs), and Jack-Up Rigs.

1.2. Floating Production Storage and Offloading (FPSO):

FPSO systems are key in offshore oil and gas production. These floating vessels receive, process, and store fluids from subsea reservoirs, separating crude oil, natural gas, water, and impurities. FPSOs are versatile, designed for various water depths and environmental conditions.

Figure 1 - Floating Production Storage and Offloading

1.3. Pipe Rack:

A central hub in process units, a pipe rack supports pipes, cable trays, and equipment. It facilitates efficient fluid conveyance, cable routing, and access for maintenance, safety, and space optimization on offshore platforms. Detailed development requires data like plot plans, P&ID's, client specifications, construction materials, fireproofing requirements, and statutory guidelines.

Figure 2- Pipe Rack

1.4. Pipe Rack Types:

- Steel Structure: Fabricated in workshops, bolted or welded on-site, requiring regular maintenance to combat corrosion.

- RCC/Pre-cast: Concrete racks erected on-site, with pre-cast beams and columns increasingly used for time and cost savings.

In summary, offshore structures, FPSOs, and pipe racks are vital components of the oil and gas industry, ensuring the efficient extraction, processing, and transportation of hydrocarbons from challenging marine environments.

II.LITERATURE SURVEY

1. Kamesh A Rajai et al., [2018] This study delves into the comparison of two distinct pipe rack structures employing different bracing systems: one featuring an X bracing pattern (Case 1) and the other adopting an inverted V bracing pattern (Case 2). The primary objectives were to assess their behavior concerning displacement, structural safety, handling of extreme forces, material usage efficiency, and cost-effectiveness. Notably, Case 1 exhibited less movement, indicating structural stability, while both designs were deemed structurally safe within acceptable stress and movement limits. When facing extreme forces, Case 2 showcased superior performance by experiencing lower axial and shear forces compared to Case 1, suggesting enhanced load-bearing capacity. Material usage analysis revealed Case 2 as more efficient, requiring significantly less steel (34.31 tonnes) compared to Case 1 (57.23 tonnes), contributing to its cost-effectiveness. It is emphasized that maintaining pipe rack length less than 60 meters is crucial for structural integrity and the recommendation leans towards Case 2 due to its economical material utilization. However, the study underscores the importance of considering practical aspects such as construction feasibility, maintenance implications, and adaptability to future changes alongside structural factors for a comprehensive assessment.

2. J. K. Sumanth at., [2018] This meticulous literature review provides a comprehensive examination of the design and analysis of the PR 18-01 pipe rack steel structure, offering detailed insights into its construction, load-bearing capabilities, and essential features. Adhering to rigorous standards and employing a well-established design code for precision, the study unveils the remarkable strength of the structure, showcasing its ability to support an impressive load of 1365.068 tonnes. The strategic placement of columns, considering their shapes and weight distribution characteristics, is highlighted, while specialized bracings play a pivotal role in fortifying the structure against lateral forces, particularly from elements like wind, ensuring heightened safety. The utilization of diverse bracing shapes not only serves specific purposes but also contributes to the structure's efficiency, resulting in cost-effectiveness. The review underscores the significance of connections within the structure, elucidating their role in even load distribution and resilience against twisting forces, enhancing both strength and flexibility. Addressing temperature fluctuations, the inclusion of special loops is detailed, demonstrating the structure's minimal bending under varying conditions. The integration of real-world foundation data reinforces the accuracy and practical relevance of the findings. Visual aids, including a picture of a single column, enhance reader comprehension, while discussions on different loads, such as wind and pipe weight, provide valuable insights into the structure's real-world performance. In essence, this detailed review significantly advances our understanding of the PR 18-01 pipe rack steel structure, encompassing both technical intricacies and practical considerations for constructing resilient and robust infrastructures

3. Mohammad ishtiyaque et al., [2015] This detailed study explores how to make pipe racks, the structures that hold pipes, even better. It focuses on making them strong, cost-effective, and practical. The study uses what we already know from research to improve these structures. It looks closely at different aspects of design to achieve this. Firstly, the study talks about the importance of strong connections in the design. Strong connections help spread the weight and make the whole structure work better. Think of it like having a strong foundation for a house – it keeps everything stable. The study also looks at where to place supports and how to manage stress. Imagine trying to balance things on a see-saw; you want to put the supports in the right places to keep everything steady. This is crucial because it helps maintain stability while using materials wisely. Arranging beams in specific patterns to fit larger pipes is another smart idea highlighted in the study. It's like fitting pieces of a puzzle together – it makes the structure flexible and efficient in using materials. Saving costs is an important consideration, and the study suggests using fewer supports to achieve this. It's like finding a smart way to build something strong without unnecessary extras. This careful balance between safety and cost comes from good planning. The study also talks about using bracings (supports in specific shapes) to prevent the structure from bending sideways. It's similar to adding extra support to a tall tower to make sure it stays steady. Smart bracing not only keeps the structure stable but also uses less material, which is better for the environment. Different types of connections are discussed as well, focusing on how they handle forces and stress. Imagine building with different types of Lego blocks – each connection plays a specific role in making the structure strong. The study suggests a strategy to reduce forces by adding anchor bays. It's like adding extra support in specific areas to keep everything secure. Doing this right not only saves money and materials but also maintains the structure's strength. Managing temperature changes is also considered by adding loops. It's like having a flexible rubber band – it helps the structure adapt to changes in temperature, making it last longer and stay strong. Balancing connections is a smart idea highlighted in the study. Think of it like balancing your backpack – making sure the weight is distributed evenly so it's comfortable. This approach keeps the connections strong and the overall structure stable. Smart distribution of base plates based on how forces work is like organizing things in a smart way. It helps spread the load evenly, making the structure stronger and reducing stress points.

4. **Haritos et al., [2007]** study are conducted on an overview of the analysis and design of offshore structures. This paper basically deals with critical factors used in offshore structure structures. Hydrodynamic force, airy wave theory, stretch wave theory, load on offshore structures, and the response of offshore structures are discussed. Hydrodynamic contact and dynamic response are major factors which should consider in the design kinematic of water particle, which causes the load on structures in terms of wave load and current. LRFD method is considered for design. Water particle kinematics is also affected by the topology of the ocean sea bed. Water particle forms elliptical shape for low water depth and circular shape for the high water depth. The wind is the main reason for the generation of ocean waves. P-M wave spectrum is used for spectral density with full sea state condition. Fourier series of air wavelets are taken for irregular sea state. Wind load that acts on an offshore structure differs from wind load act on land because the ocean does not provide any restriction to the moment of wind. Wind load is calculated by using wind speed, an area exposed, and drag coefficients. For wave load calculation Morison equitation is used. If the diameter to wavelength ratio is more significant than 2, it undergoes diffraction regime. Marine growth increments width of diameter along with increment in the roughness coefficients. Many offshore structures in the world are designed using Morison equation and airy wave theory.

III. OBJECTIVES

1. Analysis of offshore pipe rack structure using SACS software.
2. To study the Unity Check comparison for normal and extreme operating condition.
3. To study the Unity Check comparison for normal operating condition with and without wind consideration.
4. To study the Unity Check comparison for extreme operating condition with and without wind consideration.
5. Joint displacement comparison for normal operating condition with and without wind consideration.

IV. METHODOLOGY

Literature review on offshore structure analysis and guideline for offshore structure construction has been reported in detail in the previous chapter. In this chapter, various methodologies that are involved in this study have been explained briefly, along with the necessary diagrams and Tables. The analysis is done by using finite element analysis software SACS 5.7 version. Static, dynamic, and soil-structure interaction analysis is done. API RP 2A recommendation is to consider for the analysis. SACS is finite element analysis software by Bentley Systems. Structural Analysis Computer System developed by Engineering Dynamics Inc. USA. SACS is a finite element structural analysis suite of programs for the offshore and civil engineering industries. This software is one of the best offshore stricter analysis software compared to others.

2.0. Modeling

Modeling is a crucial step in creating offshore structures, and the SACS software is employed in a three-dimensional view to accurately represent the actual geometry. The modeling process involves collecting essential data, including the type of offshore platform, water depth, number of columns, and tray supports. Before choosing a modeling option, the unit for analysis is set, with force measured in kilo Newton (KN) and length in meters (m). Three main modeling options include modifying an existing model, opening the last model for adjustments, or creating a new model from scratch. The coordinate system is employed, specifying X and Z directions for length, width, and depth. Another modeling method, the structural wizard definitions system, offers a three-dimensional view of an existing structure, allowing for additions or deletions of properties. Water depth, working point elevation, joints, and members are critical components considered during modeling. The joint creation involves selecting the joint type, such as butt, corner, edge, lap, or tee, each serving different purposes. Tubular joints, especially for underwater welding, require special care and testing for factors like NRL and v-notch tests. Members are primarily made up of steel with a wide flange (I) section, including columns, primary and secondary beams, tray supports, and bracing elements. The cross-sectional properties of these members are crucial for accurate modeling. In summary, the modeling process ensures that offshore structures are represented with precision and adhere to necessary design considerations for safety and performance.

Table.1: Offshore pipe rack structural steel sections used

Sl. No	Level	Sections Labels Used(SeeTable4-3forPGsectiondetails)
1	Primary Beams	• H194X150 • H294X200 • H340X250 • H488X300
2	Columns	• PG-390B • H390300

3	Secondary Beams	• H194X150 • H294X200
4	Tertiary Member	• C14A • H100X100

Table1.2: Member Section Details

Sl. No	Section	Type	Flange Width [cm]	Flange Thickness [cm]	Height [cm]	Web Thickness [cm]	Fillet Radius [cm]	Bottom Flange Width [cm]	Bottom Flange Thickness [cm]	Side Plate Thickness [cm]
1	PG390B	PLG	30	2.5	39	2.0	-	30	2.5	-
2	H3903000	WF	30	1.6	39	1.	-	30	1.6	-
3	H194150	WF	15	0.9	19.4	0.6	-	15	0.9	-
4	H294200	WF	20	1.2	29.4	0.8	-	20	2	-
5	H488300	WF	30	1.8	48.8	1.1	-	30	1.8	-
6	H340250	WF	25	1.4	34	0.9	-	25	1.4	-
7	H100100	WF	10	0.8	10	0.6	-	10	0.8	-
8	H200200	WF	20	1.2	20	0.8		20	1.2	-
9	H250250	WF	25	1.4	25	0.9	-	25	1.4	-

Channel Sections

Sl. No.	Section	Type	Depth [cm]	Flange Width [cm]	Web Thickness [cm]	Flange Thickness [cm]	Fillet Radius [cm]
25	C10A	CHL	14	6	0.6	0.99	-

2.1. Details of load applied

1. **Self Weight/Dead weight of the structure:** Structure is modeled with all primary, secondary and tertiary members with a density of 7850kg/m^3

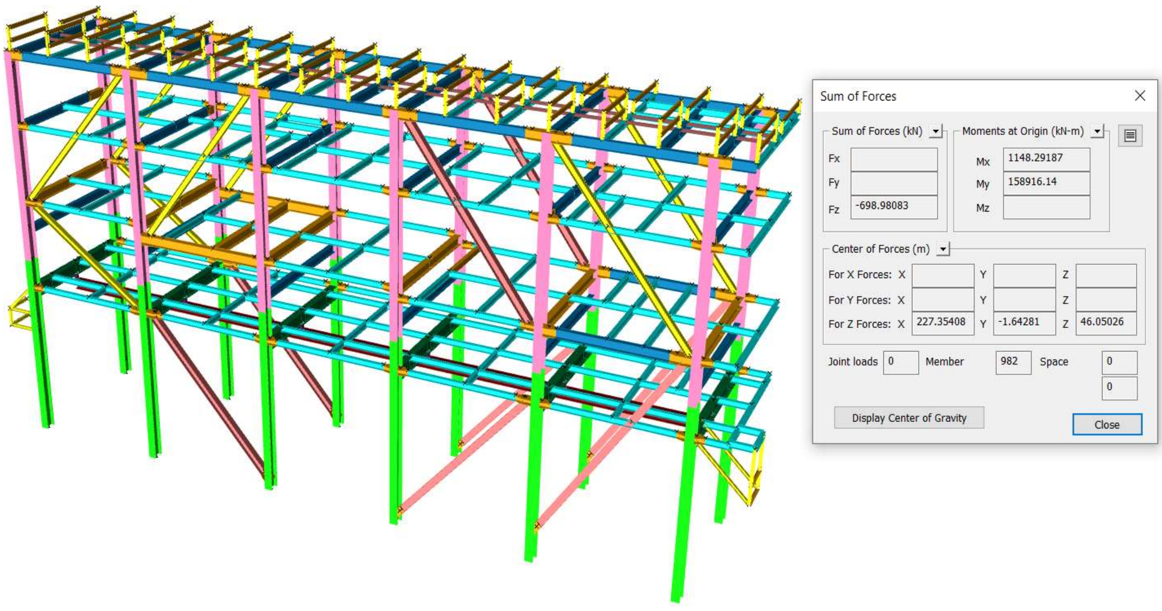

Figure 3: Self weight details

2. **Non model structural weight (STN):** STN includes Handrail, Grating and Connection weight

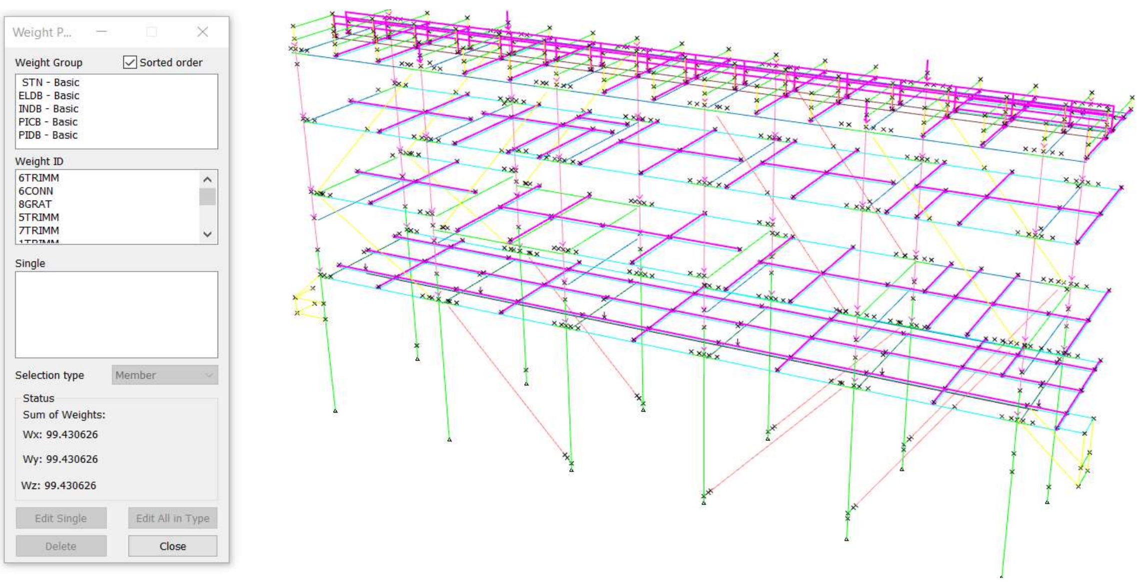

Figure 4: Non model structural weight details

3. Pipe weight: This includes dry weight and contains weight of the pipe, piping load applied as a UDL with respective grids.

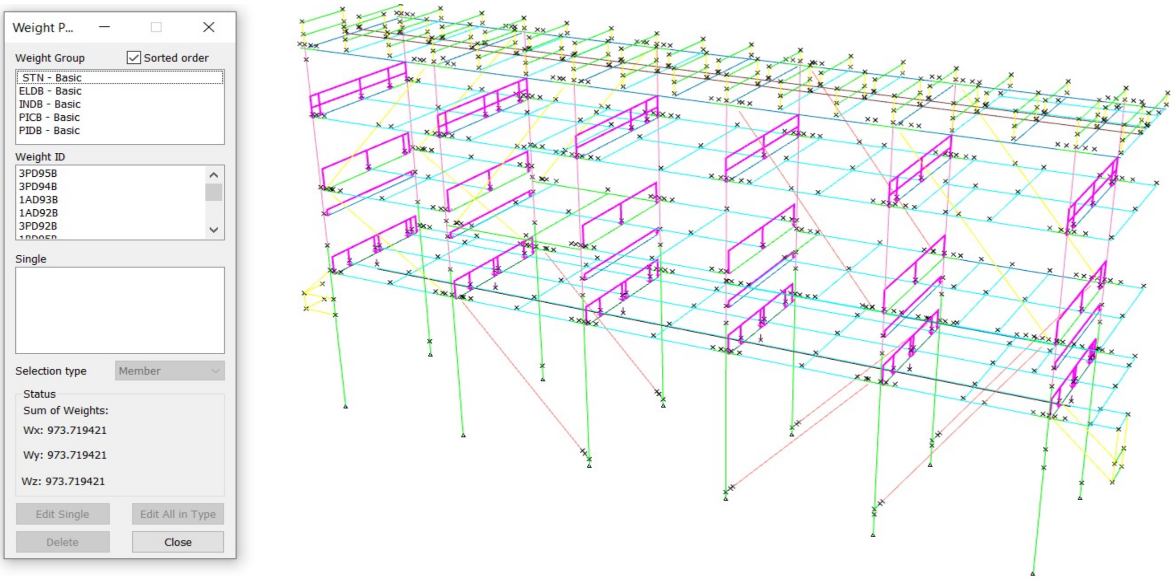

Figure 5: Piping dry weight details

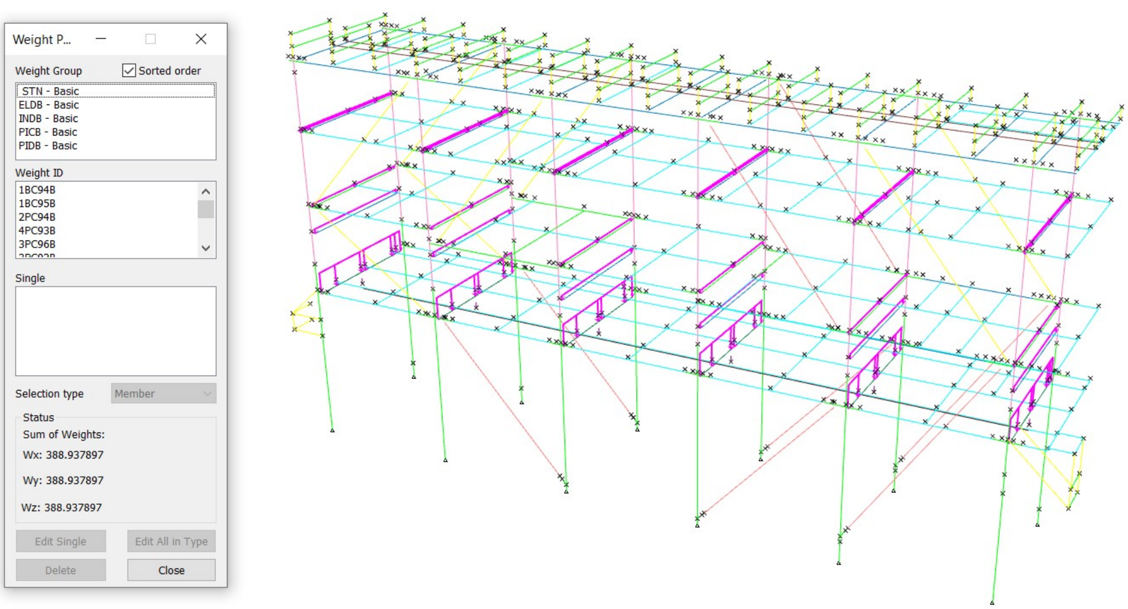

Figure 6: Piping contain weight details

4. Electrical weight (EIDB): Tray length is assumed as 2.075 and 6inch 3 tray are placed at each tray support beam. Tray length is assumed as 2.075 and 6inch 3 tray is placed at each tray support beam.

Weight of each tray (6”) = 0.67 KN

Number of trays=3

Total eight on each tray support beam= 0.67x3 =1.998KN

Weight as UDL=1.998/2.075=0.96 KN/M

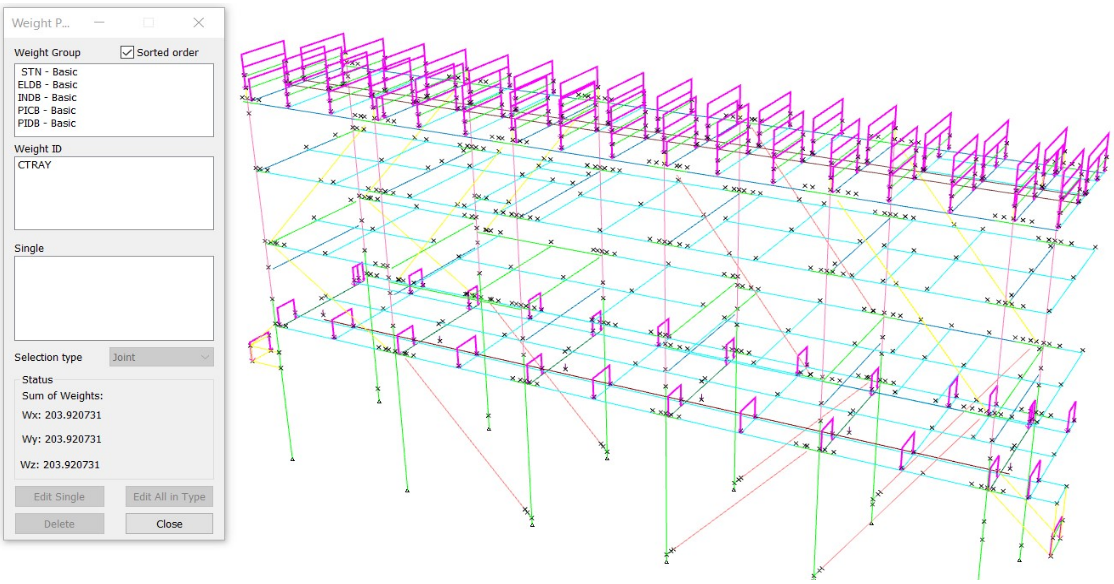

Figure 6: Electrical weight details

5. Instrumentation weight: Tray length is assumed as 2.075 and 6inch 3 tray are placed at each tray support beam.

Weight of each tray (6") = 0.67 KN

Number of trays=3

Total eight on each tray support beam= 0.67x3 =1.998KN

Weight as UDL=1.998/2.075=0.96 KN/M

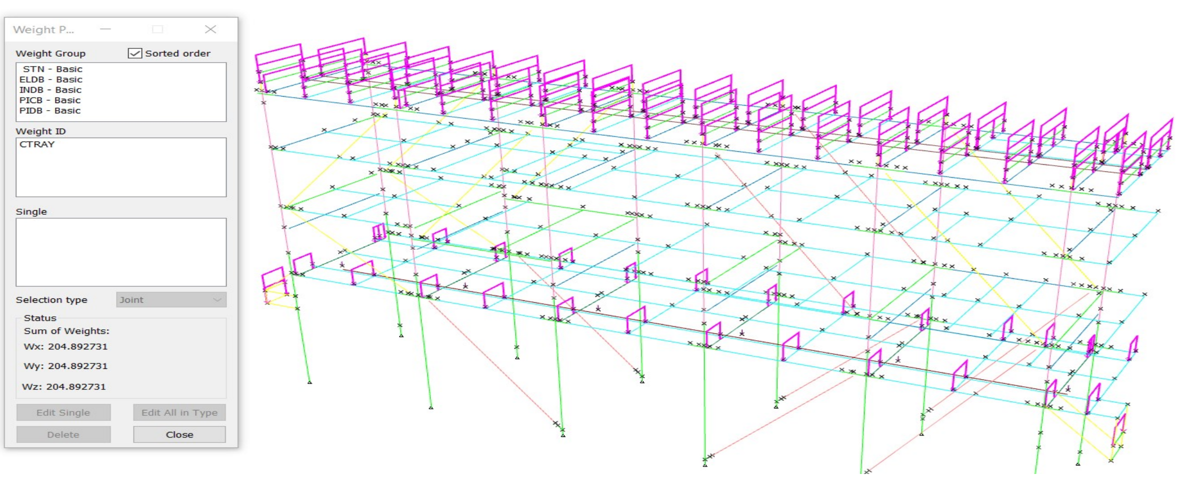

Figure 7: Instrumentation weight details

2.1: **Wind load**

1- Hour average wind speed is considered for analysis .open area wind method is used by considering area & design wind speed. Wind is applied in the 8 direction from 0 to 360 degree. Four faces of the structure are considered for wind area calculation & load application.

1. South Face

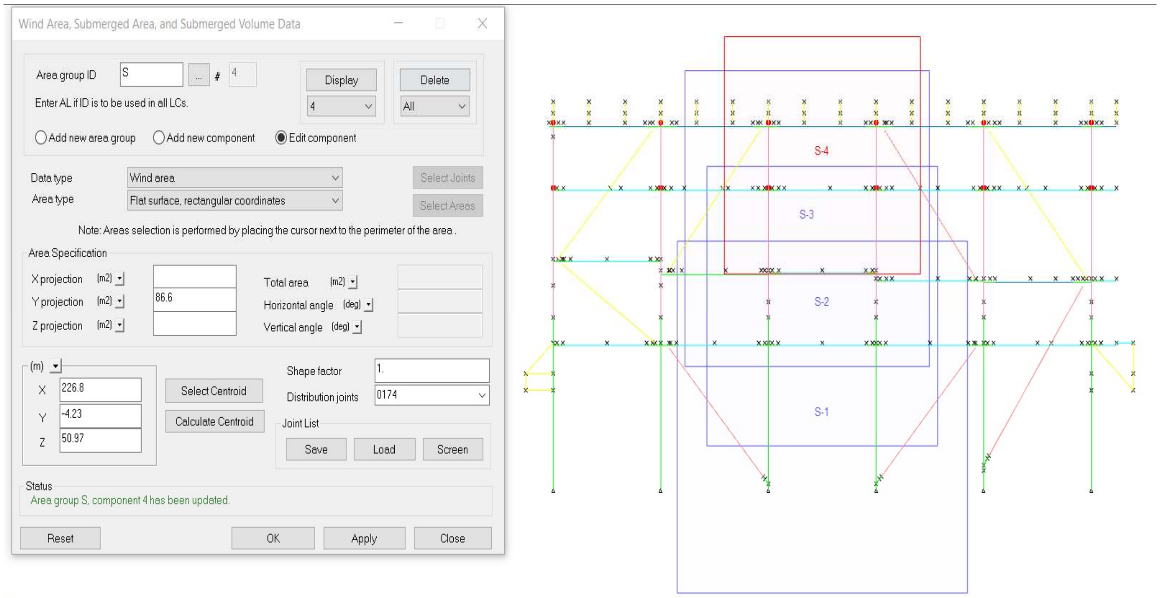

Figure 8: Wind load details acting on south face

2. North Face

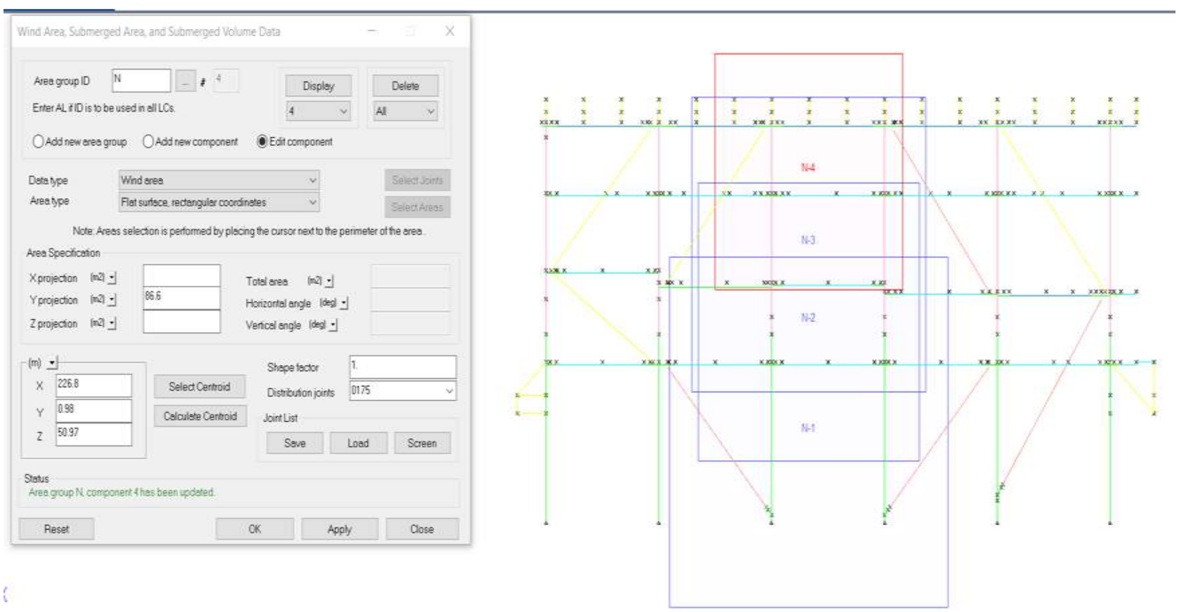

Figure 9: Wind load details acting on North face

3. East Face

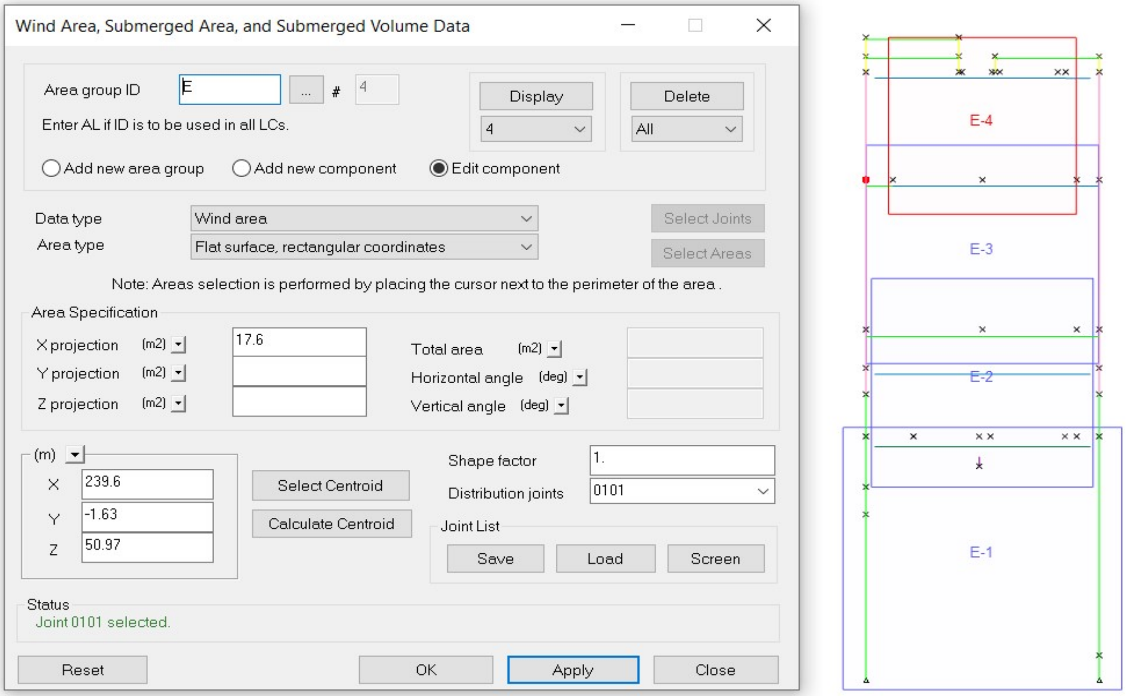

Figure 10: Wind load details acting on East face

4. West Face

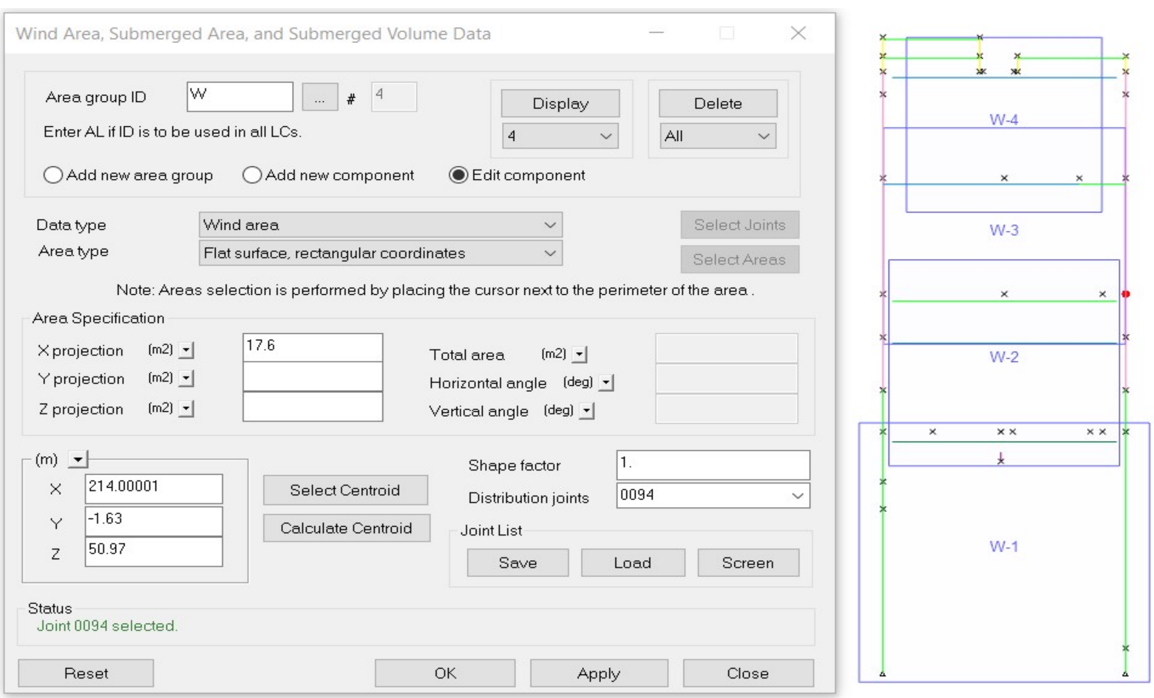

Figure 11: Wind load details acting on west face

V RESULT AND DISCUSSION

The comparison of Unity check Ratios (UC) for different structural elements under various conditions reveals noteworthy findings. Firstly, for PB5 section PG390B column group, the UC increases by 35.6% in extreme operating conditions, indicating higher stress. Conversely, for TA4 section H194X150 Beam group, there is a 32% decrease in UC during extreme conditions, suggesting improved performance. Bracing groups V08 and V06 exhibit an 8% and 15.4% decrease in UC, respectively, under extreme operating conditions.

Further exploration into wind considerations during normal operating conditions indicates a 30% decrease in UC for PB5 column group without wind, whereas SA6 column group experiences a 17.4% reduction. For Beam group TA4, wind consideration leads to an 11% increase in UC, while SA3 Beam group sees a 27% reduction without wind. Bracing groups V08 and V06 show a 17.4% and 7.1% decrease in UC, respectively, without wind during normal operating conditions.

In extreme operating conditions with wind consideration, there is a 26.1% decrease in UC for PB5 column group, contrasting with a 15.2% reduction for SA6 column group. Beam group TA4 witnesses an 11% increase in UC, while SA3 Beam group experiences a 23.2% reduction without wind. Bracing groups V08 and V06 exhibit a 31.6% and 30% decrease in UC, respectively, without wind during extreme operating conditions.

Considering joint displacements, the analysis indicates a 50% increase in Y-direction displacement for columns under normal operating conditions with wind. This suggests that wind loads significantly impact the structure's displacement in the Y-direction.

In summary, these findings underscore the sensitivity of structural elements to different operating and environmental conditions, emphasizing the importance of considering factors like wind in design and analysis to ensure structural integrity and safety. The variations in UC and displacement highlight the dynamic nature of structural behavior under diverse scenarios, guiding engineers in optimizing designs for performance and stability.

VI. CONCLUSION

1. UC Comparison - Normal vs. Extreme Operating Conditions
   - I. PB5 PG390B Column Group
     - In normal conditions, the UC ratio is 0.56, while in extreme conditions, it increases to 0.87.
     - This represents a significant 35.6% increase in UC for extreme operating conditions, indicating higher structural demand.
   - II. SA6 Column Group
     - The UC ratio rises from 0.27 in normal conditions to 0.38 in extreme conditions.
     - This signifies a substantial 28.6% increase in UC for extreme operating conditions, highlighting heightened structural stress.

2. UC Comparison - Normal Operating Condition With and Without Wind
   - I. PB5 PG390B Column Group
     - With wind, the UC ratio decreases from 0.5 to 0.43 without wind, indicating a 30% reduction in UC without wind.
     - This suggests that the structure experiences less stress under normal operating conditions without wind.
   - II. SA6 Column Group

- The UC ratio decreases from 0.27 with wind to 0.23 without wind, representing a 17.4% decrease in UC without wind.
- This implies a lower structural demand under normal operating conditions without wind.

3. UC Comparison - Extreme Operating Condition With and Without Wind

I. PB5 PG390B Column Group
- In extreme conditions, the UC ratio decreases from 0.87 with wind to 0.69 without wind.
- This reflects a substantial 26.1% decrease in UC without wind, indicating potential vulnerability in extreme conditions.

II. SA6 Column Group
- The UC ratio drops from 0.38 with wind to 0.33 without wind, representing a 15.2% decrease in UC without wind.
- This suggests a reduction in structural stress under extreme operating conditions without wind.

4. Joint Displacement for Normal Operating Conditions With and Without Wind
- While there's no significant difference in X-direction displacement between normal operating conditions with and without wind.
- There is a notable 50% increase in Y-direction displacement when wind load is applied, indicating a heightened impact on vertical movement under wind conditions.

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