ANALYSIS OF OFFSHORE JACKET STRUCTURE

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Abstract - *One of the greatest discoveries of 20th century was oil and it has so many applications that it cannot be separated from mankind. The oil exploration has started as early as 1900 and the oil exploration initially was concentrated on land. As the need for oil expands in an explosive rate, need for find new discoveries was eminent. During the middle of 20th century, oil discovery started in near shore and medium range of water depth. The need for qualified offshore structural personnel are rapidly increasing as the oil industry moves into deeper water in the search for additional supplies of oil and gas, new technology is emerging at a rapid peace for the development of new concepts for offshore platforms. Fixed jacket platforms are huge steel framed structures used for the exploration and extraction of oil and gas from the earth's crust. Jacket type structures are appropriate for relatively shallow water depth. These structures will be fixed to seabed by means of tubular piles either driven through legs of jacket or through skirt sleeves attached to the bottom. Since Jacket structures are very expensive, weight optimization could reduce their capital investment. The focus of this Thesis is to study and to analyze the offshore jacket structure. This study is done by using SACS software for design and analysis. Static Analysis is done using the options available on the software which can take inputs for multiple loads and load details accurately. The results of this analysis are shown in brief.*

***Key Words*: Offshore Structure, Jacket, Linear Static Analysis, Simulation, SACS Software, Unity Check.**

1.INTRODUCTION

One of the greatest discoveries of 20th century was oil and it has so many applications that it cannot be separated from mankind. The oil exploration has started as early as 1900 and the oil exploration initially was concentrated on land. As the need for oil expands in an explosive rate, need for and new discoveries were eminent. During the middle of 20th century, oil discovery started in near shore and medium range of water depth.

The need for qualified offshore structural personnel are rapidly increasing as the oil industry moves into deeper water in the search for additional supplies of oil and gas, new technology is emerging at a rapid peace for the development of new concepts for offshore platforms.

Offshore construction is the installation of structures and facilities in a marine environment, usually for the production and transmission of electricity, oil, gas and other resources. Construction and pre-commissioning is typically performed as much as possible onshore. To optimize the costs and risks of installing large offshore platforms, different construction strategies have been developed.

One strategy is to fully construct the offshore facility onshore, and tow the installation to site floating on its own buoyancy. Bottom founded structure are lowered to the seabed by de-ballasting, whilst floating structures are held in position with substantial mooring systems.

The size of offshore lifts can be reduced by making the construction modular, with each module being constructed onshore and then lifted using a crane vessel into place onto the platform. A number of very large crane vessels were built in the 1970s which allow very large single modules weighing up to 14,000 tones to be fabricated and then lifted into place.

Specialist floating hotel vessels known as flotels are used to accommodate workers during the construction and hook-up phases. This is a high cost activity due to the limited space and access to materials

Oil platforms are key fixed installations from which drilling and production activity is carried out. Drilling rigs are either floating vessels for deeper water or jack-up designs which are a barge with lift-able legs. Both of these types of vessel are constructed in marine yards but are often involved during the construction phase to pre-drill some production wells. Other key factors in offshore construction are the weather window which defines periods of relatively light weather during which continuous construction or other offshore activity can take place. Safety is another key construction parameter, the main hazard obviously being a fall into the sea from which speedy recovery in cold waters is essential.

1.1 Types of Offshore Structures

The offshore structures built in the ocean to explore oil and gases are located in depths from very shallow water to the deep ocean. Depending on the water depth and environmental conditions, the structural arrangement and need for new ideas required. Based on geometry and behaviour, the offshore structures for oil and gas development has been divided into following categories.

1. Fixed Platforms
   - Steel template Structures

- Concrete Gravity Structures

2. Compliant tower
    - Compliant Tower
    - Guyed Tower
    - Articulated Tower
    - Tension Leg Platform
3. Floating Structures
    - Floating Production System
    - Floating Production, Storage and Offloading System

1.2 Linear Static Analysis

In-place analysis is the structural analysis used to simulate the behavior of the structure as close as possible to give the response of the structure during its service. It is done to check the global integrity of the structure against premature failure. Among all analysis of jackets the most critical one is in-place. In a linear structural analysis with respect to ultimate limit state design (ULS), the characteristic capacity is normally taken as first yield or first component buckling. If tubular members of a jacket do not satisfy the ultimate strength requirements, resulting in yielding or buckling, it is assumed that the tubular member is not fit for the purpose. Ultimate strength criteria advocated in various codes specify structural strength and stability requirements for jacket tubular members to avoid yielding or buckling. The buckling of a member could be either lateral deformation in the length direction of a column or hoop buckling. Tubular members subjected to combined axial compression and bending may give rise to lateral buckling. The effect of hydrostatic pressure loading on a column may lead to hoop buckling. And the aim of in-place ULS design with respect to code checking is to avoid buckling of members. It is important to determine the maximum shear force of the environmental loads for dimensioning of jacket bracings. Meanwhile, the maximum overturning moment should be established for dimensioning of jacket legs.

Static analysis calculates displacements, strains, stresses, and reaction forces under the effect of applied loads. When loads are applied to a body, the body deforms and the effect of loads is transmitted throughout the body. The external loads induce internal forces and reactions to render the body into a state of equilibrium. All loads are applied at full magnitudes. On applying the full magnitudes, loads remain constant (time-invariant). Time-variant loads induce considerable inertial or damping forces, leading to the static analysis. Here we used static analysis to calculate the structural response of bodies affected with constant velocities or travelling with constant accelerations since the generated loads do not change with time. The relationship between loads and induced responses is linear that is stress is directly proportional to strain and the induced displacements are small enough to ignore the change in stiffness caused by loading. The boundary conditions do not vary during the application of loads which are constant in magnitude, direction, and distribution while the model is deforming. Stiffness of the jacket structure below the deck is accounted for by use of linear beam elements. The deck is modeled by increasing material density, mainly in the deck plating.

1.3 Objectives

- To ease the complication arising in Analysis of offshore structures using popular software called SACS, which is being largely preferred by most people in the world now
- To analyse tubular offshore structures by applying environmental loads that are consistent and repetitive
- Reducing time of analysing complex offshore structures by using software as the interface

1.4 Advantages of Fixed Offshore Structure

- support large deck loads
- may be constructed in sections & transported
- large field, long term production supports a large number of wells
- piles result in good stability
- little effect from seafloor scour

2. ENVIRONMENTAL CONDITIONS AND DESIGN LOADS FOR OFFSHORE STRUCTURES

2.1 Types of Loads

Loads on offshore structures are gravity loads and environmental loads. Gravity loads are arising from dead weight of structure and facilities either permanent or temporary. Seismic loads are arising from gravity loads and are a derived type.

Environmental loads play a major role governing the design of offshore structures. Before starting the design of any structure, prediction of environmental loads accurately is important. Various environmental loads acting on the offshore platform is listed below.

1 Gravity Loads

- Structural Dead Loads
- Facility Dead Loads
- Fluid Loads
- Live Loads
- Drilling Loads

2 Environmental Loads

- Wind Loads
- Wave Loads
- Current Loads
- Buoyancy Loads
- Ice Loads
- Mud Loads

3 Seismic Loads

2.2 Maximum Global Loads

Maximum global loads on a platform can be calculated using two principles.

1 Maximum Base Shear Method
2 Maximum Overturning Moment Method

It is important that the wave loads on the structure be checked for both conditions. The maximum overturning moment method will give more pile loads than the other. Similarly, the maximum base shear method may govern the design of some jacket leg members near seabed due to high shear.

2.2.1 Maximum Base Shear

Maximum base shear or maximum total force on a structure has to be determined for the global analysis of structures. As the wave propagates across structure wave force on each member is different and all the locations will not be attaining the maximum forces.

2.2.2 Maximum Overturning moment

Maximum overturning moment on a structure can be determined following the procedure for the maximum base shear case. In this case, the loads on the members shall be multiplied by the lever arm from mud-line. This shall be summed up and the procedure shall be repeated for all the steps in the wave.

2.3 Load Combinations

The load combinations used for adequacy checking of any offshore structure can be divided into following two categories.

- Normal Operating Case - Maximum gravity loads arising from normal operation of the platform with 1 year return period wave, current and wind. This case is used to check the structure against loads during the normal operation of the platform.
- Extreme Storm Case - Maximum gravity loads arising from extreme case with 100 year return period storm wave, current and wind. This case is used to check the structure due to loads during 100 year return period storm together with platform gravity loads.

3. SIMULATION

Simulation is the imitation of the operation of a real-world process or system over time. The act of simulating something first requires that a model be developed; this model represents the key characteristics or behaviours/functions of the selected physical or abstract system or process.

With the advancement in computer and software technology and availability of computers, the structural analysis of structures has been made easy and fast. There are a number of commercial computer programs available specifically coded to carry out three dimensional structural analysis for offshore structures. Few programs are listed below.

- SACS - Structural Analysis Computer System - from Engineering Dynamics Inc. USA
- Strucad - Also from Engineering Dynamics INC. USA
- SESAM - from Det Norske Veritas, Norway

The modern day offshore development project schedules do not permit designers to carry out hand calculations due to faster requirement of design and drawings for fabrication. Usually, the first discipline to produce documents and drawings is structural so that the materials can be ordered to mill for production. Hence the structural designers are under very high pressure from fabricators to produce the structural material take off for order placement. The use of structural analysis programs with fast computers has made possible some of the largest structures to be designed in 6 to 8 months.

Following preparatory activities are required before analysis and design can be carried out.

- Structure Geometry selection
- Geometry Simulation
- Foundation Simulation
- Load Simulation

3.1 Structure Geometry selection

Structure geometry shall be selected based on various requirements such as layout, water depth, environmental condition, installation methodology and topside loads etc.

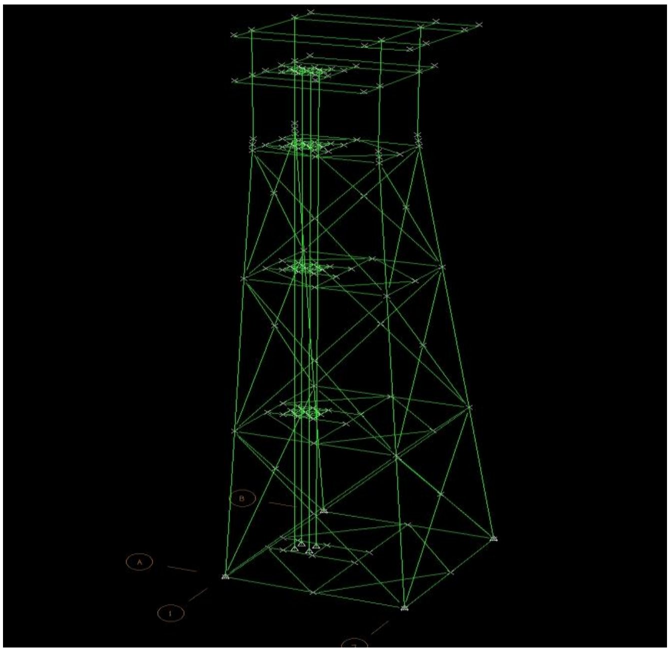

Fig -2: Computer Model of a Wellhead Jacket and Deck

3.2 Geometry Simulation

A geometric model of a structure contains a database of following information.

- Joints or Nodes
- Members and Properties
- Foundation
- Loads

Each of the above information can be entered in a planned and systematic way so that the post processing and correlating the design drawings with analysis results becomes easier and faster.

3.3 Foundation Simulation

3.3.1 Pile Modelling

In an offshore structure, the piles hold them on to the sea bed. This needs to be simulated in the structural analysis involving their inplace strength and stability. There are types of pile system that can be used in the offshore structures.

- Main Pile
- Skirt Pile

The skirt pile is always grouted with the skirt sleeve of the jacket. But in the case of main pile, the annulus between the pile and the jacket leg may be grouted or not grouted depending on the design water depth. Like other structural elements of the jacket structure, pile is also a structural member and shall be modelled according to the diameter, wall thickness and material properties. It is the load transfer mechanism between the jacket leg and pile that requires special care in simulation of actual load transfer.

4. Sacs Software for Design and Analysis

SACS (Structural Analysis Computer Systems), a Design and Analysis software for offshore structures and vessels, is used for the modeling and analysis of the jacket.

SACS is an integrated suite of finite element based software that supports the analysis, design and fabrication of offshore structures, including oil, gas, and wind farm platforms and topsides. Its ability to dynamically iterate designs allows users to perform advanced analysis, comply with offshore design criteria, and visualize complex results. SACS provides reliable beam member code checking and tubular joint code checking capacity ; therefore it is very suitable for topsides structures consisting of plate girders and tubular columns/ braces.

4.1 Inputs for Structural Definition

Elevations:
In this window we enter the elevation data that is

- Working point : Where the deck is to be installed
- Water depth : It is the average depth of water in that area
- Pile connecting elevation : It is the point at which the jacket structure starts to act
- Mud line elevation : It is the point at which the water level starts
- pile stub elevation : It is the starting point of piles that connect the jacket structure to pile foundation

The inputs given are as follows:
Water depth: 79.5 m
Working point elevation: 4.0 m
Pile connecting elevation: 3.0 m
Mud line elevation, pile stub elevation, and leg extension elevation: -79.5m
Other intermediate elevations: -50.0, -21.0, 2.0, 15.3 (cellar deck), 23.0m (main deck)

Leg Data:

The next step is to enter the data about the spacing of legs at different levels on the elevation. Here in this thesis we choose the leg spacing at mud line and working point in order to define the structure.
The inputs given are as follows:
Number of legs: 4
Leg type: Ungrouted
Leg spacing at working point: X1=15 m, Y1=10 m.
Row Labeling: Define the Row label to match the drawing

Pile/Leg Batter: Row 1 (leg 1 and leg 3, 1st Y Row) is single batter in Y
Row 2 (leg 2 and leg 4, 2nd Y Row) is double batter

Conductor Data:

Up to 3 conductor bays can be generated automatically. The number of conductor, rows in the global X direction and the global Y direction are entered for each well bay. The top conductor elevation and any other elevation at which the conductor should not be connected to the structure are also specified. For each well bay the spacing between the conductors and location of the well bay are specified.
One conductor well bay that has four conductors
The top conductor elevation: 15.3m
First conductor number: 5
Number of conductors in X direction: 2
Number of conductors in Y direction: 2
The location of first conductor (LL): X= -4.5m, Y= -1.0m
The distance between conductors: 2.0m in both X and Y directions.
Disconnected elevations: -79.5m, 3.0m, and 4.0m.

Definitions of member groups:

The inputs given in the structural definition gives to member groups with undefined properties, the properties of these groups are LG1, LG2, LG3 are defined in segments as follows:
Segment 1: D =48.5in, T = 1.75in, Fy = 34.50 kN/cm2, Segment Length = 1.0 m
Segment 2: D =47.0in, T = 1.0in , Fy = 24.80 kN/cm2
Segment 3: D = 48.5in, T = 1.75in, Fy = 34.50 kN/cm2, Segment Length = 1.0 m
Member is flooded

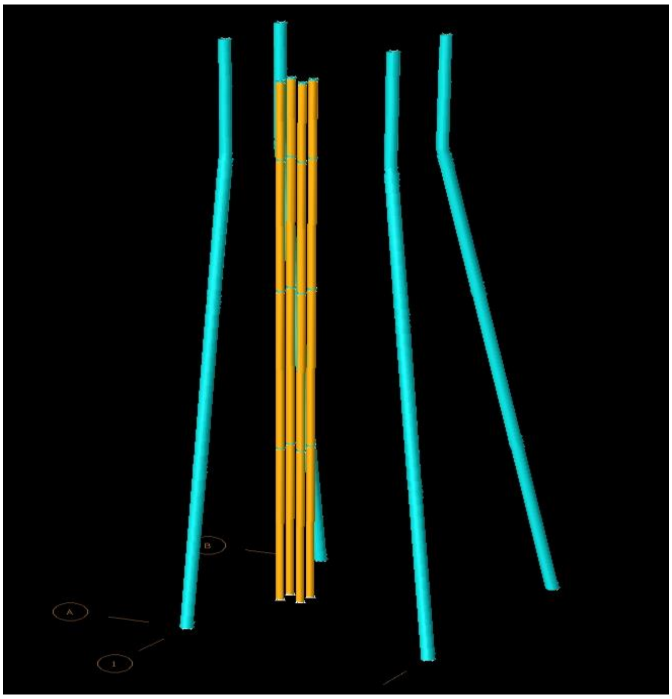

Fig -3: pile and conductor model

LG4 = 48.5”x1.75”
DL6 = 42”x1.5”
DL7 = 42”x1.5”
CON = 30”x1” flooded
PL* = 42”x1.5”
W.B. = 30”x1” flooded
Where D is outer diameter and T is thickness
Density of all members is 7.849 tonne/m^3

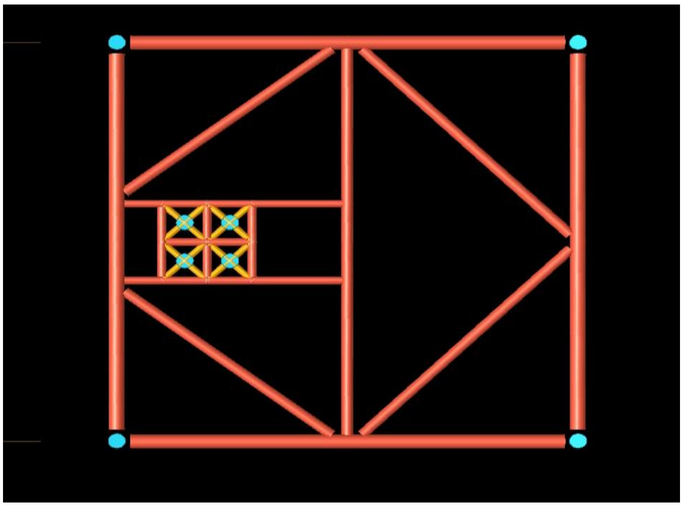

Fig -4: Conductor connections at Z=-50m

DECK GIRDER DATA:

1. Deck elevation: select 15.30
   Deck extension: input 4.0m at structure North and South
2. Deck elevation: select 23.00
   Deck extension: input 4.0m at structure north and south, 5.0m at structure east

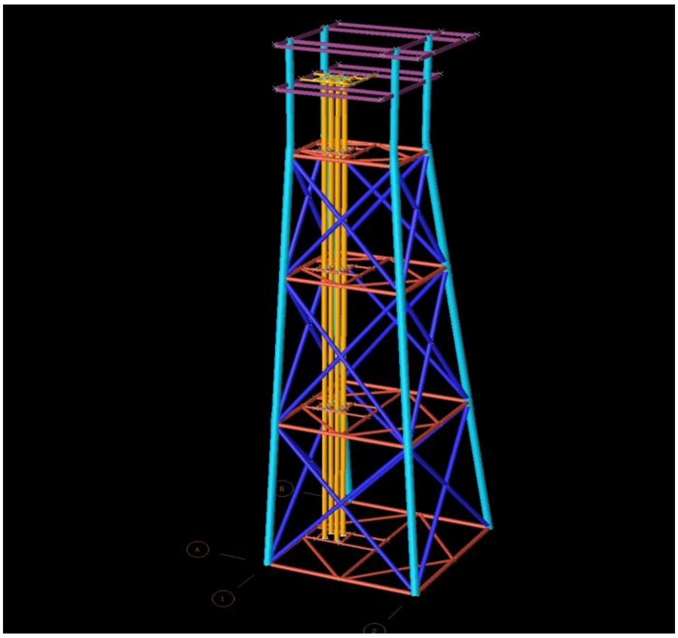

Fig -5: Basic structure after structural definitions

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4.2 Input of Loading Details and Its Impact on Structure

The load and the applications of these loads to the structure are to be done in this module. The load of structure is taken into consideration for stability and design. As we are applying the loads to the existing structure we know the details of the dead loads acting on the structure. But the environmental loads change for Indian conditions. We shall discuss these loads and enter them into the correct joints in order to complete the analysis.

4.2.1 Surface Loads

Local coordinate joints: Joint 71BD, 71ED, and 74BD for Input 0.5 for Tolerance and pick up71BD, 71ED, 74ED and 74BD by holding CTRL key for Boundary joints. These joints are subjected to surface loads input weight pressure of 0.5 kN/m^2 for cellar deck and move **CELLWT1**

Pick up joint 81BD, 81FD and 84BD for local coordinate joints, input 0.5 for Tolerance, and pick 81BD, 81FD, 84FD and 84BD by holding CTRL key for Boundary joints. Load direction to negative direction of Y-axis, Surface ID: **MAINWT1**

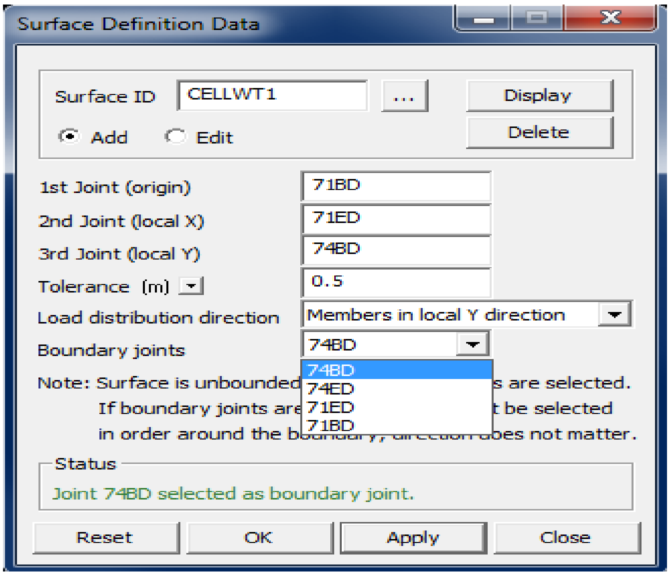

Fig -6: Input Values for Surface Loads

Add weight group **LIVE** by using surface weight feature. Weight ID **MAINLIVE** includes the main deck weight pressure of 5.0 kN/m2and ID **CELLLIVE** includes the cellar deck weight pressure = 2.5kN/m2.

4.2.2 Footprint Weights

Weight group is EQPT and Footprint ID is SKID1;
Weight = 1112.05 KN; Footprint center (5.0, 2.0, 23.0); Relative weight center (0, 0, 3.0)
Skid Length = 6 m; Skid Width = 3 m; 2 skid beams in X direction (longitudinal)

4.2.3 Miscellaneous Weights

Walkway weight on main and cellar decks
Weight group: MISC
Weight ID: Walkway
Weight Category: Distribute
Coordinate system: Global
Initial weight value: 2.773 kN/m
Final weight value: 2.773 kN/m

Crane Weight
Weight Group: MISC
Weight ID: CRANEWT
Weight: 88.964kN

Firewall Weight
Weight Group: MISC
Weight ID: FIREWALL
Weight Category: concentrated
Coordinate system: Global
Concentrated Weight: 15.0kN
Distance: 1.5m

4.3 Seastate Load Generation

The inputs for seastate loads are for load conditions
Operating Storm (three directions considered: 0.00, 45.00, 90.00): load case **P000**, **P045**, **P090**
Extreme Storm (three directions considered: 0.00, 45.00, 90.00): load case **S000**, **S045** and**S090**
In **S000** that is extreme storm the inputs are as follows:
Wave-I; Water Depth Override=81m: Direction of Gravity=-Z
Wave-II: Wave position step size=20deg; No of crest positions=18; Max member segmentation=10
Wind-I: Velocity=45.17m/sec;
Current-I; Distance=0; Velocity=0.514m/sec; Direction=0; Distance=79.5; Velocity=1.029m/sec;
Similarly the load for **S045** and **S090** are defined for other directions.
For **P000** that is Operating Storm Conditions the significant change in velocity of wind that is taken as 25.72m/sec

4.4 Load Combinations

Six load combinations **OPR1**, **OPR2**, **OPR3**, **STM1**, **STM2** and **STM3** will be added into the model. Three of them are corresponding to operating storms and the other three are corresponding to extreme storms. Load factor of 1.1 will be used for environmental loads. The live load will be included with a factor of 0.75 in extreme storm load combinations.
Go to **"Load">"Combine load conditions"** to define the load combinations. The following two pictures show the combinations of operating and extreme storm conditions.

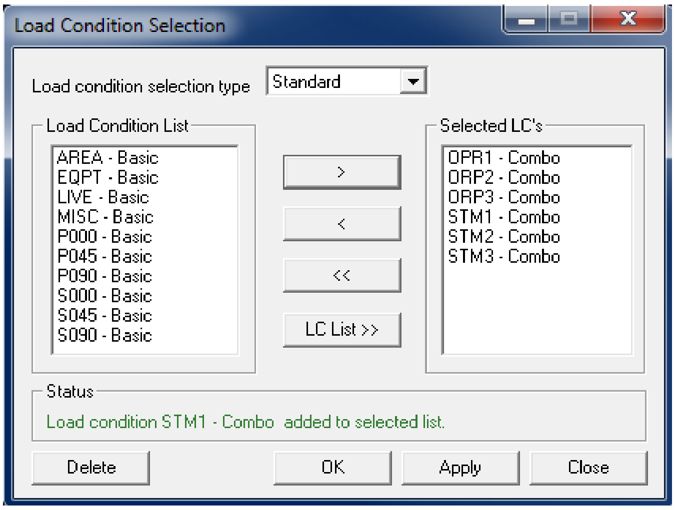

Fig -8: Load Condition Selection

5. RESULTS AND DISCUSSION

By creating the static analysis directory and separate the model file as sea state data and model data as seainp.dat and sacinp.dat. By clicking on Analysis Generator from the Executive window and select Statics for Type and Static analysis for subtype. And selecting the relative environmental options for the Structure to run the Analysis. A file psvdb.dat is created to run the analysis.

The unity check ratio for maximum combined stress, axial stress, Z axis bending or Y axis bending may be labelled using the Unity Check labelling features.

- Maximum Combined - The maximum combined stress unity check ratio for all active load cases may be alternately displayed or concealed using this toggle.
- Axial - The maximum axial stress unity check ratio for all active load cases may be alternately displayed or concealed using this toggle.
- Y-Bending - The maximum unity check ratio for bending about the local Y axis for all active load cases may be alternately displayed or concealed using this toggle.
- Z-Bending - The maximum unity check ratio for bending about the local Z axis for all active load cases may be alternately displayed or concealed using this toggle.

Table -1: Member Unity Check Range Summary

Member	Group ID	Maximum combined Unity check	Load Condition No	Axial stress N/mm²	Bending stress Y N/mm²	Bending stress Z N/mm²	Shear Force Fy KN	Shear Force Fz KN
102P-202P	PL1	0.680	S000	-50.89	16.91	-22.58	29.90	-5.97
103P-203P	PL1	0.724	S090	-56.44	25.75	-1.33	1.54	-22.78
104P-204P	PL1	0.850	S045	-68.34	23.68	2.03	-2.80	-14.76
202P-302P	PL2	0.530	S000	-48.62	-8.18	6.56	-5.82	23.83
203P-303P	PL2	0.580	S090	-54.17	-9.89	0.16	0.05	19.95
204P-304P	PL2	0.705	S045	-66.07	-9.97	-0.70	0.92	25.13
304P-404P	PL3	0.571	S045	-63.83	-4.51	0.18	0.13	18.05

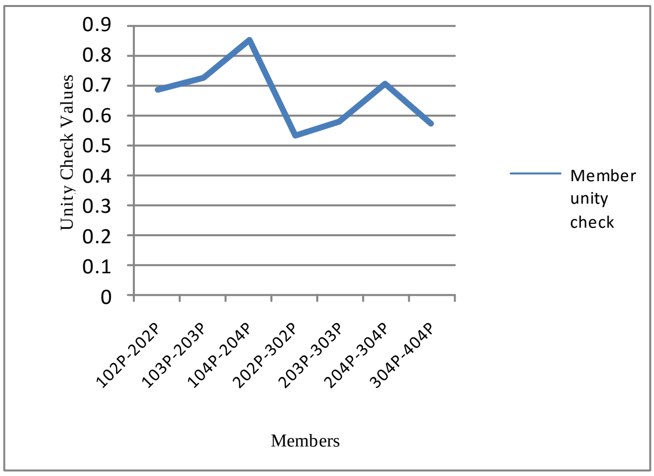

Chart -1: Member Unity Check Graph

For the jacket structure the Unity check has been performed for pile group members and found that the ratio of actual stress to allowable stress is less than unity for all members. Thus the pile members in the structure are safe. The Unity check is performed for pile group members and the maximum combined unity check ratio is for member 104P-204P which is relatively more affected for static loads.

6. CONCLUSIONS

The static responses of a frame jacket type offshore platform have been studied using a frame model in computer program SACS. This structure is capable of accounting for static load and buckling behavior of tubular struts. For linear study of braced frames especially for the jacket type offshore structures behavior, this methodology can be used. This structure predicts the overall behavior accurately. The following conclusions can be drawn:

- Calculation of the stresses acting on the structure for different load cases as found by selecting the maximum stress producing load combination gives maximum structural stability.
- The use of the analysis gave values of axial load, which is found to give a better representation for the structure model. This provides more resistance to the structure against lateral forces, since laterally acting forces when resolved will lead to higher overturning moments on the structure.
- The stresses acting on the structure for different load cases are within the limits of Allowable stresses so the structure is safe for axial stresses and bending stresses.
- From the Static Analysis, the members at Z=-79.5m are effected more by static loads, for example the unit ratio of member 104P-204P is more than all other members, showing relatively more effect of static loads.
- The critical members in the member groups are obtained from the static analysis results.

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