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OFFSHORE STRUCTURAL ENGINEERING

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ABSTRACT

Platform structures are commonly utilized for various purposes including offshore drilling, processing and support of offshore operations. Jacket type structures are attractive in relatively shallow water regions. A jacket is a supporting structure for deck facilities stabilized by leg piles through the seabed. The size of a jacket is dependent on deck size, pile dimensions and environmental loads. In a jacket design, operational and environmental loads are very important and must be investigated intensively to secure the stability of structures during their operation life and installation phase as well. To confirm the stability, several analyses including In-place (Static & dynamic), load-out, transportation, lifting, and launching are performed.

***KEYWORDS**: Offshore, Structural, Engineering*

1. NTRODUCTION

Offshore structural engineering is a relatively new field concerned with the design and installation ofvarious types of offshore platforms. In 1911, the world's first over water oil well was drilled in Coddo Lake near Shreveport, Louisiana. It consisted of a wooden platform founded on cypress piles in only 3mof water (Reeves, 1975). However, later platforms had been constructed in Lake Maracaibo in the 1920s. In 1938, the first offshore oil rig was constructed by Humble Oil Co. in 18m of water. It was founded on timber piles and connected to shore by a timber trestle which was approximately one mile offshore in the Gulf of Mexico.

The forerunner of today's monumental offshore platforms was constructed in Louisiana in 1947 by Kerr—McGee Co. to stand in 6m of water, approximately 12 miles offshore in the Gulf of Mexico. It was a jacket template type platform consisted of tubular steel members connected by bracing. The platform structure was prefabricated and towed to the site. After positioning, steel pipe piles were driven through the hollow columns (Gaythwaite, 1981). This method of construction is still widely used today.

Since the installation of that first platform in the Gulf of Mexico, the offshore industry has seenmany innovative structures placed in deeper waters and in more hostile environment. By 1975, structures had been successfully installed in waters extending up to approximately 144m. Within the next three years, the frontier depth was more than doubled with the completion of a structure in 312m of water (Chakrabarti, 1987). Today, fixed offshore platform structures are located at the very edge of the continental shelves and stand in up to 488m water depths (Chakrabarti, 1987). They are constructed in harsh environments such as the Gulf of Alaska and the North Sea. There are numerous structural configurations, both of steel and of concrete.

1.1 AIM & OBJECTIVE

Objective of the present study is to explore the capabilities of the SACS program in analysis of jacket platform.

The specific objectives are

1. Studying the analysis and design provisions given in API code & classify them under certaingroups in order to identify the analysis and design requirement.
2. To perform different kinds of analyses related to jacket platform as per API code requirement,like,
    - i. In-place analyses (static and dynamic, with and without soil-pile interaction).
    - ii. Load out, transportation, launching and upending analyses.

2. LITERATURE REVIEW

2.1 Introduction of Offshore Structures

An offshore structure has no fixed access to dry land and may be required to stay in Position in all weather conditions. The major use of these platforms is in the drilling for oil and gas beneath the seafloor. Offshore structures may be fixed to the seabed or may be floating. Floating structures may be moored to the seabed, dynamically positioned by thrusters or may be allowed to drift freely.

While the majority of offshore structures support the exploration and production of oil and gas, other major structures, e.g. for harnessing power from the sea, Offshore bases, offshore airports are also coming into existence.

The range of offshore platform is very great. In general, the offshore platforms use in the oil and gas development projects can be firstly divided into two types, namely, the steel template platformsand the concrete gravity platforms. Then, they can be further sub-divided according to construction or their functions.

According to Graff (1981), economics control the specific choice of platforms to be placed at a given offshore location. In deep water (approaching 400ft or 122m), a self-contained platform would be most advantageous. Self-contained platform combines all functions on one multilevel structure.

2.2 TYPES OF OFFSHORE PLATFORMS

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

1. Fixed Platforms

- Steel template Structures
- Concrete Gravity Structures

2. Compliant structures

- Compliant Tower
- Guyed Tower
- Articulated Tower
- Tension Leg Platform

3. Floating Structures

- Floating Production System
- Floating Production, Storage and Offloading System

2.2.1 Fixed Platforms

The fixed type of platform shall exhibit a low natural period and deflection against environmental loads.

2.2.1.1 Steel template Structures

The steel template type structure consists of a tall vertical section made of tubular steel members supported by piles driven into the sea be with a deck placed on top, providing space for crew quarters, a drilling rig, and production facilities. The fixed platform is economically feasible for installation in water depths up to 500m.

These template type structures will be fixed to seabed by means of tubular piles either driven through legs of the jacket (main piles) or through skirt sleeves attached to the bottom of the jacket.

The principle behind the fixed platform design is to minimize the natural period of the structure below 4 seconds to avoid resonant behaviour with the waves (period in the order of 4 to 25 seconds. The structural and foundation configuration shall be selected to achieve this concept.

2.2.1.2 Concrete Gravity Platforms

Concrete gravity platforms are mostly used in the areas where feasibility of pile installation is remote. These platforms are very common in areas with strong seabed geological conditions either with rock outcrop or sandy formation.

Some part of North Sea oil fields and Australian coast, these kind of platforms are located. The concrete gravity platform by its name derive its horizontal stability against environmental forces by means of its weight. These structures are basically concrete shells assembled in circular array with stem columns projecting to above water to support the deck and facilities. Concrete gravity platforms have been constructed in water depths as much as 350m.

2.2.2 Compliant Structures

In addition to the developing technologies for exploration and production of oil and natural gas, new concepts in deep water systems and facilities have emerged to make ultra-deep water projects a reality. With wells being drilled in water depths of 3000m, the traditional fixed offshore platform is being replaced by state-of-the-art deep water production facilities. Com- pliant Towers, Tension Leg Platforms, Spars, Subsea Systems, Floating Production Systems, and Floating Production, Storage and

2.2.2.1 Compliant Tower

Compliant Tower (CT) consists of a narrow, flexible tower and a piled foundation that can support a conventional deck for drilling and production operations. Unlike the fixed platform, the compliant tower withstands large lateral forces by sustaining significant lateral deflections, and is usually used in water depths between 300m and 600m.

2.2.2.3 Guyed Tower

Guyed tower is an extension of complaint tower with guy wires tied to the seabed by means of anchorsor piles. This guy ropes minimises the lateral displacement of the platform topsides.

This further changes the dynamic characteristics of the system.

2.2.3 Articulated Tower

Articulated tower is an extension of tension leg platform. The tension cables are replaced by one singlebuoyant shell with sufficient buoyancy and required restoring moment against lateral loads.

The main part of the configuration is the universal joint which connects the shell with the foundation system. The foundation system usually consists of gravity based concrete block or sometimes with driven piles. The articulated tower concept is well suited for intermediate water depths ranging from 150m to 500m.

2.2.4 Floating Structures

2.2.4.1 Floating Production System

Floating Production System (FPS) consists of a semi-submersible unit which is equipped with drilling and production equipment. It is anchored in place with wire rope and chain, or can be dynamically positioned using rotating thrusters. Production from subsea wells is transported to the surface deck through production risers designed to accommodate platform motion. The FPS can be used in a range of water depths from 600m to 2500m feet.

2.2.4.2 Floating Production, Storage and offloading System

Floating Production, Storage and Offloading System (FPSO) consists of a large tanker type vessel moored to the seafloor. An FPSO is designed to process and stow production from nearby subsea wells and to periodically offload the stored oil to a smaller shuttle tanker. The shuttle tanker then transports the oil to an onshore facility for further processing. An FPSO may be suited for marginally economic fields located in remote deep water areas where a pipeline infrastructure does not exist. Currently, thereare no FPSO’s approved for use in the Gulf of Mexico. However, there are over 70 of these systems being used elsewhere in the world.

2.2.5 Subsea System

Subsea System (SS) ranges from single subsea wells producing to a nearby platform, FPS, or TLP to multiple wells producing through a manifold and pipeline system to a distant production facility. These systems are presently used in water depths greater than 1500m.

2.2.6 Fixed Platform Concepts

For the last few decades, the fixed platform concept has been utilized extensively over 300m depth with various configurations

3. METHODOLOGY

The design of offshore structure is not a single step design process. The structural configuration, arrangement, member sizes and its specification requirements can be arrived after few design cycles. In order to achieve an optimum design suitable for the installation method proposed and satisfy the final operating requirements, a design procedure suitable for the project shall be developed. The various design stages in an offshore project is listed below.

- Basic Design

- Detailed Design

The first step in initiating an offshore project is a concept selection. This stage of project will involve following steps in all disciplines such as Process, Mechanical, Electrical and Instrumentation in addition to Structural Engineering.

- Collection Process Data and identifying process needs and equipment

- Preliminary equipment sizing and area requirements

- Weight estimation based on past projects

- Identification of Structural configurations

- Preliminary estimation of structural weight

- Identification of installation methods

- **Basic design**

A Design Basis (DB) will be developed for the proposed facility containing following information.

- **Process** information containing type of well fluid (oil or gas) and its characteristics, safety requirements and kind of process technology to be adopted.
- **Mechanical** requirement such as type of facility and basic equipment required for the process, andmaterial handling and safety
- **Electrical** requirement such power generation equipment, lighting and switch gears etc.

- **Instrumentation** requirement such as basic control system, feedback requirement etc.

- **Piping** information such as pressures, pipe sizes required etc.

- **Meta-Ocean** information such as water depth, wave, current, wind and tidal information at the site.

- **Structural** requirement such as materials proposed or available for use in the country, design method to be adopted, codes and specifications to be used etc.

- **Detailed Design**

Detailed design of offshore platform will be initiated once the basic design confirms the economic viability and technical feasibility.

In the Detailed design of an offshore platform all items of the jacket and deck will be developed and inplace, load out, sea transportation and lift or float over analyses are performed.

4. LIVE LOADS

Live loads are defined as movable loads and will be temporary in nature. Live loads will only be appliedon areas designated for the purpose of storage either temporary or long term. Further, the areas designed for laydown during boat transfer of materials from boat shall also be considered as live loads.

Other live load includes open areas such as walkways, access platforms, galley areas in the living quarters, helicopter loads in the helipad, etc. These loads shall be applied in accordance with the requirement from the operator of the platform.

Table: 2.1 Description of Loads

S. No	Location	Load(KN/m^2)
1	Storage /laydown	10
2	Walkway	5
3	Access Platform	5
4	Galley	10

- **Drilling Loads**

Drilling loads are due to drill rigs placed on top of the platform for drilling purposes. These are large equipment assembled together and placed on top. Normally, drilling rigs are as heavy as 500 Tonnes to1000 Tonnes. These will deliver reaction forces on the deck and the stiffness of the drilling rigs are notconsidered in the structural analysis. Hence the weight of the structure shall be applied as load on the structure. Further, during drilling, additional loads will be developed due to drill string and pulling operations. These loads also shall be considered in the analysis.

- Environmental Loads
- **Wind Loads**

The wind speed at 10m above LAT (Lowest Astronomical Tide) is normally provided (Vo). This wind speed shall be extrapolated to the height above for the calculation of wind speed. The extrapolation shall be calculated as below.

$$V=V0\ y/10^{1/7}$$

Where y is the elevation of point in consideration in m above LAT and V is the velocity at that point.Wind loads shall be calculated as per API RP2A guidelines.

Sustained wind speeds (10min mean) shall be used to compute global platform wind loads and gust wind (3 second) shall be used to compute the wind loads to design individual members The wind pressure can be calculated as

$$f_W = \rho q/2V^2$$

Where F is the wind pressure per unit area, ρ (0.01255 kN/m3) is the density of air, g is the gravitationalacceleration (9.81 m/sec2) and V is the wind speed in m/sec.

- **Buoyancy Loads**

The offshore structural members mostly made buoyant by air tight sealing of the welds to avoid water entry. This is purposely planned so that the overall structure will have adequate buoyancy during installation. Typical example is the jacket structure. This kind of structure requires at least a reserve buoyancy of 10% to 15%. The reserve buoyancy is defined as buoyancy in excess of its weight. To obtain this buoyancy, structural tubular members are carefully selected such that their buoyancy / weight ratio is greater than 1.0. This means that the member will float in water. On other hand, if the member is part of a structure supported at its two ends and forced to be submerged by weight of other members, this member will experience a upward force equal to the displaced volume of water. This is called buoyancy force.

- **Maximum Global Loads**

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

- Maximum Base Shear Method

- 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.

- **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. To find the maximum total force a structure, following steps need to be considered.

- Position the wave crest at the origin of the structure.

- Divide one wave cycle into number of segments either in terms of θ or in terms of length.

- Compute the wave forces on all members at that instant of time using water wave velocities and accelerations computed.

- Sum up the forces in horizontal direction for all the members.

- Repeat the calculation for all the points for one wave cycle.

The maximum of all the total forces computed in step 5 is the maximum base shear or total force.

5. WAVE THEORY

Ocean waves are, generally, random in nature. However, larger waves in a random wave series may begiven the form of a regular wave that may be described by a deterministic theory. Even though these wave theories are idealistic, they are very useful in the design of an offshore structure and its structural members. The wave theories that are normally applied to offshore structures are described in this section. There are several wave theories that are useful in the design of offshore structures. These theories, by necessity, are regular. Regular waves have the characteristics of having a period such that each cycle has exactly the same form. Thus the theory describes the properties of one cycle of the regular waves and these properties are invariant from cycle to cycle. There are three parameters that areneeded in describing any wave theory. They are:

1. Period (T), which is the time taken for two successive crests to pass a stationary point,

2. Height (H), which is the vertical distance between the crest and the following trough. For a linear wave, the crest amplitude is equal to the trough amplitude, while they are unequal for a non-linear waveand water depth (d), which represents the vertical distance from the mean water level to the mean oceanfloor. For wave theories, the floor is assumed horizontal and flat. Several other quantities that are important in the water wave theory may be computed from these parameters.

3. wavelength (L), which is the horizontal distance between successive crests, wave celerity or phase speed (c), which represents the propagation speed of the wave crest, frequency (f), which is the reciprocal of the period, wave elevation which represents the instantaneous elevation of the wave from the still water level (SWL) or the mean water level (MWL), horizontal water particle velocity (u), whichis the instantaneous velocity along x of a water particle, vertical water particle velocity (v), which is theinstantaneous velocity along y of a water particle, horizontal water particle acceleration (G), which is the instantaneous acceleration along x of a water particle, and vertical water particle acceleration (G), which is the instantaneous acceleration along y of a water particle.

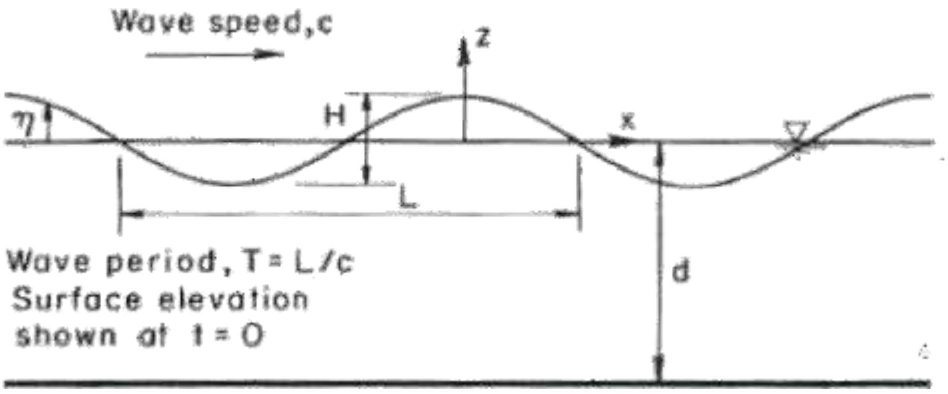

Fig: 2.1 Definition sketch for a progressive train (Sarpkaya &Isaacson)

- **Selection of Wave Theory**

The computation of wave kinematics such as velocity and acceleration involves the equations from wave theory. There are various kinds of solutions available depending on the accuracy required, and parameters involved in the computation. The various wave theories are listed below:

- Linear / Airy Wave Theory
- Stokes Wave Theory
- Stream Function Wave Theory
- Cnoidal Wave Theory

Depending on the location such as deep water or shallow water and associated wave param- eters, a suitable wave theory shall be selected for use. API RP 2A recommends to use a Chart for such selection based on d/gT^2 and H/gT^2 as the X and Y axis. Refer to Figure. The wave theories discussed above are for non-breaking waves. For $H/h > 0.78$, these theories are not applicable as the waves tend to break. In such situation, empirical equations shall be used to calculate the breaking wave forces on the structures.

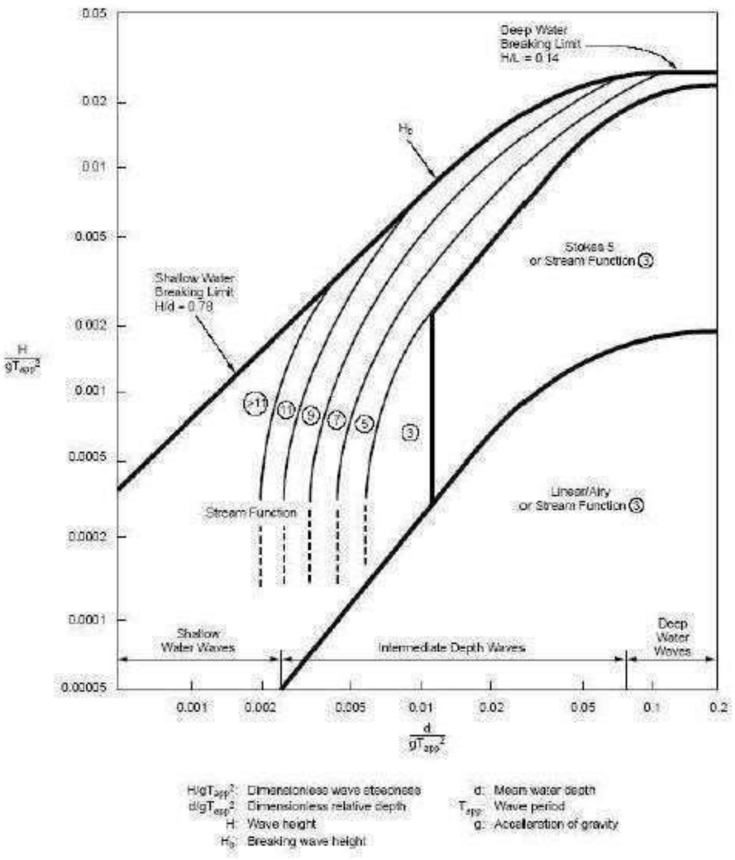

Figure 2.2: Selection of wave theory for load calculation (API RP 2A)

6. STATIC ANALYSIS

6.1 Static Analysis

Static analysis for the platform structures using SACS software is of two types, first one is for direct loads experienced by structure like gravity, and environmental loads etc. as faras inertia forces are not predominant.

Another type is, for the loads generated by the software when operations like Load out, launching, transportation, or upending are performed.

One of the main loadings for which offshore structures are designed is caused by extreme waves generated during intense, rare storms. The dominant periods of such waves are typically much longer than the fundamental periods of most fixed offshore structures and therefore static analyses are usually sufficient for obtaining the design response of these structures to extreme waves. In practice, regular (i.e. periodic), unidirectional wave theories (e.g. Airy, Stokes, etc.) have traditionally been used as providing adequate representations of extreme sea states for static design applications. For a typical solution tothis problem, a regular wave, described by its height, period and direction, is passed throughthe structure and forces on the various structural elements are computed for a wave cycle by summing up elemental forces predicted by the well-known Morison's equation. Velocities from currents are superimposed on the water particle velocities due to the wave. Design envelopesare typically obtained by analyzing the structure for several directions of wave travel.

Matrix method of structural analysis can be used to find out the response of the structure andmembers are adequately sized. In performing this kind of analysis it is sufficient to consideronly the two cases where the direction of wave motion is along each of the principal horizontal axes the structure and limit attention to a two-dimensional frame analysis. In second case a complete 3-dimensional analysis should be performed.

6.2. Analysis Procedure in Sacs

PSI is designed to use pile and soil data, specified in an input file, in conjunction with linear structural data produced by the SACS IV program. The nonlinear foundation model, including the pile and the soil properties, is specified separate from the model information in a PSI input file. The interface joints between the linear structure and the nonlinear foundation must be designated in the SACS model by specifying the support condition ‘FIXED’ on the appropriate JOINT input line. The analysis option ‘PI’must be specified either on the model OPTIONS line or designated in the Executive.

6.3. Model Data

The geometry of the jacket structure used in this study is described in the following section. Meanwhile the elements used to model the jacket structure are also discussed.Fig3-1 show the structure model developed using SACS.

The structure analysed in this study is basically a four leg steel offshore jacket installed in water depthof 80m. The jacket with deck is modelled as a space truss, consists of tubular members with various orientation braced together to form the structure.

The jacket legs are divided into seven groups and different properties of these groups are listed below.

Table 3.1 Model Data for Static Analysis

Member group	Group type	OD (cm)	WT (cm)
LG1	Tubular	150	3
LG2	Tubular	150	3
LG3	Tubular	150	3
LG4	Tubular	150	3
LG5	Tubular	150	2.4
LG6	Tubular	120	2.4
LG7	Tubular	120	2.4
PL1	Tubular	120	2.4
PL2	Tubular	120	2.4
TO1	Tubular	60	2
TO2	Tubular	50	1.8
DKP	Wide flange	W 30*90	
DKG	Wide flange	W 33*118	

Operational Condition

Wind Speed = 25.7 (m/s)

Wave Height = 6.1m

Period = 13.0 sec

Current Speed = 0.305, .610 m/sec

Storm Condition

Wind Speed = 77.2

Wave Height = 12.19 m,

Period = 13.0 sec

Current Speed =1.5, 3.5 m/sec

Stake’s wave theory of order 5 is used for the analyses. Coefficient of drag and inertia are taken as 0.6 and 1.2. Other loads like live, area, equipment, miscellaneous are combined with the above loads to create worst conditions.

Table: 3.2 Description of Wave

Wave Description for Load Cases		
	Operation Condition	Storm Condition
Wave Theory	Stoke's 5th Order	Stoke's 5th Order
Wave Height	6.100 m	12.19 m
Water Depth	80.000 m	80.000 m
Wave Period	13.000 sec.	13.000 sec
Wave Length	255.529 m	259.650 m
Mud line Elevation	-80.000 m	-80.000 m

Table: 3.3 Description of Load Combination

Load	Combination
P000	6.1m Wave + 0.305 m/sec Current + Buoyancy +Marine Growth+ Wind
P045	6.1m Wave + 0.305 m/sec Current + Buoyancy +Marine Growth+ Wind
P090	6.1m Wave + 0.305 m/sec Current + Buoyancy +Marine Growth+ Wind
S000	12.19m Wave + 0.305 m/sec Current + Buoyancy +Marine Growth + Wind
S045	12.19m Wave + 0.305 m/sec Current + Buoyancy +Marine Growth+ Wind
S090	12.19m Wave + 0.305 m/sec Current + Buoyancy +Marine Growth+ Wind
OPR1	DL+LL+EQP.+MISC+P000
OPR2	DL+LL+EQP.+MISC+P045
OPR3	DL+LL+EQP.+MISC+P090
STM1	DL+0.75LL+EQP.+MISC+S000
STM2	DL+0.75LL+EQP.+MISC+S045
STM3	DL+0.75LL+EQP.+MISC+S090

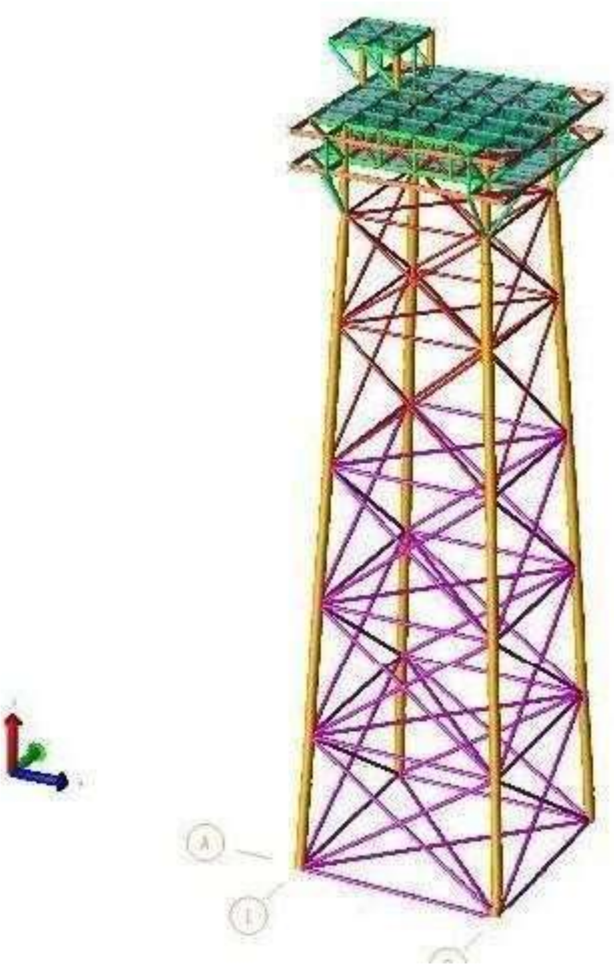

Fig: 3.1 Structure Model

7. RESULTS

Sea state Loads for Wave Passing Through Structure was acted upon the structure and analysis results were found using SACS. The maximum and minimum values of overturning moment, base shear etc. were calculated as tabulated below in Table 3.4. And 3.5.The structure is analysed for different Wave theories .From the results provided in the table the Base Shear and Overturning Moment increases with increase in wave height. The maximum overturning moment and Base Shear are in load case S090.

Table: 3.4 Sea state Loads (Stoke's 5thorder)

Sea state Loads for Wave Passing Through Structure				
Load Case	Maximum		Minimum	
	Overturning Moment	Base shear	Overturning Moment	Base shear
	kN-m	kN	kN-m	kN
P000	40330.930	762.255	28464.572	503.813
P045	40070.742	756.219	28159.791	496.729
P090	40330.934	762.255	28464.602	503.813
S000	144374.547	2454.132	123392.320	2035.812
S045	142240.828	2428.204	122249.164	2010.353
S090	144374.609	2454.132	123392.430	2035.814

Table: 3.5 Sea state Loads (Airy Theory)

Seastate Loads for Wave Passing Through Structure				
Load Case	Maximum		Minimum	
	moment	shear	moment	shear
	kN-m	KN	kN-m	KN
P000	40111.590	758.942	28214.842	499.418
P045	39821.844	752.863	27904.771	492.279
P090	40111.625	758.942	28214.867	499.418
S000	141691.031	2419.035	120920.148	1997.771
S045	139808.812	2394.548	119640.883	1970.745
S090	141691.078	2419.037	120920.297	1997.773

Table: 3.5 Base Shear and Overturning Moment for different Load Combination

Load Condition	Base shear		Overturning moment	
	FX (kN)	FZ (KN)	MX (kN-m)	MZ (kN-m)
OPR1	1085.87	-67770.3	-36127.5	-457.4
OPR2	762.18	-67779.1	-91090.5	-610.1
OPR3	0	-67772.9	-114132.2	-405.4
STM1	5366.17	-71746.2	-48647.6	-4116.2
STM2	3771.99	-71755.6	-388842.7	-5489.9
STM3	0	-71769.1	-531582.7	-3647.7

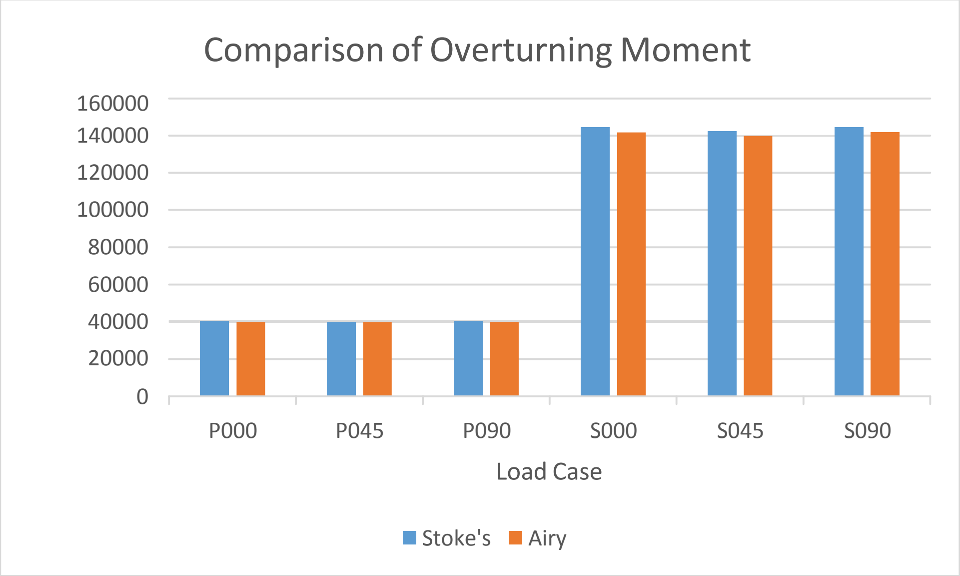

Fig: 3.2 Comparison of Overturning Moment

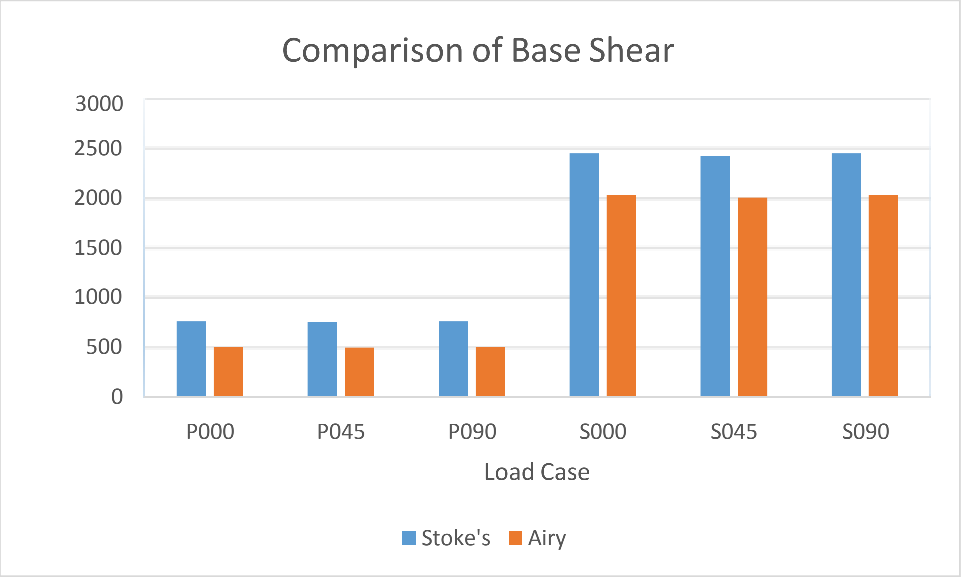

Fig: 3.3 Comparison of Base Shear

8. CONCLUSIONS

The Dynamic load summation for different transportation load case were calculated .We realize that themoment and force at origin of the structure are decreasing in downward Heave taking Heave force(0.2g) for all load cases. he jacket was transported on board and launched from the launch barge. This case uses the nominal weight and CoG of the jacket, a dynamic coefficient of friction of 0.05, and an initial draft of 5 meters and an initial Pitch of 7.36 degrees. A three dimensional time domain analysis was carried out for the jacket. The time steps that were used during the launch analysis is 10 seconds prior to tipping, 1 seconds after tipping and before separation, 5 seconds after separation until end of simulation, respectively.

The relative motion between the barge and the jacket after separation was examined by looking at the relative velocities of the jacket and barge. As shown in Fig: 5.2.1 the launch output results, the barge and jacket are moving in opposite directions at separation. The relative velocity in the x direction is 2.60 m/sec, much greater than the minimum requirement of 1.0m/sec. The clearance between the jacketand the barge was also examined. The minimum distance between the rocker pin and the trailing ends of the launch legs was 15.3 m.

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