

# ANALYSIS OF OFFSHORE STEEL JACKET DURING LOAD-OUT

## AND TRANSPORT

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### A B S T R A C T

In transporting large offshore structures on barges to the installation sites, the structure and seafastenings will be experiencing very high stresses due to rough sea and severe wind conditions. This is more critical in cases where the installation sites are located farther away from the shore.

The analysis of the Jacket tower during loadout and the different loading conditions encountered by the barge-jacket system during towing to the site are discussed and the relevant formulae for the determination of loads, in each of the cases have been derived and calculated. A typical jacket tower of height about 90 m mounted on the barge and held in position by seafastenings is considered and the analysis is carried out using the finite element technique. The displacements and rotations at each joint (nodal point) and the forces (axial and shear) and moments (torsion and bending) in each of the members have been obtained. Then the stresses in each members are calculated. The members in the tower are checked for stresses during loadout and the combined stresses in seafastenings for the worst combination of loads are determined.

## 1. Introduction

As the exploration and exploitation for hydrocarbons is increasing, more and more offshore platforms are installed in distant locations. The transportation of the jacket from the construction yard to the installation site is a critical stage in the construction of offshore platform. The operation of transferring the jacket to the barge is called 'load out'. While transporting, the jacket is to be fixed on to the barge by means of connectors called seafastenings. Sekita, Yamamoto and Okumura (1) have carried out structural analysis of the jacket frame subjected to inertial forces occurring at each node due to the barge motion and evaluated the stresses in the structural members. Sekita ~~saxda~~ and Kimura (2) have conducted model tests to evaluate the barge stability and structural safety during transportation. It was confirmed that the computer analysis truly predicts the behaviour of jacket during transportation. In this paper the stresses on a jacket at the critical position of load out are computed and also the stresses in the jacket and seafastenings when the jacket is transported on a barge.

## 2. Load Out :

The jacket tower is provided with the launching trusses as shown in fig 1a. The launching trusses are intended to support the dead load of the jacket tower during load-out and transport. The jacket is pulled from the construction yard to,

the barge by winches kept on the barge. When the centre of gravity position of the jacket has crossed the edge of the berth wall, the jacket end touches the barge. At this point the jacket is supported on four points as shown in Fig 1.a and the members in the launching truss near the supporting points will be highly stressed which may cause permanent deformation, if proper care is not taken.

### 3. Jacket during transport

The important forces acting on the jacket of the offshore platform when it is transported on the barge are

- (i) the inertial forces due to rolling, pitching and heaving
- (ii) loads due to self weight
- (iii) Wind loads

#### 3.1 Forces due to rolling

The barge may undergo purely oscillatory motion about the longitudinal axis if it is displaced from its equilibrium position and then released. The equation of motion for unresisted rolling, assuming small angle of roll  $\phi$  can be expressed as

$$I_T \ddot{\phi} + \Delta \overline{GM} \phi = 0$$

where  $\Delta$  is the barge displacement,  $\overline{GM}$  is the transverse meta centric height of the barge,  $I_T$  is the mass moment of inertia about the longitudinal axis.

The rolling motion can be expressed as  $\phi = \phi_a \sin \omega t$  where  $\phi_a$  is the maximum angle of roll,  $\phi$  is the rolling displacement and  $\omega$  is the circular frequency

$$\omega = \frac{2\pi}{T_\phi}$$

If the weight of the component on board of the barge is  $W$  (Fig 2a), the tangential force  $Q$  can be expressed as

$$Q = -\frac{W}{g} \frac{4\pi^2}{T_\phi^2} \left( \frac{\pi}{180} \phi_a \right) \sin \omega t$$

where  $\phi$  is the maximum angle of roll in degrees

$T_\phi$  is the period of roll given by  $T_\phi = 2\pi \sqrt{\frac{I_T}{\Delta \overline{GM}}}$

$r_1$  is the distance of  $W$  from the axis of rolling.

The transverse and vertical component of the force is

$$Q_z = -\frac{W}{g} \frac{4\pi^2}{T_\phi^2} y_0 \left( \frac{\pi}{180} \phi_a \right) \sin \omega t$$

$$Q_y = -\frac{W}{g} \frac{4\pi^2}{T_\phi^2} x_0 \left( \frac{\pi}{180} \phi_a \right) \sin \omega t$$

$Y_0$  and  $Z_0$  are the distances of  $W$  along  $Y$  and  $Z$  axis, as shown in fig 2.

The Centrifugal force due to rolling is  $P = \frac{W}{g} (\dot{\phi})^2 r_1$

and the transverse and vertical components are

$$P_z = -\frac{W}{g} (\dot{\phi})^2 z_0$$

$$P_y = +\frac{W}{g} (\dot{\phi})^2 y_0$$

The total transverse force is given by

$$R_z = \bar{W} \sin \phi + \frac{4\pi^2}{gT_\phi^2} \gamma_0 \left( \phi_a \frac{\pi}{180} \right) \sin \omega t + \frac{W}{g} (\phi')^2 z_0$$

and vertical force is given by

$$R_y = \bar{W} \cos \phi + \frac{4\pi^2}{gT_\phi^2} z_0 \left( \phi_a \frac{\pi}{180} \right) \sin \omega t + \frac{W}{g} (\phi')^2 \gamma_0$$

Since  $\phi$  is not very large the centrifugal force is negligible in comparison with the gravity force and the centrifugal force is maximum when angle of roll of the barge is zero.

### 3.2 Forces due to Pitching

The equation of motion for pitching (Fig 2 b) is analogous to that for rolling and is expressed as

$$I_L \ddot{\theta} + \Delta G \bar{M}_L \theta = 0$$

where  $I_L$  is the mass moment of inertia about the transverse axis through centre of pitching.

$\theta$  is the angle of pitch

In general for pitching alone, the total force component

$$R_x = \bar{W} \sin \theta + \frac{W}{g} (\dot{\theta})^2 x_0 + \frac{W}{g} \gamma_0 \frac{4\pi^2}{T_\theta^2} \left( \theta_a \frac{\pi}{180} \right) \sin \omega t$$

$$R_y = \bar{W} \cos \theta + \frac{W}{g} (\dot{\theta})^2 \gamma_0 + \frac{W}{g} x_0 \frac{4\pi^2}{T_\theta^2} \left( \theta_a \frac{\pi}{180} \right) \sin \omega t$$

### 3.3 Forces due to heaving

The inertial force due to heaving is  $m \times \frac{d^2 y}{dt^2}$  where

$y$  is the displacement due to heaving motion.

The direction of the inertial force depends on the direction of acceleration, and acts upward or downward.

### 3.4 Forces due to Self weight

The self weight of the structure is determined from the weight of the component members of the structure.

### 3.5 Force due to wind

The barge carrying a jacket tower has a large exposed surface area that is subjected to wind loads. The wind loads depend on the speed of the wind, the exposed area and also on the shape of the body and height of the body from sea level.

Wind force is given by  $F = \frac{1}{2} \frac{W}{g} (V^2) C_h A_p C_s$

where  $W$  is the unit weight of air

$V$  is the wind velocity in m/Sec

$A_p$  = effective projected area in  $m^2$

$g$  = acceleration due to gravity  $m/Sec^2$

$C_s$  = Shape Coefficient

$C_h$  = Coefficient for height

$F$  is the force in Kilograms.

The wind force is determined using this formula the value of  $C_s$  for cylindrical surface is 0.5 and  $C_h$  varies from 1.0 to 1.4 depending on the position of the member.

#### 4. Analysis

The analysis of the jacket is done as a space frame using Structural Analysis Program (SAPIV) developed by Bathe, Wilson, Peterson (4). The three dimensional beam elements are used to model the members of the Jacket. Inertia loading and other loadings are specified to form the element load cases. Resulting forces and moments are computed in the local co-ordinate system. The typical Jacket showing the numbering of the Joints and the members are shown in fig.3 . The global axis system of the tower is also shown in the figure. The layout of the sixteen sea fastenings, connecting the launching trusses to the barge is also shown in the figure.

The inertial forces due to rolling, pitching heaving, and self weight of the jacket and wind loads are calculated at the nodes. The end conditions for the seafastenings are assumed to be fixed.

The output of the program gives the displacement and rotations at each node and the forces and moments in each member. The stresses in the members are calculated.

#### 5 Example

A typical jacket as shown in fig 3 is analysed for the critical position during load out and also for stresses during transportation. The height of the jacket is 90.7 m, the top

dimensions are 6.5 m x 15.5 m and the bottom dimension 29.2 x 31.3 m. The weight of the jacket is 1800 tonnes. The barge dimensions are length 110.0 m Beam 29.3m and depth=7.5m  
 weight of barge = 13200 tons  
 Period of roll = 10 Sec  
 Period of Pitch = 6.2 Sec

## 6. Results and Conclusions

The analysis of the Jacket during transport and the need for the design of seafastenings for Jacket is emphasized. A typical jacket is considered for the analysis and the analysis is carried out using SAP-IV program. The displacements and rotations at each nodal point, and the forces (axial and shear) and moments (torsion and bending) in each of the member have been obtained. The stresses in each members are calculated to check for the worst combination of loads against permissible values .

A study has been carried out to find the stresses in the members, during load out. Fig/<sup>(1a)</sup> shows the load out of the jacket on the barge. This shows the case when the centre of gravity of the structure has just crossed the edge of the berth and the jacket is supported on four points for a short period. The whole weight of the structure is supported on two launching stresses, and hence members in the launching trusses should be safe enough to resist this load.



The total stress distribution due to self weight of the structure for this case is shown in fig 1b. The maximum stresses are in members 117,118,119 and 120 and are - 1603; -1726, 1592 and 1616 kg/cm<sup>2</sup> respectively.

The inertial forces due to pitching, rolling and heaving and the self weight and wind loads are seperately used for the analysis of the structure. Fig 4 shows the total stress distribution due to rolling motion. Similarly, the stress distribution due to other motions are calculated. The consideration of maximum wind loads and rolling yields the maximum stresses in structure. Then all this total stress distribution on seafastening are presented in tabular form (Table :I).

In the analysis of the seafastenings, the ends of the seafastenings are assumed to be fixed with the base. But a case has also been analysed where one set of the seafastings may get detached due to strong winds and waves. The effect of such a case on the stresses in other sea fastenings are calculated. The sea fastenings 111,113,222 and 224 the connection to the barge are assumed to be lost and then the system is analyses for the loads. The total stress distribution for this case is shown in Table II. The maximum total stress is in the members 250 (1992 kg/cm<sup>2</sup>)

From the above discussions the following conclusion can be arrived.

The stresses in the members of the jacket tower and also seafastings for loading cases are found to be within permissible limits.

2. In the case when the centre of gravity of the Jacket passes the edge of the berth, a few members in the launching truss are likely to be over stressed and this case is to be checked in detail.

3) The maximum stresses in sea pastenings for different loading cases in percentage of permissible stresses, are

- a) due to rolling 49.4%
- b) due to pitching 22.4%
- c) due to heaving including self weight 47.2%, and
- d) due to wind loads 24.2%.

#### 7. Acknowledgements

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Table : I

TOTAL STRESS DISTRIBUTION ON SEA-FASTENINGS				
Member No	Total Stresses Kg/Cm <sup>2</sup> , Due to			
	Pitching	Rolling	Heaving+Self Wt	Wind&Rolling
61	-311.1	1227.5	-953.4	1726.8
62	-582.8	-1170.3	-1216.4	-1610.2
63	-483.4	-1249.5	-1027.4	1724.7
64	-648.4	-1222.7	1369.4	-1679.4
111	216.4	1169.9	374.1	1683.8
112	-119.1	-1071.7	- 121.9	-1493.2
113	-272.9	1140.9	429.0	1610.5
114	-274.4	-1068.9	177.6	-1493.4
222	141.2	1202.0	237.3	1753.2
223	187.1	-1087.2	230.0	-1539.5
224	-96.0	1194.1	245.0	1725.9
225	-83.1	-1094.2	258.4	-1514.5
248	260.1	1207.1	154.7	1803.8
249	313.4	-1134.9	122.8	-1679.1
250.	239.8	1433.0	164.8	2134.7
251	309.1	-1332.5	135.9	1970.4

Table II

Total stress distribution in seafastings due to rolling motion when some sea fastenings (member 111,113,222, 224) are ineffective.

Sea Fastings	Total Stress (Kg/Cm <sup>2</sup> )
61	1782.6
62	-1511.0
63	1865.6
64	-1602.3
111	----
112	-1253.0
113	----
114	-1270.5
222	----
223	-1287.6
224	----
225	-1889.0
248	1689.7
249	-1479.7
250	1992.0
251	-1727.1

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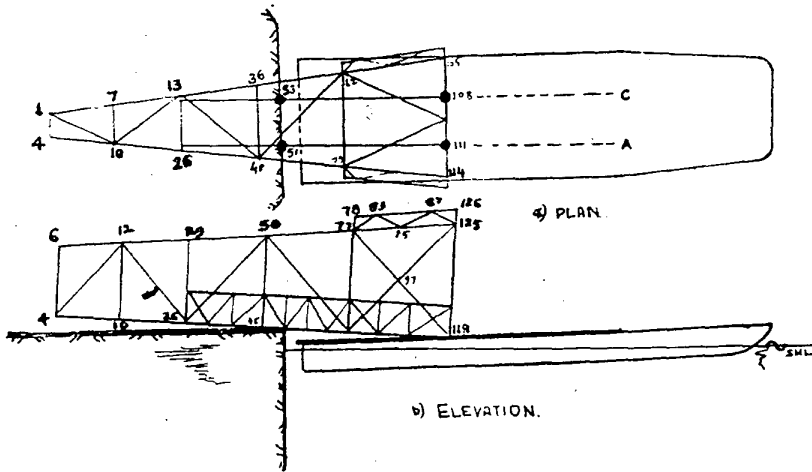


FIG. 1.a LOADOUT OF THE JACKET ONTO THE BARGE.

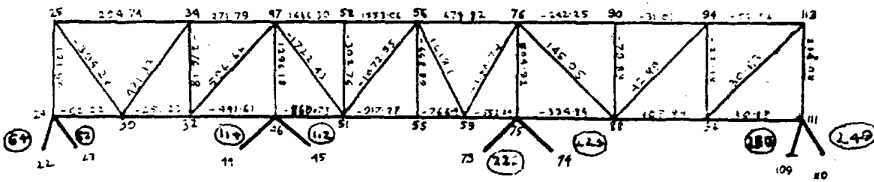
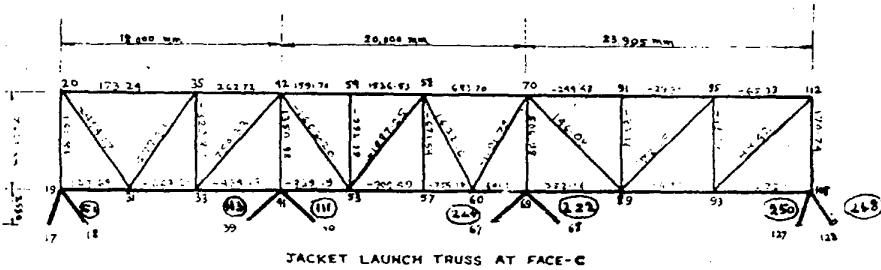


FIG. 1.b TOTAL STRESS DISTRIBUTION DUE TO SELF-WT. WHILE LOADING.

STRESS IN kg/cm<sup>2</sup>

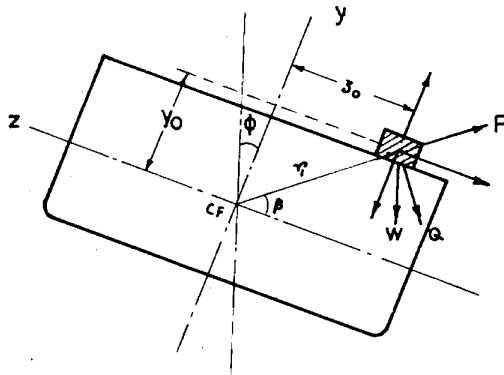


FIG.2a.FORCES DUE TO ROLLING

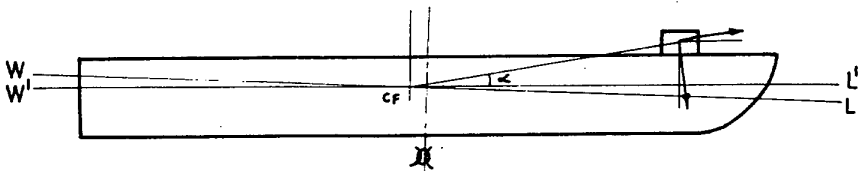


FIG.2b.FORCES DUE TO PITCHING

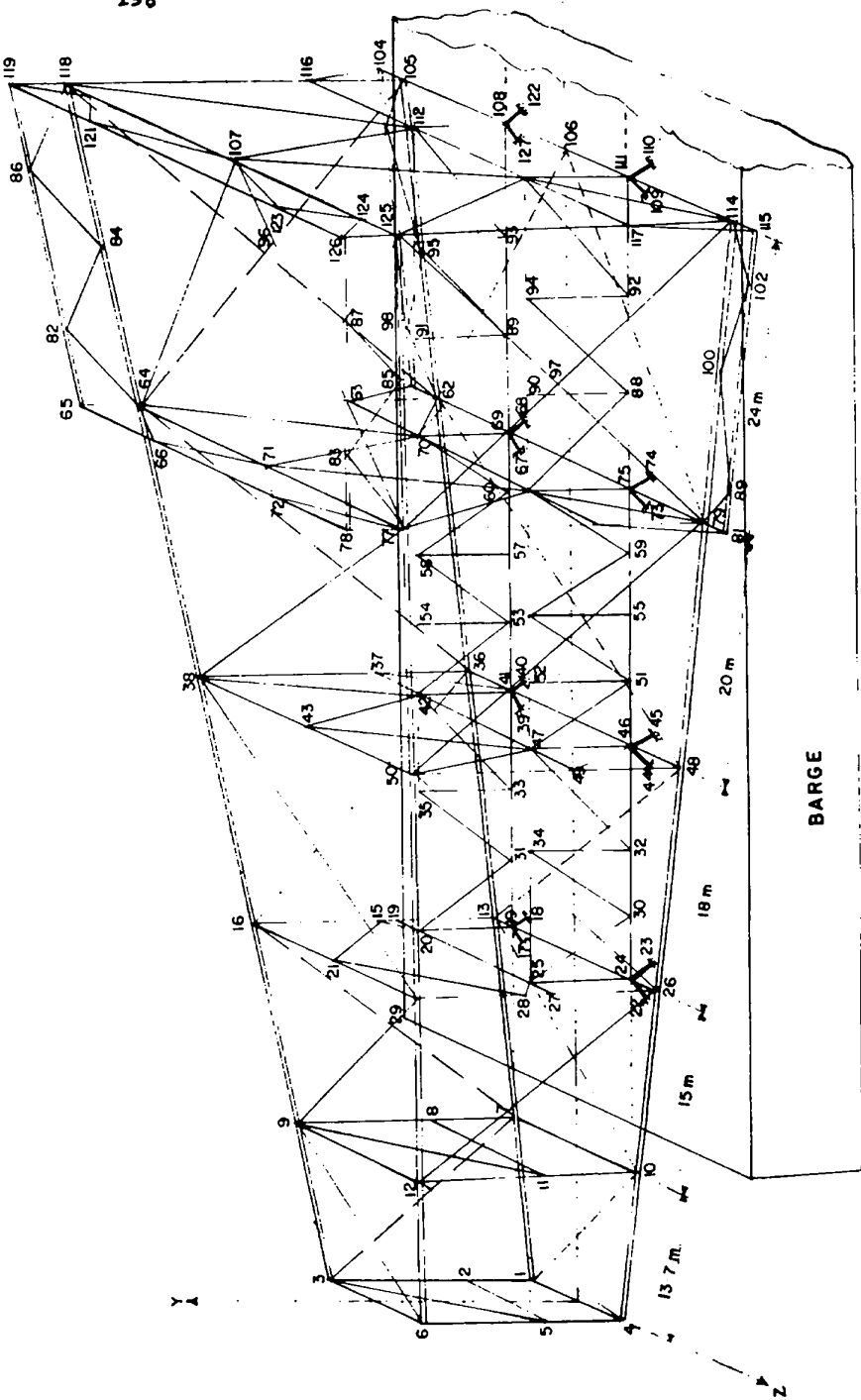


Fig .3 . A TYPICAL JACKET - BARGE SYSTEM



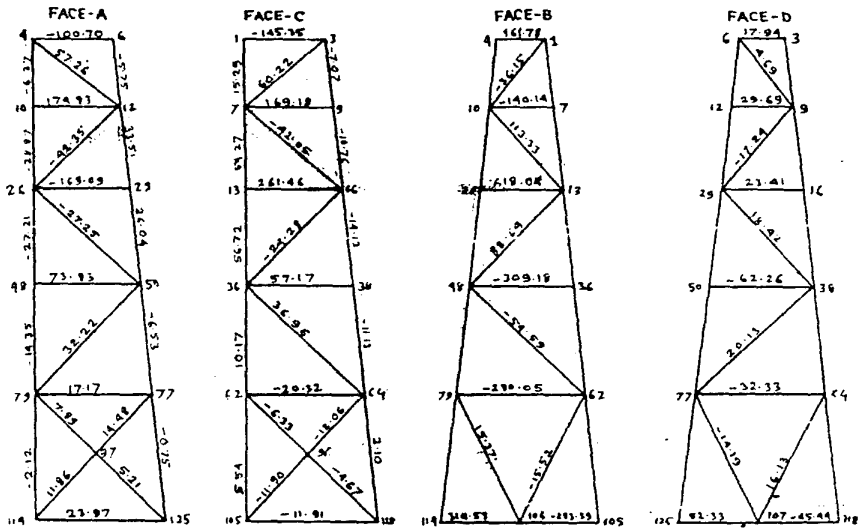


FIG-4 TOTAL STRESS DISTRIBUTION DUE TO ROLLING.

STRESS IN kg/cm<sup>2</sup>