International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-2, Issue-8, August 2014

# Concept of Hydrodynamic Load Calculation on Fixed Jacket Offshore Structures - An Overview of Arbitrarily Mounted Cylinder

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***Abstract*— This paper focuses on the analysis of hydrodynamic loads on fixed offshore structures (Arbitrarily mounted cylinder) that are operating in shallow water and are often subjected to huge wave loading. For the purpose of this study, linear (Airy) wave theory was adopted together with the application of (15a), (15b) and (15c) in the load computation. The loads for six different sea states were computed using spread sheet for the following values of time interval t = 0, T/4, and T/2.**

***Index Terms*— Airy wave theory, Fixed Jacket Offshore Structure, Morrison equation, Arbitrarily Mounted Cylinder**

## I. INTRODUCTION

Hydrodynamic wave loading on fixed offshore structures has been an issue of concern to the offshore oil and gas industry. The analysis, design and construction of offshore structures are arguably one of the most demanding sets of tasks faced by the engineering profession. Over and above the usual conditions and situations met by land-based structures, offshore structures have the added complication of being placed in an ocean environment where hydrodynamic interaction effects and dynamic response become major considerations in their design.

In general, wave and current can be found together in different forms in the ocean. The existence of waves and currents and their interaction play a significant role in most ocean dynamic processes and are important for ocean engineers.

In addition, the range of possible design solutions, such as: Tension Leg Platform (TLP) deep water designs; the more traditional jacket and jack-up oil rigs; and the large number of sized gravity-style offshore platforms themselves, pose their own peculiar demands in terms of hydrodynamic loading effects, foundation support conditions and character of the dynamic response of not only the structure itself but also of the riser systems for oil extraction adopted by them. Invariably, non-linearity in the description of hydrodynamic loading characteristics of the structure-fluid interaction and in the associated structural response can assume importance and need be addressed. Access to specialist modeling software is often required to be able to do so [1].

Manuscript received August 04, 2014.
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### A. Basics of Offshore Engineering

A basic understanding of a number of key subject areas is essential to an engineer likely to be involved in the design of offshore structures, [2], [3], [4] and [5].
These subject areas, though not mutually exclusive, would include;

- Hydrodynamics
- Structural dynamics
- Advanced structural analysis techniques
- Statistics of extreme among others.

### B. Hydrodynamics

Hydrodynamics is concerned with the study of water in motion. In the context of an offshore environment, the water of concern is the ocean. Its motion, (the kinematics of the water particles) stems from a number of sources including slowly varying currents from the effects of the tides and from local thermal influences and oscillatory motion from wave activity that is normally wind-generated [1].
The characteristics of currents and waves, themselves would be very much site dependent, with extreme values of principal interest to the LFRD approach used for offshore structure design, associated with the statistics of the climatic condition of the site interest [6].

The topology of the ocean bottom also has influence on the water particle kinematics as the water depth changes from deeper to shallower conditions, [7]. This influence is referred to as the "shoaling effect", which assumes significant importance to the field of coastal engineering. For so called deep water conditions (where the depth of water exceeds half the wavelength of the longest waves of interest), the influence of the water bottom topology on the water particle kinematics is considered negligible, removing an otherwise potential complication to the description of the hydrodynamics of offshore structures in such deep water environment.

## II. METHODOLOGY AND MATERIALS

The jacket structure used for this study (Fig. 1) is a HD accommodation platform to be operated in shallow water and is similar to all fixed jacket offshore structures. The part of the structure under water was discretized in to (264) beam elements (TABLE I). The water depth for the HD field is approximately 25.3m. The loads were computed using spread sheet. See TABLE II for the most probable wave heights and time periods for different sea states.

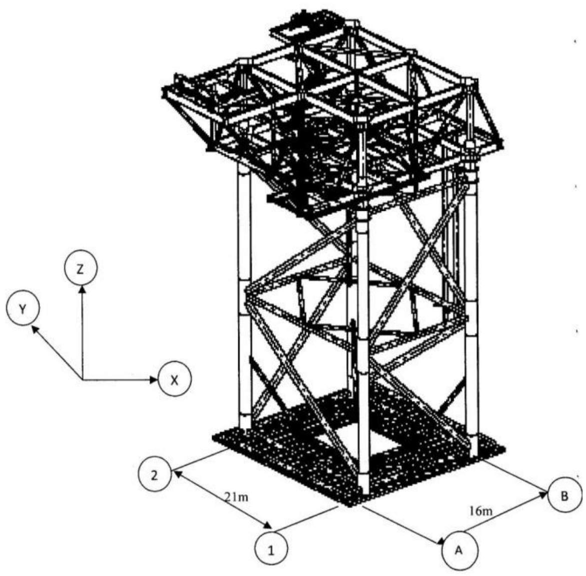


Figure 1: HD accommodation platform

## III. WAVE THEORIES

All wave theories obey some form of wave equation in which the dependent variable depends on physical phenomena and boundary conditions [8]. In general, the wave equation and the boundary conditions may be linear and non linear.

### A. Airy Wave Theory

The surface elevation of an Airy wave amplitude $\zeta_a$, at any instance of time $t$ and horizontal position $x$ in the direction of travel of the wave, is denoted by $\eta(x,t)$ and is given by:

$$\eta(x,t) = \zeta_a \cos(kx - \omega t) \quad (1)$$

where wave number $k = 2\pi/L$ in which $L$ represents the wavelength (See Fig. 2) and circular frequency $\omega = 2\pi/T$ in which $T$ represents the period of the wave. The celerity, or speed, of the wave $C$ is given by L/T or $\omega/k$, and the crest to trough wave height, $H$ is given by $2\zeta_a$. The along wave u(x, t) and vertical v(x, t) water particle velocities in an Airy wave at position $z$ measured from the Mean Water Level (MWL) in depth water $h$ are given by:

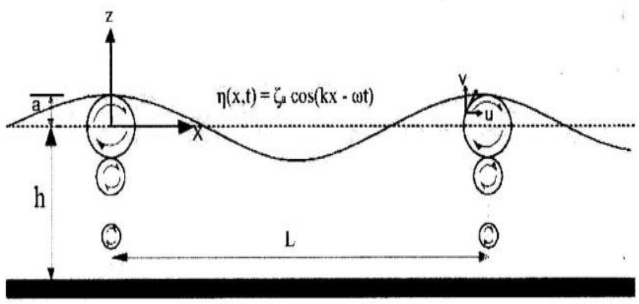


Figure 2: definition diagram for an airy wave [1]

$$u(x,t) = \frac{\omega\zeta_a \cosh[k(z+h)]}{\sinh(kh)} \cos(kx - \omega t) \quad (2)$$

$$v(x,t) = \frac{\omega\zeta_a \,\mathrm{sinsh}[k(z+h)]}{\sinh(kh)} \sin(kx - \omega t) \quad (3)$$

The dispersion relationship relates wave number $k$ to circular frequency $\omega$ (as these are not independent), via:

$$\omega^2 = gk\tanh(kh) \quad (4)$$

where $g$ is the acceleration due to gravity (9.8 m/s$^2$). The along wave acceleration $\dot{u}(x,t)$ is given by the time derivative of (2) as:

$$\dot{u}(x,t) = .\frac{\omega^2\zeta_a \cosh[k(z+h)]}{\sinh(kh)} \sin(kx - \omega t) \quad (5a)$$

while the vertical velocity $\dot{v}(x,t)$ is given by the time derivative of (3) as:

$$\dot{v}(x,t) = -\frac{\omega^2\zeta_a \sinh[k(z+h)]}{\sinh(kh)} \cos(kx - \omega t) \quad (5b)$$

It should be noted here that wave amplitude, $a = \zeta_a$, is considered small (in fact negligible) in comparison to water depth $h$ in the derivation of Airy wave theory.

For deep water conditions, kh > π, (2) to (5) can be approximated to:

$$u(x,t) = \omega\zeta_a e^{kz} \cos(kx - \omega t) \quad (6)$$

$$v(x,t) = \omega\zeta_a e^{kz} \sin(kx - \omega t) \quad (7)$$

$$\omega^2 = gk \quad (8)$$

$$\dot{v}(x,t) = \omega^2\zeta_a e^{kz} \sin(kx - \omega t) \quad (10)$$

This would imply that the elliptical orbits of the water particles associated with the general Airy wave description in (2) and (3), would reduce to circular orbits in deep water conditions as implied by (6) and (7).

### B. Stoke's Second Order Wave Theory

Stokes employed perturbation techniques to solve the wave boundary value problem and developed a theory for finite amplitude wave that he carried to the second order. In this theory, all the wave characteristics (velocity potential, celerity, surface profile, particle kinetics….e.tc) are formulated in terms of a power series in successively higher orders of the wave steepness (H/L).

A condition of this theory is that (H/d) should be small so that the theory is applicable only in deep water and a portion of the immediate depth range.

For engineering applications, the second-order and possibly the fifth-order theories are the most commonly used [9].

Stoke's wave expansion method is formally valid under the conditions [10]:

H/d << (kd)2 for kd < 1 and H/L << 1.

Stoke's wave theory is considered most nearly valid in water where the relative depth (D/L) is greater than about (1/10) [11]. Stoke's theory would be adequate for describing water waves at any depth of water. In shallow water, the connective terms become relatively large, the series convergence is slow and erratic and a large number of terms are required to achieve a uniform accuracy [12].

The fluid particle velocities are then given by;

$$v_x = \frac{\pi H}{T}\frac{\cosh[k(z+h)]}{\sinh(kh)} \cos(k(kx - \omega t)) + \frac{3(\pi H)^2}{4TL}\cdot\frac{\cosh[2k(z+h)]}{\sinh^4(kh)} \cos 2(kx - \omega t) \quad (9a)$$

$$v_z = \frac{\pi H}{T}\frac{\sinh[k(z+h)]}{\sinh(kh)} \sin(k(kx - \omega t)) + \frac{3(\pi H)^2}{4TL}\cdot\frac{\sinh[2k(z+h)]}{\sinh^4(kh)} \sin 2(kx - \omega t) \quad (9b)$$

The fluid particle accelerations are then given by;

$$a_x = 2\frac{\pi^2 H}{T^2}\frac{\cosh[k(z+h)]}{\sinh(kh)} \sin(kx - \omega t)$$

$$+ \frac{3\pi^3 H^2}{T^2 L} \cdot \frac{\cosh[2k(z+h)]}{\sinh^4(kh)} \sin 2(kx - \omega t) \quad (10a)$$

$$a_z = 2\frac{\pi^2 H}{T^2} \frac{\sinh[k(z+h)]}{\sinh(kh)} \cos(kx - \omega t)$$

$$+ \frac{3\pi^3 H^2}{T^2 L} \cdot \frac{\sinh[2k(z+h)]}{\sinh^4(kh)} \cos 2(kx - \omega t) \quad (10b)$$

These velocities and accelerations in (9) and (10) are used in Morison's equation to calculate load vectors of hydrodynamic loading by using Stoke's wave theory after being transformed from global coordinates for each member of the offshore structure.

### C. Wave load on an Arbitrary Cylinder Member

Various methods exist for the calculation of the hydrodynamic loads on an arbitrary oriented cylinder by using Morison's equation. The method adopted here assumes that only the components of water particles and accelerations normal to the member produce loads [13].

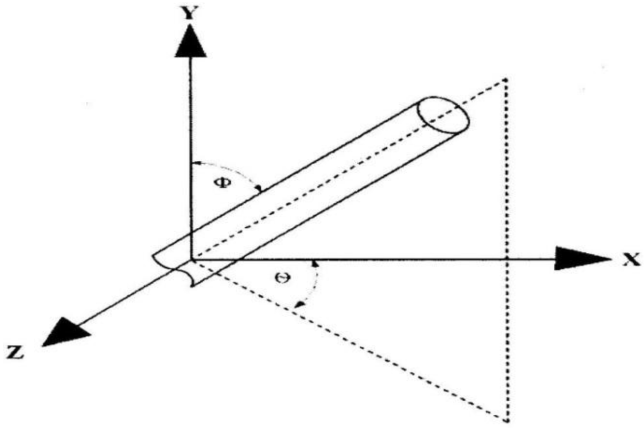


Figure 3: Arbitrarily Oriented Cylinder Member [14]

With polar coordinates Φ, Θ defining the orientation of the member axis, (See Fig. 3), the magnitude v, of the water velocity normal to the member axis is given by:

$$V = \left[u^2 + v^2 - (c_x u + c_y v)^2\right]^{1/2} \quad (11)$$

And its components in the x, y and z directions are given, respectively by:

$$u_n = [u - c_x (c_x u + c_y v)] \quad (12a)$$

$$v_n = [v - c_y (c_x u + c_y v)] \quad (12b)$$

$$w_n = [u - c_z (c_x u + c_y v)] \quad (12c)$$

Where,

$$c_x = \sin\Phi \cos\theta \quad (13a)$$

$$c_y = \cos\Phi \quad (13b)$$

$$c_z = \sin\Phi \sin\theta \quad (13c)$$

The components of the normal water acceleration in the *x*, *y* and *z* directions are given, respectively by:

$$a_{nx} = [a_x - c_x (c_x a_x + c_y a_y)] \quad (14a)$$

$$a_{ny} = [a_y - c_y (c_x a_x + c_y a_y)] \quad (14b)$$

$$a_{nz} = [- c_z (c_x a_x + c_y a_y)] \quad (14c)$$

With these relations, the components of the force per unit of member length acting in the *x*, *y* and *z* directions are given respectively by the generalized Morison equations:

$$F_x = \rho\, \pi \frac{D^2}{4} C_m\, a\, n_x + \frac{1}{2} \rho\, D\, C_d V u_n \quad (15a)$$

$$F_y = \rho\, \pi \frac{D^2}{4} C_m\, a\, n_y + \frac{1}{2} \rho\, D\, C_d V v_n \quad (15b)$$

$$F_z = \rho\, \pi \frac{D^2}{4} C_m\, a\, n_z + \frac{1}{2} \rho\, D\, C_d V w_n \quad (15c)$$

*Where*, $D$ = outer diameter of cylinder, $\rho$ = sea water density.
$C_d$ = drag coefficient (= 1.0).
$C_m$ = inertia coefficient (= 0.95).
These coefficients are found to be dependent upon Reynold's number, Re, Keulegan Carpenter number, KC, and the β parameter, Viz;

$$KC = \frac{u_m}{D} T;\ \beta = \frac{Re}{KC} \quad (16)$$

Where $u_m$ = the maximum along wave water particle velocity. It is found that for KC < 10, inertia forces progressively dominate; for 10 < KC < 20 both inertia and drag force components are significant and for KC > 20, drag force progressively dominates [1].

## IV. RESULTS

The loads for six different sea states were computed using spread sheet for the following values of time intervals, t = 0, T/4, T/2. The magnitudes of these forces in X, Y and Z components are presented in TABLES 2, 3, 4, 5, 6 and 7 when distance x, varies from 0 to 16.

## V. CONCLUSIONS

For an arbitrarily mounted cylinder member, the following assertions are drawn:

1) The hydrodynamic force is directly proportional to the depth *z* and is minimum at z = 0.
2) For a complete sea state, all the positive hydrodynamic forces follow the same directions as the direction of the wave propagation (i.e forces pushing the member) in the same direction.(see TABLES 5, 8 and 10)
3) Also, all the negative hydrodynamic forces in the direction similar to the direction of the wave propagation are (forces) pulling the member in that direction. (see TABLES 3, 4, 6, 7, 9 and 11)
4) At constant t, x and z, all the hydrodynamic forces are different for different sea state.

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Concept of Hydrodynamic Load Analysis of Fixed Jacket Structure - An Overview of Horizontal Cylinder, IJER, Vol. 3, No. 4, Pages 196-200.

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## APPENDIX

Table I: Detail of Discretized HD Accommodation Platform

| Members | Length(m) | Immersed Length (m) | Outer Diameter (m) | Inner Diameter (m) | No. of divisions | Orientation |
|---|---|---|---|---|---|---|
| M1 | 27.800 | 27.800 | 1.320 | 1.290 | 15 | Vertical |
| M2 | 27.800 | 27.800 | 1.320 | 1.290 | 15 | Vertical |
| M3 | 27.800 | 27.800 | 1.320 | 1.290 | 15 | Vertical |
| M4 | 27.800 | 27.800 | 1.320 | 1.290 | 15 | Vertical |
| M5 | 21.000 | 21.000 | 0.061 | 0.560 | 10 | Horizontal |
| M6 | 16.000 | 16.000 | 0.061 | 0.560 | 8 | Horizontal |
| M7 | 21.000 | 21.000 | 0.061 | 0.560 | 10 | Horizontal |
| M8 | 16.000 | 16.000 | 0.061 | 0.560 | 8 | Horizontal |
| M9 | 21.000 | 21.000 | 0.061 | 0.560 | 10 | Horizontal |
| M10 | 16.000 | 16.000 | 0.061 | 0.560 | 8 | Horizontal |
| M11 | 21.000 | 21.000 | 0.061 | 0.560 | 10 | Horizontal |
| M12 | 16.000 | 16.000 | 0.061 | 0.560 | 8 | Horizontal |
| M13 | 26.121 | 26.121 | 0.762 | 0.722 | 8 | Arbitral |
| M14 | 22.301 | 22.301 | 0.762 | 0.722 | 8 | Arbitral |
| M15 | 26.121 | 26.121 | 0.762 | 0.722 | 8 | Arbitral |
| M16 | 22.301 | 22.301 | 0.762 | 0.722 | 8 | Arbitral |
| M17 | 26.491 | 19.868 | 0.762 | 0.732 | 8 | Arbitral |
| M18 | 22.733 | 17.050 | 0.762 | 0.732 | 8 | Arbitral |
| M19 | 26.491 | 19.868 | 0.762 | 0.732 | 8 | Arbitral |
| M20 | 22.733 | 17.050 | 0.762 | 0.732 | 8 | Arbitral |
| M21 | 21.000 | 21.000 | 0.061 | 0.560 | 10 | Horizontal |
| M22 | 21.000 | 21.000 | 0.061 | 0.560 | 10 | Horizontal |
| M23 | 21.000 | 21.000 | 0.406 | 0.373 | 8 | Horizontal |
| M24 | 21.000 | 21.000 | 0.406 | 0.373 | 8 | Horizontal |
| M25 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| M26 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| M27 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| M28 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| M29 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| M30 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| M31 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| M32 | 13.200 | 13.200 | 0.406 | 0.373 | 4 | Arbitral |
| | | | | Total = | 264 | |

Table II: Most Probable Wave Heights and Time Periods for Different Sea States (Area 59)

| Sea State | Hs (m) | Tp (sec) | ζa (m) | t (sec) | k |
|---|---|---|---|---|---|
| 1 | 1 | 5.5 | 0.5 | 4.125 | 0.133 |
| 2 | 2 | 5.5 | 1 | 4.125 | 0.133 |
| 3 | 3 | 6.5 | 1.5 | 4.875 | 0.0961 |
| 4 | 4 | 7 | 2 | 5.25 | 0.08371 |
| 5 | 5 | 7.5 | 2.5 | 5.625 | 0.0739 |
| 6 | 6 | 7.5 | 3 | 5.625 | 0.0739 |

Table III: Magnitude of Hydrodynamic Loads (Member 15) @ time t = 0

| **Load Component = X** | | | | **Load Type = Local** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 0.00 | 0 | -724.98 | -700.10 | -695.97 | -687.31 | -680.81 | -667.00 |
| 0.00 | -1.8775 | -730.47 | -711.08 | -704.77 | -696.22 | -689.44 | -677.36 |
| 0.00 | -3.755 | -734.74 | -719.62 | -712.10 | -703.80 | -696.91 | -686.32 |
| 0.00 | -5.6325 | -738.07 | -726.28 | -718.20 | -710.25 | -703.36 | -694.06 |
| 0.00 | -7.51 | -740.66 | -731.46 | -723.27 | -715.71 | -708.91 | -700.72 |
| 0.00 | -9.3875 | -742.67 | -735.48 | -727.47 | -720.33 | -713.68 | -706.44 |
| 0.00 | -11.265 | -744.23 | -738.60 | -730.93 | -724.21 | -717.74 | -711.32 |

Table IV: Magnitude of Hydrodynamic Loads (Member 15) @ time t = T/4

| **Load Component = X** | | | | **Load Type = Global** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 0.00 | 0 | -272.52 | -31.73 | 0.21 | 54.92 | 189.74 | 484.27 |
| 0.00 | -1.8775 | -357.51 | -108.83 | -16.75 | 6.02 | 74.44 | 250.58 |
| 0.00 | -3.755 | -431.66 | -200.77 | -62.10 | -3.11 | 17.43 | 109.97 |
| 0.00 | -5.6325 | -494.21 | -291.66 | -121.69 | -28.61 | 0.11 | 34.50 |
| 0.00 | -7.51 | -545.80 | -374.08 | -186.28 | -70.35 | -8.87 | 3.62 |
| 0.00 | -9.3875 | -587.66 | -445.21 | -250.17 | -120.03 | -33.85 | -2.26 |
| 0.00 | -11.265 | -621.22 | -504.67 | -310.04 | -172.07 | -67.92 | -19.47 |

Table V: Magnitude of Hydrodynamic Loads (Member 15) @ time t = T/2

| **Load Component = X** | | | | **Load Type = Global** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 0.00 | 0 | -774.74 | -799.62 | -803.74 | -812.40 | -818.90 | -832.71 |
| 0.00 | -1.8775 | -769.25 | -788.64 | -794.94 | -803.49 | -810.27 | -822.35 |
| 0.00 | -3.755 | -764.97 | -780.09 | -787.61 | -795.91 | -802.80 | -813.39 |
| 0.00 | -5.6325 | -761.64 | -773.43 | -781.51 | -789.46 | -796.35 | -805.65 |
| 0.00 | -7.51 | -759.05 | -768.25 | -776.44 | -784.00 | -790.80 | -798.99 |
| 0.00 | -9.3875 | -757.04 | -764.23 | -772.25 | -779.38 | -786.04 | -793.27 |
| 0.00 | -11.265 | -755.48 | -761.11 | -768.78 | -775.50 | -781.97 | -788.39 |

Table VI: Magnitude of Hydrodynamic Loads (Member 16) @ time t = 0

| **Load Component = Y** | | | | **Load Type = Local** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 0 | -11.265 | 244.09 | 217.28 | 164.88 | 112.36 | 53.63 | -7.50 |
| 2 | -13.207 | 260.33 | 250.53 | 217.00 | 182.44 | 141.29 | 102.44 |
| 4 | -15.149 | 271.28 | 273.34 | 259.28 | 242.63 | 219.78 | 201.41 |
| 6 | -17.091 | 277.85 | 287.11 | 291.61 | 291.98 | 287.43 | 286.90 |
| 8 | -19.033 | 281.12 | 293.97 | 314.99 | 330.92 | 344.14 | 358.56 |
| 10 | -20.974 | 282.11 | 296.04 | 330.95 | 360.69 | 390.75 | 417.41 |
| 12 | -22.917 | 281.64 | 295.07 | 341.09 | 382.84 | 428.61 | 465.15 |
| 14 | -24.858 | 280.27 | 292.27 | 346.77 | 398.86 | 459.17 | 503.62 |
| 16 | -26.8 | 278.33 | 288.29 | 349.01 | 409.92 | 483.66 | 534.45 |

Table VII: Magnitude of Hydrodynamic Loads (Member 16) @ time t = T/4

| **Load Component = Y** | | | | **Load Type = Local** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 0 | -11.265 | 222.47 | 180.75 | 111.02 | 61.62 | 24.32 | 6.97 |
| 2 | -13.207 | 229.04 | 192.47 | 122.72 | 71.52 | 30.24 | 9.15 |
| 4 | -15.149 | 237.03 | 207.11 | 137.96 | 85.10 | 39.41 | 14.66 |
| 6 | -17.091 | 245.21 | 222.55 | 156.01 | 102.59 | 53.05 | 25.90 |
| 8 | -19.033 | 252.78 | 237.21 | 175.87 | 123.53 | 71.43 | 43.57 |
| 10 | -20.974 | 259.35 | 250.16 | 196.60 | 147.18 | 94.15 | 67.30 |
| 12 | -22.917 | 264.83 | 261.08 | 217.50 | 172.77 | 120.58 | 96.25 |
| 14 | -24.858 | 269.33 | 270.12 | 238.21 | 199.77 | 150.14 | 129.60 |
| 16 | -26.8 | 273.08 | 277.69 | 258.76 | 228.02 | 182.56 | 166.89 |

Table VIII: Magnitude of Hydrodynamic Loads (Member 16) @ time t = T/2

| **Load Component = Y** | | | | **Load Type = Local** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 0 | -11.265 | 290.97 | 311.91 | 345.31 | 374.12 | 404.77 | 437.44 |
| 2 | -13.207 | 275.26 | 280.74 | 297.70 | 310.88 | 325.77 | 338.61 |
| 4 | -15.149 | 265.11 | 261.10 | 263.87 | 264.85 | 267.10 | 266.45 |
| 6 | -17.091 | 259.13 | 249.70 | 240.06 | 231.34 | 223.59 | 214.26 |
| 8 | -19.033 | 256.17 | 244.07 | 223.49 | 206.74 | 190.97 | 176.35 |
| 10 | -20.974 | 255.27 | 242.36 | 212.18 | 188.47 | 165.98 | 148.18 |
| 12 | -22.917 | 255.71 | 243.22 | 204.81 | 174.81 | 146.34 | 126.53 |
| 14 | -24.858 | 257.01 | 245.74 | 200.47 | 164.70 | 130.64 | 109.40 |
| 16 | -26.8 | 258.88 | 249.40 | 198.60 | 157.51 | 118.09 | 95.77 |

Table IX: Magnitude of Hydrodynamic Loads (Member 17) @ time t = 0

| **Load Component = X** | | | | **Load Type = Global** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 16.00 | 0 | -1353.73 | -2128.01 | -3045.92 | -3737.23 | -4260.95 | -5311.42 |
| 16.00 | -1.8775 | -1205.83 | -1765.30 | -2565.03 | -3171.53 | -3663.11 | -4512.36 |
| 16.00 | -3.755 | -1096.41 | -1505.86 | -2196.07 | -2726.78 | -3182.54 | -3873.82 |
| 16.00 | -5.6325 | -1014.72 | -1317.85 | -1910.97 | -2375.38 | -2794.96 | -3361.89 |
| 16.00 | -7.51 | -953.29 | -1180.01 | -1689.24 | -2096.52 | -2481.55 | -2950.33 |
| 16.00 | -9.3875 | -906.81 | -1077.98 | -1515.87 | -1874.46 | -2227.64 | -2618.81 |
| 16.00 | -11.265 | -871.50 | -1001.86 | -1379.77 | -1697.24 | -2021.85 | -2351.58 |

Table X: Magnitude of Hydrodynamic Loads (Member 17) @ time t = T/4

| **Load Component = X** | | | | **Load Type = Global** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 16.00 | 0 | -316.38 | -53.30 | -1.60 | 27.69 | 88.53 | 304.52 |
| 16.00 | -1.8775 | -397.38 | -148.40 | -18.36 | -9.55 | 12.47 | 131.59 |
| 16.00 | -3.755 | -466.19 | -245.42 | -63.53 | -16.55 | -16.72 | 34.71 |
| 16.00 | -5.6325 | -523.24 | -334.87 | -122.94 | -44.32 | -20.61 | -9.59 |
| 16.00 | -7.51 | -569.72 | -412.88 | -187.36 | -86.93 | -38.51 | -18.68 |
| 16.00 | -9.3875 | -607.13 | -478.62 | -251.12 | -136.59 | -68.82 | -28.22 |
| 16.00 | -11.265 | -636.92 | -532.70 | -310.86 | -188.08 | -105.61 | -52.09 |

Table XI: Magnitude of Hydrodynamic Loads (Member 17) @ time t = T/2

| **Load Component = X** | | | | **Load Type = Globa** | | | |
|---|---|---|---|---|---|---|---|
| **Sea States =** | | **1** | **2** | **3** | **4** | **5** | **6** |
| **Hs (m) =** | | 1 | 2 | 3 | 4 | 5 | 6 |
| **Tz (sec) =** | | **5.5** | **5.5** | **6.5** | **7** | **7.5** | **7.5** |
| **X (m)** | **Z (m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** | **$F_x$ (N/m)** |
| 16.00 | 0 | -1076.78 | -1469.86 | -646.25 | -315.58 | -75.26 | 1.36 |
| 16.00 | -1.8775 | -998.96 | -1288.23 | -663.06 | -369.67 | -133.04 | -54.31 |
| 16.00 | -3.755 | -940.59 | -1155.73 | -677.09 | -417.73 | -189.15 | -111.29 |
| 16.00 | -5.6325 | -896.50 | -1058.00 | -688.79 | -460.04 | -242.17 | -167.07 |
| 16.00 | -7.51 | -863.03 | -985.25 | -698.52 | -496.97 | -291.21 | -219.99 |
| 16.00 | -9.3875 | -837.51 | -930.68 | -706.60 | -528.94 | -335.79 | -268.98 |
| 16.00 | -11.265 | -818.00 | -889.52 | -713.28 | -556.39 | -375.66 | -313.44 |