Effects of Current Velocity and Profile on Loading of Offshore Jacket Structure

Iberahin Jusoh and Shadi M.A. Munshi
Mechanical Engineering Department
College of Engineering and Islamic Architecture,
Umm Al-Qura University, Makkah.
Kingdom of Saudi Arabia

Abstract *A jacket structure installed on the seabed will experience external loading mainly from the environment. Current-structure interaction is known to directly contribute in the increment of total environmental load. In addition, current profile as well as the magnitude of it velocity may affects it final contribution of external loading on the structure. In this paper, the effects of current parameter and profile on loading of off shore jacket structure is investigated. Details studies focused on current velocity, wave-current interaction and current profiles affecting the magnitude of base shear and overturning moment on a typical shallow water jacket structure. In this study, the result shows there is significant effect of current velocity on the loading of drag dominated structure.*

Keywords — *jacket structure, current velocity ratio, wave-current interaction, current profile.*

I. INTRODUCTION

It is well understood that the main source of loading on a typical jacket structure is coming from the environment. Current contributing a small percentage of this environmental loading. Although it is of a small percentage from the total loading on to the structure, it presence cannot be ignored in the design and analysis of the structure. International acceptable standard of practice where certain procedure to treat this issue at the design stage so that it can be cooperated in the structure's design consideration.

This paper investigates the effects of variation current velocities ratio at mean sea level to the current velocity at seabed. Other aspects of studies focused in this paper are the effects of wave-current interaction as well as current profile section on the loading of jacket structure. The range of values chosen for each parameter is applicable for the Southern North Sea sector and they are either used in current design practice or in present research predictions. The assessment of structural response was performed for wave action coming from one direction of attack only because the configuration of the structure has a square shape and a wave phase angle of 35 degree gave a distinct maximum loading on to the structure [1].

II. STRUCTURAL MODEL

Jacket structure used in this study modelled as shown in Fig.1. It is a shallow water structure installed at a water depth of 25.06 m. The structure is a four-legged platform having horizontal, vertical and inclined members then piled-fixed to the seabed. The square cross-section jacket measures 17.3 m x 17.3 m (plan view) at the base and 9.84 m x 9.84 m at elevation (+)5.65 m. It has the same measurement (9.84 m x 9.84 m) down to elevation (+)15.82 m. The jacket consists of four large-diameter tubular legs framed together by a large number of smaller tubular braces. These legs have diameter of 0.838 m and thickness of 0.0127 m extended from elevation (-)25.06 m to elevation (+)15.82 m above MSL. They extend with a batter 1 in 5.822 from sea bed to elevation (+)5.65 m then vertically from elevation (+)5.65 m to elevation (+)15.82 m. The jacket's vertical legs is purposely battered to provide a larger base at the mud-line to increase its stability.

III. LOADING CONSIDERATION

The basic study has been performed using a set of base case parameter values given in Table 1. Results from this base case were used to compare any variational effects due to changes in current parameters. The small amplitude wave theory with 100-year return wave height is adopted in this study. Base case current profile used is a 'stretched profile' as explained in later current profile study. Current velocities are based on the extreme design current for the Southern North Sea [2]. The structure is assumed to be a cleaned structure, i.e. free from any attachment of marine growth. Force coefficients assumed in the model for clean surface structure are Cd = 0.6 and Cm = 2.0. Estimation of structural response under environmental loading having base case values (where, wave height, H is 16.8m, wave period, T is 13.1 sec. and water depth of 27 .54 m.

The result for basecase condition presented in ref.[3] gives structural response magnitudes of base shear (BS) and overturning moment (OTM) are 3.01 MN and 59.55 MNm respectively.

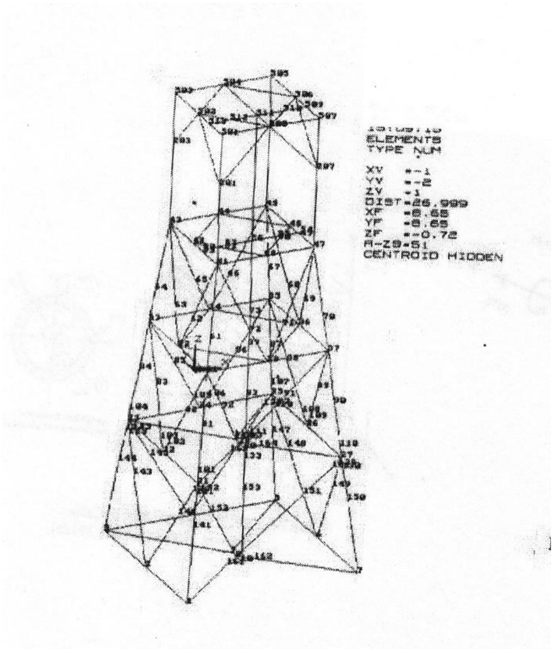

Fig.1. Jacket structural model.

The Airy wave theory is assumed in this study where the wave amplitude *a*, is considered very small as compared to the water depth, *h*. Wave loads on submerged section of jacket structure estimated using Morison equation [4].

$$F_{wave}(z,t) = \frac{1}{2}\rho C_D A u|u| + \frac{\pi}{4}\rho C_M D^2 \dot{u}$$

If the current effect is taken into consideration in a wave-current field the two velocity components in horizontal direction, *u* and vertical direction, *v* at any point of time, *t* as defined by Dean and Dalrymple [5] is given as;

$$u(x,t) = U + \frac{gkA}{\omega\left(1-\frac{U}{c}\right)}\frac{\cosh k(h+z)}{\cosh(kh)}\, sin(kx-\omega t)$$

$$v(x,t) = -\frac{gkA}{\omega\left(1-\frac{U}{c}\right)}\frac{\sinh k(h+z)}{\cosh(kh)}\, cos(kx-\omega t)$$

where *A* is the wave amplitude, $T = \lambda/c = 2\pi/kc$ is the wave period, *U* is current velocity, *h* is water depth, *k* is wave number and ω is wave angular frequency. Local acceleration of the flow may equally be obtained by simple differentiation of these equations gives the horizontal and vertical components in the following form;

$$\dot{u}(x,t) = -\frac{gkA}{\left(1-\frac{U}{c}\right)}\frac{\cosh k(h+z)}{\cosh(kh)}\, cos(kx-\omega t)$$

$$\dot{v}(x,t) = -\frac{gkA}{\left(1-\frac{U}{c}\right)}\frac{\sinh k(h+z)}{\cosh(kh)}\, sin(kx-\omega t)$$

TABLE 1. Basecase Parameter Values

Parameter	Value
Wave Theory	Small amplitude wave theory
Current Profile	Stretch
Wave-current interaction	Stretch
Maximum wave height, H_{max} (m)	16.8 m
Maximum wave period, T_{max} (sec)	13.1 sec
Phase angle (degree)	35
Water depth, d (HAT)	27.54 m
Drag coefficient, Cd	0.6
Inertia coefficient, Cm	2.0
Current velocity: (surface/seabed) m/s	1.55/0.97
Marine growth thickness	None

Velocity and acceleration components used to estimate the hydrodynamic loading on the structure.

IV. CURRENT VELOCITY STUDY

Sea driven current velocity that accompanied the wave particle motion is estimated using the following relationship;

$$U = U_{cto}\left(\frac{z+d}{d}\right)^{\frac{1}{7}}$$

where U_{cto} is current velocity at mean sea level, *z* is distance from the surface and *d* is water depth.

Two wave heights and five current velocity values were studied. Selected wave heights are at 14.5 m and 16.8 m and their associated wave periods are 12.0 second and 13.1 second respectively. Current velocity values selected are pairs of surface and seabed current velocity as shown in Table 2. The values were selected arbitrarily based on previous work in ref. [6] representing the variability of current speeds with respect to sea bed and sea surface. These values later estimate the depth average current average used in plotting the relationships between current and base shear and overturning moment.

TABLE 2. Current velocity study

Parameter	Value
Wave height (m)	14.8, 16.8
Wave period (sec)	12.0, 13.1
Current velocity: Surface/seabed (m/s)	0/0, 1.0/0.3, 1.55/0.97, 1.8/1.0, 2.1/1.5

V. WAVE-CURRENT INTERACTION STUDY

One wave height and two current velocity values with two wave current interaction profile were studied. Wave of 16.8 m height with wave period of 13.1 second (100-year return wave height) is selected as shown in Table 3. There are three type of wave-current interaction profile namely (1) constant wave-current interaction profile, (2) stretch wave-current interaction profile and (3) continuity wave-current interaction profile.

TABLE 3. Wave – current interaction study

Parameter	Value
Wave height (m)	16.8
Wave period (s)	13.1
Water depth (m)	27.54
Current velocity: Surface/seabed (m/s)	1.8/1.0, 1.55/0.97
Interaction profile	Constant Stretch Continuity

VI. CURRENT PROFILE STUDY

In this study, three current profile were used as illustrated in Fig. 2. They are listed as follows; 1. Linear Stretch, 2. Modified Stretch, and 3. Constant.

The initial input current continuity selected is the linear stretch profile. The values of current velocity used are proportioned according to type of current profile selected either linear, modified or constant profile as described earlier. The height of wave crest above SWL is extracted from Table 4 [7].

There is uncertainty as to the shape of the profile but in general the velocities of current are higher at the surface than at the seabed. In this study the current velocities are adopted from ref. [2] for extreme design current.

The current velocity variation in Case 2 of Fig. 2 approximate to the one used in Atkins's study [6]. The S profile is compressed or stretched to the top of wave crest during the analysis. Current profile in Case 1 is similar to that in the Case 2 where the sea water level (SWL) profile is extended to instantaneous water level of the wave. The second method is the 'constant' current profile as shown in Case 3. In this case the current profile is kept constant above still water level (SWL).

The linear stretch profile generally produces a constant load on the structure above SWL as compared to modified stretch and constant current profile which give slightly higher loads due to their slightly higher current velocity assumption near the surface, refer to Fig. 2.

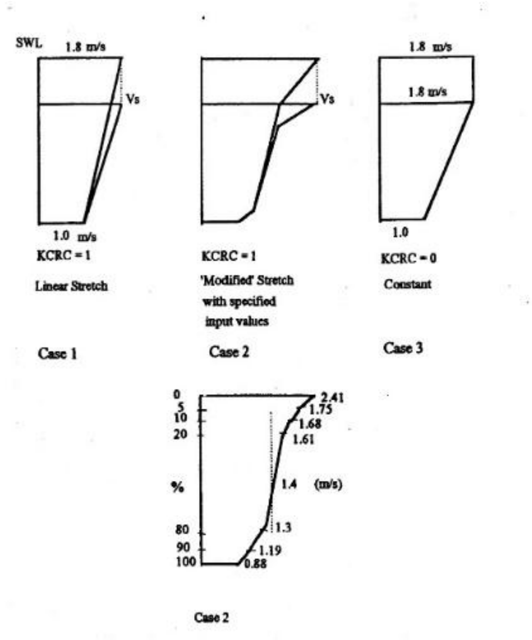

Fig.2. Current profile

TABLE 4. Factors to derive crest elevations and height of individual wave [7].

Return Period, N (years)	N-year return value of crest elevation above still water level, C_N	N-year return value of individual wave height (crest to trough), H_N
5	0.86 H_{S50}	1.56 H_{S50}
10	0.91 H_{S50}	1.65 H_{S50}
50	1.03 H_{S50}	1.86 H_{S50}
100	1.08 H_{S50}	1.95 H_{S50}
1000	1.25 H_{S50}	2.25 H_{S50}
10000	1.42 H_{S50}	2.57 H_{S50}

Values in the table are based on the relationships;
C_N=0.74(1+0.1 ln N)H_{S50}
H_N=1.34(1+0.1 ln N)H_{S50}
These relationships are good approximation in UK waters (OTH 89 300) but should be used with care for water depths less than d_1 (as defined in Section 11.4.4)
A good estimate for the significant wave height exceeded 12 times a year, H_{S1+12}=0.52H_{S50}, The individual wave height exceeded 12 times a year may be assumed to 84% of the individual wave height exceeded one a year, H_1, The derivations of these relationships are to be found in OTH 89 300, where the values of H_1 for a number of sites are also tabulated.

On the other hand, the continuity profile gives the lowest estimates of current velocity, hence forces, where the continuity ratio is used to determine the current speed near the surface and sea bed. The continuity ratio is the ratio between water depth, d, and the height from sea bed to the wave crest, d' (refer Fig. 3).

Continuity ratio = [d/d']
where: d = water depth, d' = d + wave crest.

In shallow water, this ratio is very sensitive to the increase of wave height, (i.e. increase in wave crest, C)

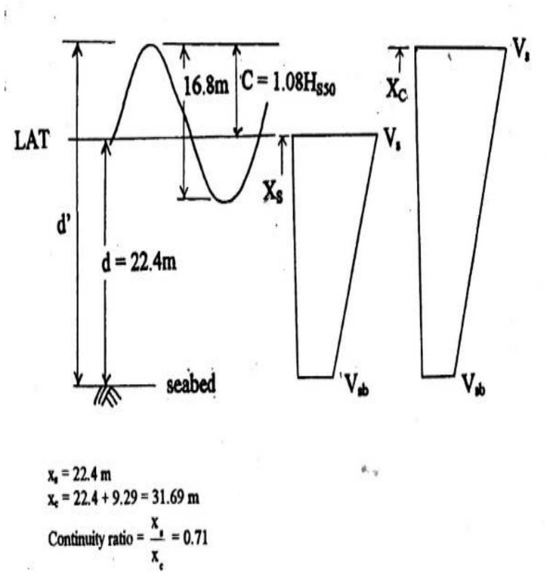

Fig. 3. Estimation of continuity ratio

VII. RESULTS AND DISCUSSION

The results obtained from current velocity studies are given in Table 5. This gives base shear and overturning moment versus current velocity for two selected wave heights. The results are plotted in term of depth mean current against base shear and overturning moment as shown in Fig. 4 and Fig. 5 respectively. It refers to the increment in BS and OTM with the presence of current in the analysis. Table 5 also shows that there are significant increase in the magnitude of 49% for BS and 48% for OTM and it is in a good agreement with results of other study [8].

Base shear and overturning moment increases in a non-linear manner with respect to the increase in depth-mean current velocity. The structure under consideration is a drag dominated structure and the estimation of forces exerted on it is based on Morison's equation where the force is a function of velocity squared. The result also shows that the sensitivity to the response increases with the increment of wave height.

The results of wave - current interaction effects are given in Table 6. Methods used in this study are either using current continuity or not using current continuity giving results of base shear and overturning moment for three sets of surface/seabed current velocities, i.e. 1.8/1.0, 1.55/0.97 and 1.0/0.3 m/s. The table also shows the percentage increase in BS and OTM for each case of current velocity if current continuity is not considered. When the continuity is ignored the global loading is increased in the order of about 13.5 percent, 12.5 percent and 8.5 percent for currents of 1.8/1.0, 1.55/0.97, and 1.0/0.3 m/s respectively.

The general trends of the result shows that the bigger the values of current, the bigger the percentage difference between the results of using and not using current continuity interaction profile.

TABLE 5. Results of Current Velocity Study

Current velocity (surf/sbed) (m/s)	BS (MN)	Increase due to current (MN)	Percent Increase (%)	OTM (MNm)	Increase due to current (MNm)	Percent Increase (%)
1. Wave Height (H_{max}) = 16.10 m. Wave Period (T_{max}) = 12.8 sec.						
0/0	1.53	0.00	0.00	29.96	0.00	0.00
1/0.3	2.01	0.48	23.88	40.07	10.11	25.23
1.55/0.97	2.50	0.97	38.80	48.74	18.78	38.53
1.8/1.0	2.63	1.10	41.83	51.61	21.65	41.94
2.1/1.5	3.00	1.47	49.00	57.63	27.67	48.01
2. Wave Height (H_{max}) = 16.80 m. Wave Period (T_{max}) = 13.10 sec.						
Current velocity (surf/sbed) (m/s)	BS (MN)	Increase due to current (MN)	Percent Increase (%)	OTM (MNm)	Increase due to current (MNm)	Percent Increase (%)
0/0	1.97	0.00	0.00	38.18	0.00	0.00
1/0.3	2.51	0.54	21.51	49.66	11.48	23.12
1.55/0.97	3.07	1.10	35.83	59.50	21.32	35.83
1.8/1.0	3.21	1.24	38.63	62.70	24.52	39.11
2.1/1.5	3.62	1.65	45.58	69.49	31.31	45.06

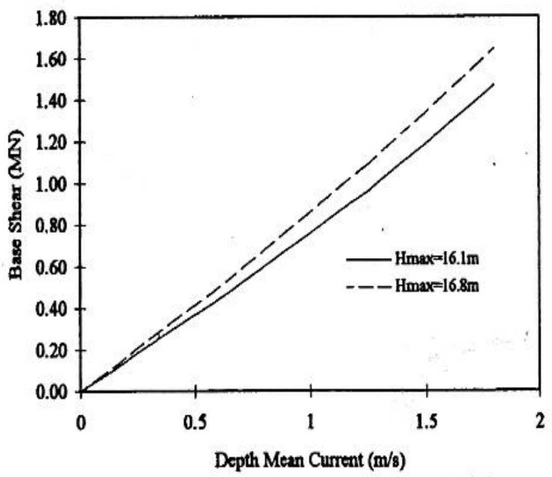

Fig. 4. Effects of Current on Base Shear (BS)

The results of current profile sensitivity study are presented in Table 7. It shows the magnitude of global loading, i.e. base shear and overturning moment for three current profiles namely, stretch, modified stretch and constant profiles. The Table also gives the percentage increase in base shear and overturning moment for the modified stretch and constant profiles relative to linear stretch profile. There are rather small increases with respect to current profile selection on the loading of jacket structures.

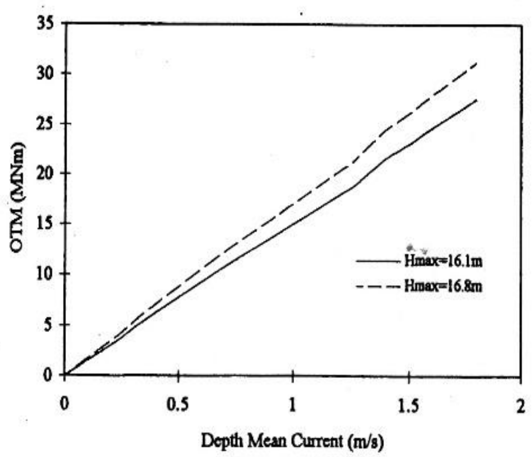

Fig. 5. Effect of Current on Overturning Moment (OTM)

TABLE 6. Results of wave-current interaction study

Current velocity (surface/seabed) (m/s)	Current continuity used?	Base shear (MN)	OTM (MNm)
1.8/1.0	Yes	2.91	56.80
	No	3.30	64.67
% increase		13.32	13.86
1.55/0.97	Yes	2.81	54.43
	No	3.13	60.89
% increase		11.39	11.87
1.0/0.3	Yes	2.38	47.02
	No	2.58	51.18
% increase		8.40	8.84

TABLE 7. Results of Current velocity profile

Current profile	Base shear (MN)	OTM (MNm)
1. Linear Stretch	3.07	59.50
2. Modified stretch	3.09	59.80
3. Constant	3.16	61.69
% increase: Profile 2/Profile 1	0.65	0.50
% increase: Profile 3/Profile 1	2.93	3.68

VIII. CONCLUSIONS

The following conclusions may be drawn from the study on the effects of current velocity on the loading of jacket structure;

1. Small amplitude wave theory with 100-year return wave height has been used in this study.
2. Current velocity profile assumed to follow general pattern where maximum magnitude occurred on the sea-surface while the minimum magnitude is at on the seabed.
3 Hydrodynamic forces increase with the increase of wave height and current velocity.
4. There is a significant contribution to structural loading with the presence of current for drag dominated structure. The results shown the increment of nearly 50% for both BS and OTM due to the presence of current velocity.
5. There are only small increases in the order of 3% and 4% for BS and OTM respectively that related to current profile selection on the loading of jacket structure.
6. The results are the outcome of environmental condition for the specifically mentioned area.

REFERENCES

[1]. Jusoh, I., “Response of Jacket Structure to Variation in Wave Height and Water Depth”, *Int J of Eng Res and Tech,* Vol.6(12), Dec 2017.

[2]. Wolfram, J., "Fluid loading on offshore platform as a result of soft marine growth: A state of the art report". Report for BP Intl. Ltd., 1988.

[3]. Jusoh, I., “Base Shear and Overturning Moment on Jacket Platform with Marine Growth” *Int J Eng Trend and Tech,* Vol 58(01), April 2018.

[4]. Morison, J.R, O’Brien, M.P., Johnson, J.W. and Schaaf, S.A., “The force exerted by surface waves on piles”, *Petroleum Transactions*, ASME, 189. 1950.

[5]. Dean, R.G. and Dalrymple, R.A., *Water Wave Mechanics for Engineers and Scientists*, ed. World Scientific. New Jersey. 1991.

[6]. Atkins, "Sensitivity of shallow water jacket structures to uncertainties in environmental loading." Report OTH88 273, Atkins Oil & Gas Engineering for the D. o. Energy, HMSO. London. 1988.

[7]. D. En., "Offshore Installations: Guidance on design, construction and certification, 4th Edition", Section 11: Environmental considerations. London. 1990.

[8]. Mendes, A.C., Kolodziej, J.A. and Correia, H.J.D, “Numerical modelling of the wave-current loading on offshore jacket structures”, *Transaction of the Built Environment.* Vol.71, 2004.