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Response of Jacket Structure to Variation in Wave Height and Water Depth

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***Abstract*— Jacket structure is a typical offshore facility installed on the seabed as part of system to recover oil and gas beneath the ocean floor. During its service life it will encounter several types of load due to interaction with environment as well as design loads purposely imposed on it. Loading due to wave-structure interaction is known to be one of the most significant loads throughout structure's operational period. This paper investigates the sensitivity of jacket structural response to variations in wave height and water depth. These variations affect water kinematics in wave and clearly observed in the magnitude of base shear and overturning moment experienced by the structure. Results of base shear and overturning moment are presented against the ranges of selected wave height and water depth.**

***Keywords*— Jacket Structure, Structural Modeling, Structural Response, Wave Height, Water Depth, Wave Loading**.

I. INTRODUCTION

This paper describes the studies of the sensitivity of a typical jacket structure in it response to the variation of wave height and water depth. The condition of structure considered as in service structure under atypical environmental loading parameters. The environmental parameters considered in this study is shown in Table 1 that comprises variation in wave height and water depth as well as base case values of current, force coefficients, wind parameters and the distribution of marine growth. The range of wave height and water depth selected for this studies are applicable for the Southern North Sea sector. In this study it was assumed that wave loads are coming from one direction that has maximum loading magnitude. Fig. 1 shows variation of loads induced within the structure with respect to angle of interaction between wave direction and the structure. It was found that the maximum load induced on the structure occurred at the angle of interaction between wave-structure is 35 degree from reference line.

TABLE 1: Base case Parameter Values

Parameter	Value
Wave Theory	Small amplitude wave theory
Current Profile	Stretch
Wave-current interaction	Stretch
Max. wave height, Hmax (m)	16.8 m
Max. wave period, Tmax (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 vel.: (surface/seabed) m/s	1.55/0.97
Marine growth thickness	None

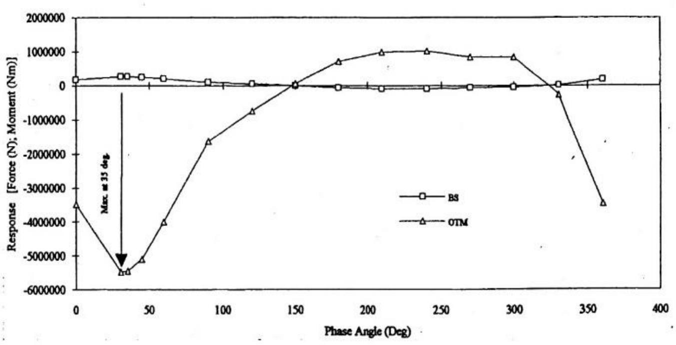

Fig. 1. Response of a pile due to variation in phase angle. Maximum load occurred at a phase angle of 35°

II. STRUCTURAL MODELING

The structure used in this study is a typical shallow/medium water depth jacket installed in the Southern North Sea at water depth of 25.06 m, Mean Sea Level (MSL). The jacket structure assembled from a tubular steel members become a four legged platform having horizontal, vertical and inclined members as shown in Fig.2 braced together forming complete jacket structure. 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 extends 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. Jacket legs are battered to provide a larger base for the jacket at the mud-line and thus assist in resisting the environmentally induced overturning moments.

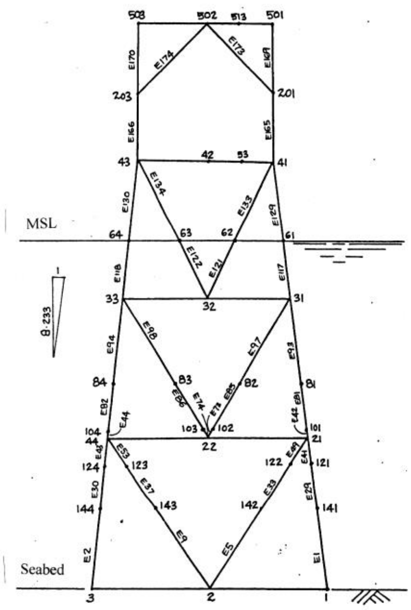

Fig. 2. Jacket structure.

III. LOADING PARAMETERS

Wave height and water depth are known to be two parameters that having very significant influence on the sensitivity of structural loading and responses. Jacket structure installed in the sea will experienced several types of loading [1]. The wave theory considered is the small amplitude linear wave theory with 100-year return wave height and its associated maximum period is given in Table 2. Study on nonlinear response of jacket structure under extreme wave may be referred elsewhere [2]. Current profile is a 'stretched profile' with values based on the extreme design current for the Southern North Sea [3]. The structure is assumed to have a cleaned surface with Cd = 0.6 and Cm = 2.0 as referred to in Table 1. Variation in wave height and water depth adopted in this study is presented in Table 3. Estimation of structural response under environmental loading having variation values may be referred to in Table 4. As refer to base case loading condition, it was found out that magnitude of structural response for base shear (BS) and overturning moment (OTM) are 3.07 MN and 59.55 MNm respectively.

IV. SENSITIVITY STUDIES

There are four wave-heights and four water-depths variations used in this study as shown in Table 3. Selected wave heights are the maximum extreme wave heights for the Southern North Sea. They are associated with l0-year, 50-year, and 100-year return maximum wave heights, as well as one arbitrary values of wave height, H of 17.55 m. Wave periods associated with the maximum wave heights are shown in Table 2. Selection of four water depths are based on the astronomical values of local tides, i.e. lowest astronomical tide LAT (water depth, d = 22.4 m), highest astronomical tide HAT (d = 27.54 m), and at mean sea level MSL (d = 25.06m).

TABLE 2: Maximum extreme wave condition [3]

Parameter	Return Period
	100 year
Hs (m)	9
Hmax (m)	16.8
Tz (sec)	10.2
Tmax (sec)	13.1
Tmax range	11.8-14.4

TABLE 3: Wave height and water depth study

Parameter	Value
Wave Height (m)	14.5, 16.1, 16.8, 17.55
Wave Period (sec)	12, 12.8, 13.1, 14.2
Water Depth (m)	22.4, 25.06, 26.00, 27.54

TABLE 4: Result of wave height and water depth study

Wave Height (m)	Wave Period (s)	Water Depth (m)	Base shear (MN)	OTM (MNm)
14.85	12.0	22.40	2.56	42.62
		25.06	2.68	49.88
		26.00	2.61	49.50
		27.54	2.50	48.74
16.10	12.8	22.40	2.96	48.39
		25.06	3.04	56.40
		26.00	2.98	56.08
		27.54	2.86	55.36
16.80	13.1	22.40	3.20	52.66
		25.06	3.26	60.53
		26.00	3.19	60.23
		27.54	3.07	59.55
17.55	14.2	22.40	3.23	59.00
		25.06	3.49	63.76
		26.00	3.41	63.57
		27.54	3.29	62.98

V. RESULTS AND DISCUSSION

The results of wave height and water depth studies are shown in Table 4. This shows the base shear and overturning moment for each selected wave height and three water depths. Fig. 3 and Fig. 4 shows the relationship between the wave height to base shear and overturning moment respectively.

The results have a significant trend on the response for this particular structure's configuration. It shows that the base shear and overturning moment increases linearly with the increase of wave height. These increments are due to higher water particles velocity thus higher wave forces in bigger wave. These resulted in higher values of base shear and overturning moment experienced by the structure. The results of the structural responses also shows that for certain wave height the force exerted on the structure increases with the decrease of water depth. These trends are due to the higher water particles velocity for the same wave height in shallow water compared with deeper water.

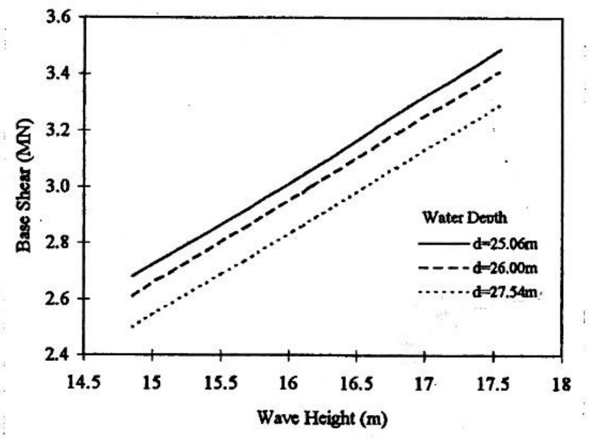

Fig.3: Wave height – base shear sensitivity study

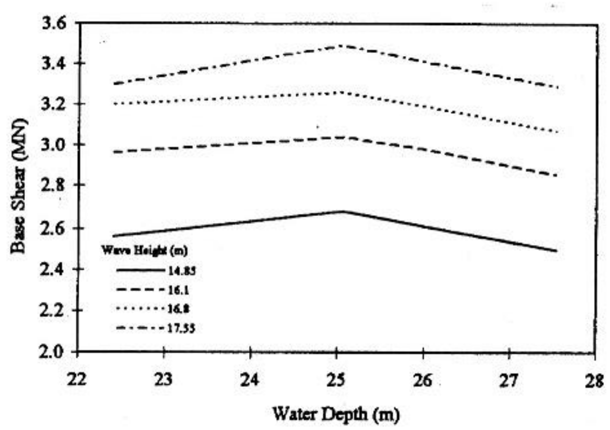

Fig. 5: Water depth – base shear sensitivity

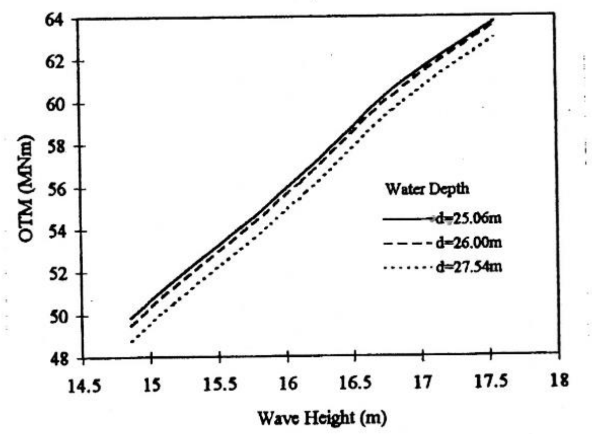

Fig. 4: Wave height – overturning moment sensitivity

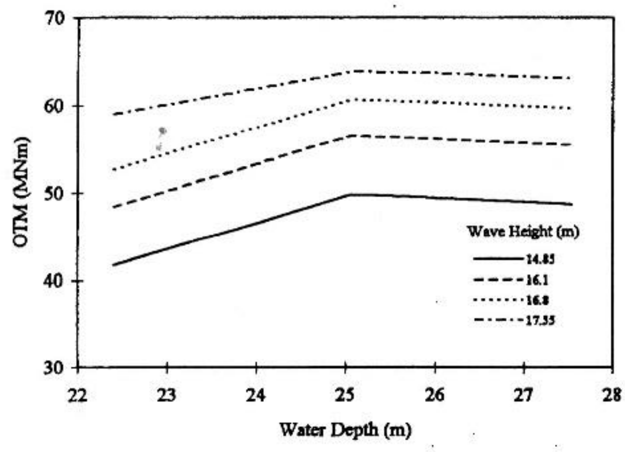

Fig. 6: Water depth – OTM sensitivity

The relationships between four selected water depths to base shear and overturning moment are plotted in Fig. 5 and Fig. 6 respectively. The result shows that base shear and overturning moment are increased with the decrease of water depth until water depth of 25 m and then they start to decrease. This is due to the relationship of water level and the configuration of the structure itself, where at LAT the maximum wave height no longer reaches the horizontal structural elements at elevation (+)5.65 m (refer to MSL). Therefore, shear forces exerted on to the structure are significantly lower than the case when the above mentioned level is submerged. Fig. 7 shows the variation in shear force with depth and the effect of each submerged level of horizontal bracing is clear where shear force was significantly increased. In addition, Fig. 5 and Fig. 6 also shows that shear forces and overturning moment exerted on the structure depends also on the configuration of the structure. Figure 7 shows the similarity with the results from Hooper *et.al* [4] as presented in Fig. 8 for the linear wave theory.

Generally, results presented here shows that it is in general agreement with previous studies [5], [6] and [7].

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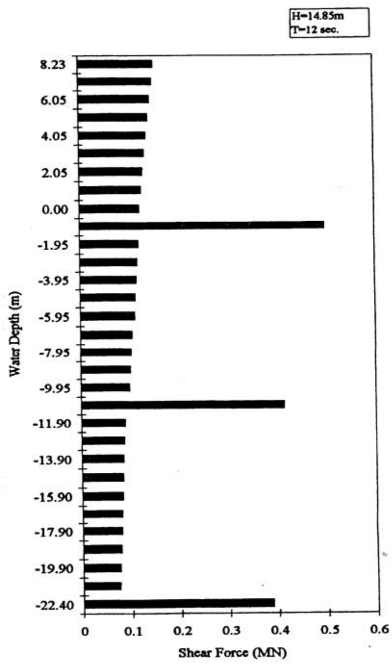

Fig. 7: Variation of shear force with water depth

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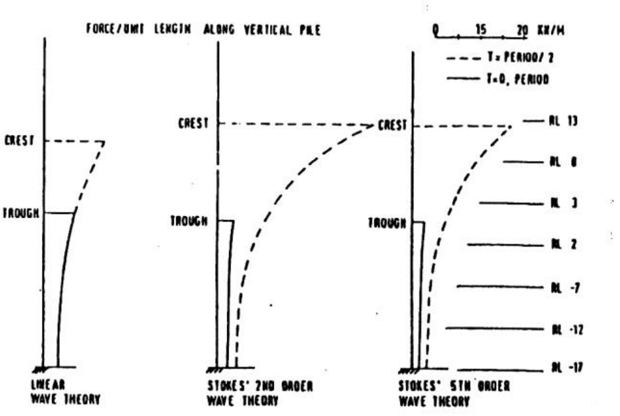

Fig. 7: Force per unit length along vertical pile [4]

The outcome of the study can further be used to investigate the details structural member response in term of stress distribution as well as it associate reserve strength as well as pushover analysis for critical elements [8].

VI. CONCLUSIONS

Responses of a typical intermediate/shallow water jacket structure with variation in wave height and water depth were investigated. The results of the study may be used to estimate the sensitivity of structural loading in term of BS and OTM. The results may be presented as follows;

(1) Changes in magnitude of BS and OTM in response to variation in wave height and water depth are not entirely linear.

(2) Highest magnitudes of response are in the order of BS equal to 3.49 MN and OTM equal to 63.76 MNm.

(2) The sensitivity trends obtained from this study are representative of a typical intermediate/shallow water structures for the Southern North Sea are indeed applicable for a similar type of structure.

(3) Application of the results to structures outside Southern North Sea area must be assumed with caution.

(4) Generally, results presented are in general agreement with the earlier studies.

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