The Response of Marine Riser to the Variation of Diameter and Wave Height

Iberahin Jusoh

Mechanical Engineering Department, College of Engineering and Islamic Architecture
Umm Al-Qura University, Makkah. Kingdom of Saudi Arabia.

Abstract — *Environmental loads are known to have exerted the highest load on marine riser attached to a jacket structure. These loads have to be properly considered and given a suitable allowance at the design stage of the structure. In this paper, the effects of wave height variation on the response of vertical steel marine riser attached to the jacket structure were investigated. Several wave heights selected to investigate the response behavior of a vertical steel marine riser to environmental loading. Due to the slender nature of the riser, the response shows its sensitivity to the variation of wave height. The 6 in diameter riser experienced maximum horizontal deformation of 139 mm under extreme wave height of 10 m. The maximum magnitude of stress developed within the riser is 129 MPa at the topside connection at element 82. The maximum stress utilization is found to be 0.2945 and this indicates that the riser is operating within a safe strength capacity. The results from this study show the stress distribution along the riser length that gives important information on the location of critical elements and associated stress magnitude to be considered in design and analysis.*

Keywords — *marine riser, deformation, stress, wave height, hydrodynamics load.*

I. INTRODUCTION

The marine riser is a very important part of the offshore structure installed in the ocean for oil and gas recovery and production. Its primary function is to facilitate the flow of oil and gas from the reservoir to the topside of the structure. It is made from tubular steel and installed vertically on a fixed structure with a major part of it submerged while the small top section is exposed above the mean sea-level. In its operational life, riser experiences several types of loading mainly from hydrodynamics sources such as wave and current, buoyancy effect, riser self-weight, internal and external pressure. Several other factors that must be considered at its design stages are vibration, fatigue, and material corrosion.

II. BACKGROUND

In an offshore oil and gas recovery, special structures are required to be installed and that offshore locations are likely to have severe environmental conditions. The load from this environment mainly comes from wave-structure interaction resulting in horizontal lateral forces on the riser. It is very important to understand these loads and due consideration must be given at the early stage of the structural design process. Vertical steel marine riser considered in the study is installed to the jacket structure fixed at the seabed and at the top side of the structure. The riser is a slender member of the structure, and for the analysis, it is categorized into the drag dominated type of structure as shown in Fig. 1 [1] and Fig. 2. The numbers of risers on a typical structure are varies depending on the needs and requirements at certain locations or oil fields. In some cases, it can be a bundle of 60 to 80 risers on one larger jacket structure. Therefore, proper analysis and consideration must be given since the loading on risers can be nearly 40% of the total wave load exerted on the offshore structure [2]. External loads as from the environment as well as internal pressure, self-weight, transferred load, dynamics response of the riser would affect the final magnitude of stresses within the structure [3]. The problem arises due to the slenderness nature of marine riser and wave-riser interaction mainly appears to be the vortex-induced-vibration. Detail study on this topic and the methods to reduce its effect were presented in [4], [5], [6].

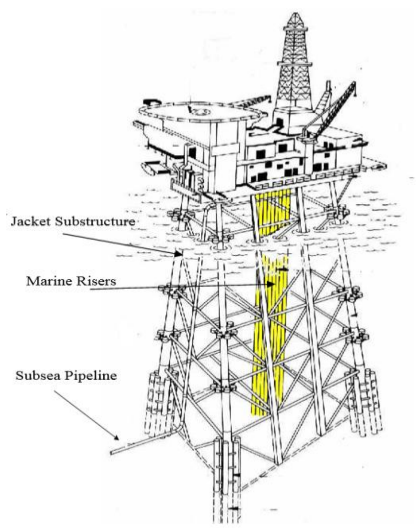


Fig.1: Marine risers attached to a fixed jacket structure [1].

III. STRUCTURAL MODELLING

Fig. 2 shows the structural model of the jacket structure attached to vertical steel marine riser. The structural model adopted in this study is an 82 m length jacket structure installed in a water of 70 m depth offshore Malaysia. The jacket structure is made of tubular members with five elevations with horizontal and cross bracings as shown. Vertical steel marine riser is also made from tubular member and modeled as part of the structure fixed at the seabed and at the topside section. The risers used in this study have a variety of diameters ranges from 6 inches to 12 inches and is divided into 81 elements. The material used for the riser has an ultimate strength of 552 MPa, yield strength of 438 MPa, Young's modulus of 205 GPa, shear modulus of 80 GPa, the density of 7995 kgm3 and Poisson's ratio of 0.3. The analysis of the loading model neglects the effect of shielding when assessing the response due to environmental loads. This will give a conservative prediction of the riser's static deformation and stresses at various stress points when the riser is under maximum or extreme forces. From the analysis, the response of riser in terms of deformation and stresses due to environmental loading was observed.

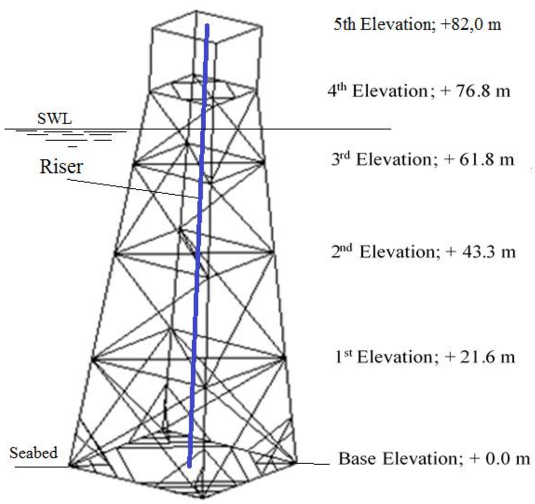


Fig. 2. Marine riser on a jacket structure.

IV. LOADING FORMULATION

Environmental loading is one of the main sources of external forces that must be properly considered and analyzed in the design of the offshore structures. These loads are contribution of forces from wave, current, and wind with waves that are known to be the major source. Interaction of environmental loads on riser will cause physical deformation, vibration as well as stress-related phenomena within the structure. In this paper, the focus in on the response of marine riser to the variation of wave height and riser diameter.

Estimation off hydrodynamics loads were performed using the Morison equation which is a combination of sinusoidal and cosine wave force with respect to time, *t*.

Fig. 3 illustrates the hydrodynamics interaction with a typical submerged section of marine riser based on the Morison equation [7], [8], [9]. It is assumed that the wave amplitude *a*, is very small as compared to the water depth, *d*.

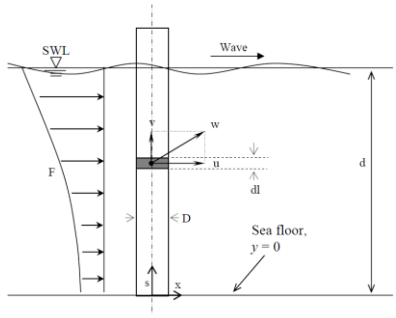


Fig. 3. Hydrodynamics loads on a marine riser

The Morison equation estimates the total wave forces by linearly added two parts of drag and inertia components.

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

where ρ denotes water density, *D* is the riser diameter, *A* is the riser projected area, C_D is the drag coefficient while, C_M is the inertia coefficient.

At any point of time, *t*, water particles velocities in x-direction, *u*, and the associated acceleration of water particles, $\dot{u}$ is given as:

$$u(x,t) = \frac{\pi H}{T}\frac{cosh[k(z+d)]}{\sinh(kd)}\cos(kx - \omega t)$$

$$\dot{u}(x,t) = \frac{2\pi^2 H}{T^2}\frac{\cosh[k(z+d)]}{\sinh(kd)}\sinh(kx - \omega t)$$

where *H* denotes wave height, *T* is the wave period, *d* is the water depth.

The relationship to estimate sea driven current velocity that accompanied the wave-particle motion is;

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

where v_{cto} is the current velocity at mean sea level, *z* is distance from the surface and *d* is water depth. Magnitude of the current velocities was adopted from earlier study by Jusoh [10].

Wind force exerted on the marine riser above mean water level (MSL) at elevation Z, can be estimated using the following relationship:

$$F_w = \frac{\rho}{2g}(\bar{U})^2 C_S A$$

where ρ is density of air, g is gravity acceleration, $\bar{U}$ is wind speed, C_s is shape factor A is projected area of the structure.

V. RESULTS AND DISCUSSION

The response of a steel vertical marine riser attached to a jacket structure exposed to ocean wave and current was investigated by using a finite element model and associated loading formulation. The riser was analyzed as a single tubular cylinder with a variation of wave height. Another study was a response of a riser with a variation of diameter under the loading of extreme wave height. The results of riser's response presented here in terms of horizontal deformation and stress distribution along the riser span. The location of the stress point as shown in Fig. 4, it is obtained at point 2 on the trailing side along the span of the riser in wave-riser interaction.

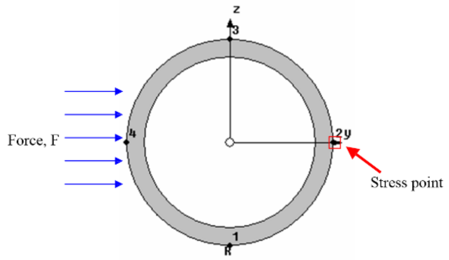
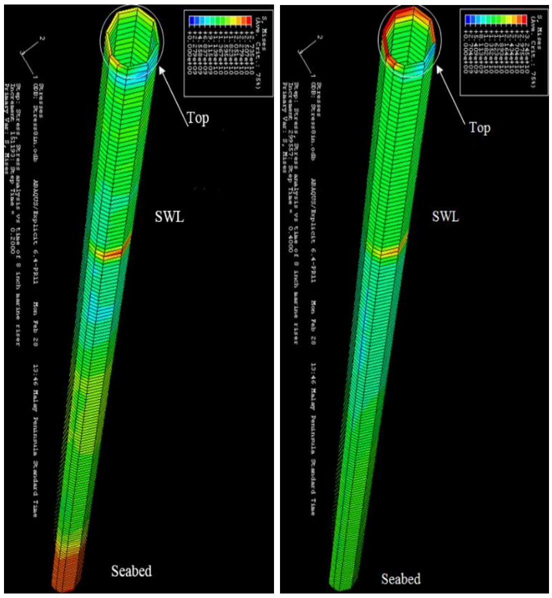


Fig. 4: Stress points on riser cross-section

Fig. 5 shows stress distribution along the riser span observed in dynamics analysis at time $t = 20$ seconds (Fig. 5a) and $t = 40$ seconds (Fig. 5b) respectively. Higher stresses on the elements found to occur near the base of the riser at the seabed for $t = 20$ seconds and switch to maximum stress occurred at element 82 at the top of the column at $t = 40$ seconds. This is due to higher bending loads experienced by the riser at those locations results from the high horizontal loading near the still water level.

The effects of wave height variation on marine riser deformation were presented in an earlier study by Jusoh [7]. The magnitude of deformation experienced by the riser under environmental loading generally follows the linear trend. The riser responses show that the higher the wave height encountered will result in the higher wave loads thus the associated deformation and stresses within the structure.

Fig. 6 shows the riser deformation with respect to the variation in riser diameter. The wave-riser interaction load was estimated for the case of wave height of 10 m which is a 100-year wave for Malaysian water. The riser models were selected for a diameter of 6 in, 8 in, 10 in and 12 in. (i.e., 0.1524m, 0.2032m, 0.2540m, 0.3048 m, respectively). The results show that the riser deformation is sensitive to the change in riser diameter. The results show that the larger the riser diameter, the smaller the deformation due to the external load. This is true because of the nature of the structure that the larger diameter gives rise to higher stiffness within the structure. It was clear that the riser with a diameter of 6 inches (0.1524 mm) experienced the largest deformation and stress as compared to other cases of larger diameter. The 6 in riser gives results of maximum compressive stress of 110 MPa and associated tensile stress of 54 MPa as presented in TABLE 1



(a) (b)

Fig. 5. Stress distribution at (a) $t = 20$ seconds and (b) $t = 40$ seconds

TABLE 1: The stress distribution and deformation of the riser with various diameters.

Riser Diameter	Maximum Deformation	Maximum Stress (T)	Maximum Stress (C)
6 in (0.1524 m)	139 mm	54 MPa	110 MPa
8 in (0.2032 m)	62 mm	32 MPa	66 MPa
10 in (0.2540 m)	37 mm	23 MPa	50 MPa
12 in (0.3048 m)	25 mm	18 MPa	40 MPa

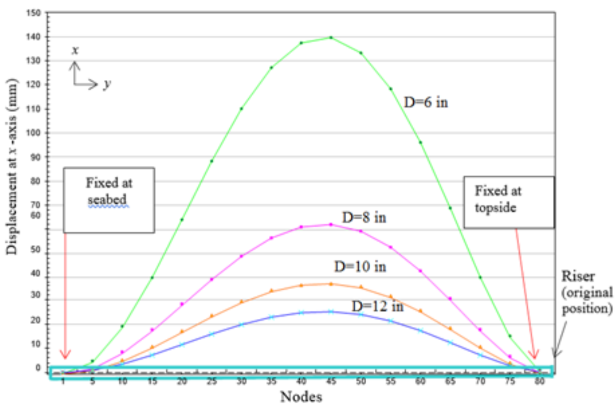


Fig. 6: Riser deformation with variation in diameter.

The stress distribution along the span of the riser under environmental load with the wave height of 10 m is presented in Fig. 7. The results are in agreement with the behavior of riser deformation that is positively deformed in the mid-span thus giving the positive stress value. The study also found that the maximum stress is found to occur at element 82 at the topside connection.

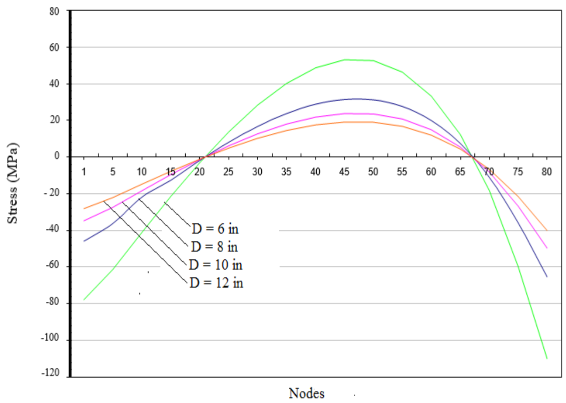


Fig. 7: Stress magnitude for riser under wave height, H=10 m, for a various riser diameter.

The results for effects of wave height variation on the stress distribution along the riser span are presented in Fig. 8. As anticipated the maximum stress developed will increases with the increment of wave height. As wave height of 11 m interacts with the riser, the maximum tensile stress at mid-span is found to be 64 MPa and compressive stress at element 82 is 129 MPa. This maximum stress magnitude gives the stress utilization value of 0.2945 at the most critical riser element. Generally, the maximum stresses developed within the riser are still within the safe region of the material capability.

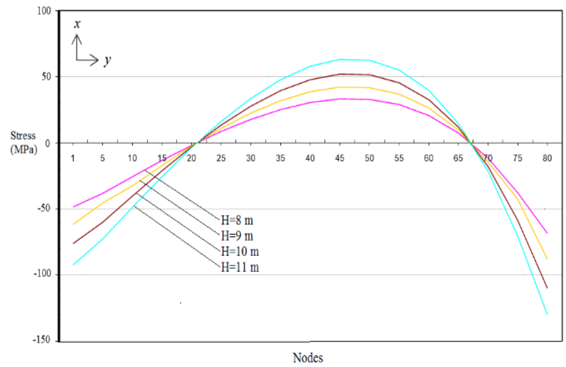


Fig. 8.: Effects of wave height variation on stress distribution on 6 in riser.

VI. CONCLUSIONS

In this study, the following conclusions may be drawn. Marine riser is one of the most important structures on offshore oil and gas production facilities. Due consideration and allowance must be given in term of loading contribution from marine risers to the total loads experienced by the main structure in its operational life.

The maximum horizontal riser deformation found to be 139 mm for a riser with 6 in diameter under an extreme wave of 10 m. From the results, it is found that riser with diameter 8 in, 10 in or 12 in, experienced smaller deformation (less than 50%) as compared to the one with 6 in diameter. The maximum magnitude of stress developed within the riser is 129 MPa at the topside connection at element 82. The maximum stress utilization is found to be 0.2945 and this indicates that the riser is operating in a safe region. The results from this study show the stress distribution along the riser length that gives important information on the location of critical elements and associated stress magnitude to be considered in design and analysis.

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