The Stress of Marine Riser on Jacket Structure

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Abstract — *Marine riser is a very important part of the structure designed for offshore oil and gas recovery. It needs to be carefully analyzed to ensure that the pipes have acceptable levels of deformations, stresses, and fatigue life due to environmental loads. These environmental loads are from current waves and wind. In this paper, the responses of marine risers due to these loads were studied. The fixed type of vertical steel riser installed on a typical jacket structure exposed to a horizontal sea current and extreme Malaysian environment. Finite element program was utilized to determine the static and dynamic behavior of the marine riser structure. Estimation of wave forces, current and wind loads is derived from the Morrison equation. The study shows that the riser is sensitive to variation in riser diameter and wave height. The maximum deformation at the mid-span of the riser is found to be 190 mm and maximum stress within the riser is 108 MPa.*

Keywords — *marine riser, hydrodynamics load, riser deformation, stresses, jacket structure..*

I. INTRODUCTION

The marine riser is part of the jacket structure installed in the sea functioned as a conductor in recovering hydrocarbon from the reservoir beneath the seabed. It is made from tubular steel and installed vertically on a fixed structure from the seabed to the topside. The major part of the riser is submerged while the small top section is exposed above the mean sea-level. During 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. Other aspects of loads contributing to the total design consideration are vortex shedding and its associated vibration.

II. BACKGROUND

It is very important to understand the loads and its related stress response in marine riser particularly at the critical location such as at the joint to the wellhead. Generally, there are two types of risers employed in the industry namely vertical steel riser and flexible catenary riser. In this paper, the study is focused on vertical steel riser. Vertical steel risers need to be carefully analyzed during design to ensure that the pipes have a suitable allowance for deformations, stresses, and fatigue failure. An earlier study identified that the operating conditions, as well as inadequacies in technology procedures of the marine riser, is a major challenge in the design of marine riser [1].

Marine risers designed to be able to withstand the lateral forces of waves, currents, and wind loads as illustrated in Fig. 1, [2]. Axial weight and buoyancy of the riser itself in seawater must be taken into consideration [3]. In recent years, the offshore industry has utilized composite steel and elastomer in the application of marine risers. Flexible risers are able to operate with much larger surface platform offset (from above the subsea wellhead) than is permissible with more rigid vertical steel risers which are generally limited to offset of 7-10% of water depth.

An earlier study on marine riser displacements and stresses due to self-weight, buoyancy, internal and external pressures, surface vessel motions, and environmental forces arising from currents and waves may be referred to in Patel et.al [4]. While Joseph et. al. presented the effects of vortex-induced vibration on marine riser [5].

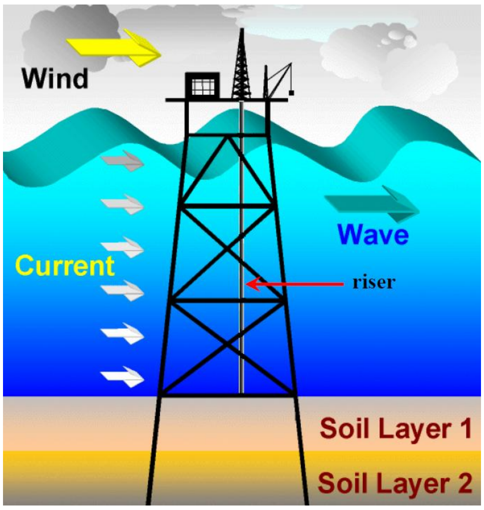

Fig. 1: Environmental forces acting on the marine riser.

III. STRUCTURAL MODELLING

In this study, the 82 m length riser was modeled as part of a fixed jacket structure installed in a water depth of 70 m. The structure experiences wave height range between 7m to 12m, typical extreme wave in Malaysian water. Materials properties for the riser may be referred to in Table 1. The steel pipe used for riser has a diameter of 6 inches and thickness on 0.5

inches. The riser model is assumed to have fixed support at both ends, at the top side of the jacket platform structure and on the seabed as shown in Fig. 2. 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. The riser was modeled from tubular beam elements with tension, compression torsion, and bending capabilities. It divided into 81 elements with each node is numbered in ascending order from the wellhead on the seabed to the topside.

TABLE 1: Material properties of marine riser

Ultimate tensile strength	σ_u = 552 MPa
Yield strength	σ_Y = 438 MPa
Young's modulus	E = 205 GPa
Shear modulus	G = 80 GPa
Density of pipe	ρ = 7995 kg/m^3
Poisson's ratio	v = 0.3

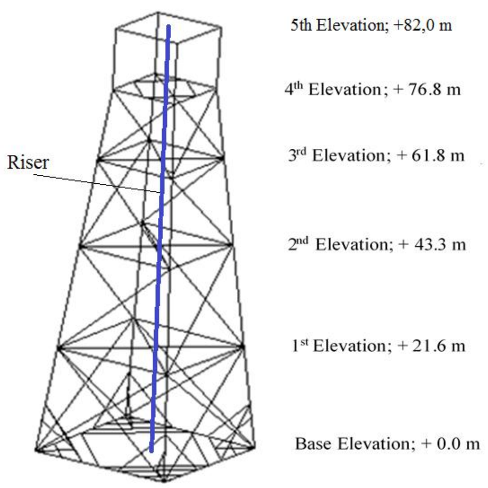

Fig. 2: Jacket structure with riser

Using the finite element model of the riser, static and dynamic analyses were performed to determine maximum displacement and associated stresses response to the prescribed loads. The dynamic explicit analysis gives the riser's behavior when a cyclic load was applied.

IV. MATHEMATICAL FORMULATION AND LOADING MODEL

Hydrodynamics induced loads are the most important factor in the design consideration of marine structures. Many studies have previously been done to address the effects of wave loads on a marine riser, and it proved to be a significant task as predictions for wave conditions are substantially random and complex. This has been a major challenge for many offshore operations as these loads could cause failure to long slender structures such as the marine riser.

The wave force derived from Morrison's Equation is a combination of sinusoidal and cosine wave force which is determined by the time, t. Since it is known that the force is periodic, a summation of forces is a sinusoidal and cosine graph, then the stresses experienced by the riser will also differ according to time.

It is assumed that in this study the wave amplitude a, is very small as compared to the water depth, h. Fig. 3 illustrates hydrodynamic loads on the submerged section of marine riser may be estimated using the Morison equation [6], [7].

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

where ρ denotes water density, C_D is the drag coefficient while, C_M is the inertia coefficient.

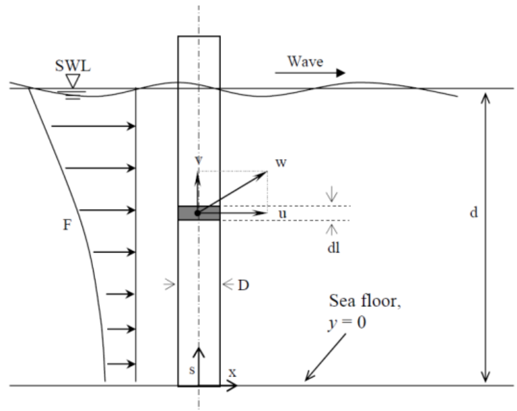

Fig. 3: Hydrodynamics loads on marine riser.

Water particles velocities in x-direction, u and z-direction, v at any point of time, t is given as:

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

The associated acceleration of water particles, $\dot{u}$ and, $\dot{v}$ at any point of time, t is defined as:

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

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

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

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

The magnitude of the current velocities was adopted from earlier study by Jusoh [8].

Wind force exerted on the marine riser above MSL at elevation Z, can be calculated as below relationship:

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

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

The study also being performed on the variation of wave height on vertical steel riser attached to the fixed jacket platform. The riser experienced variation in force magnitude and results in the different magnitude of deflection.

V. RESULTS AND DISCUSSION

The results of this study are presented in this section. The main finding is that the riser is very sensitive to horizontal loading from the environment due to its slender dimension. It is also found that the stresses are higher at the fixed points on the riser due to the restriction in its displacement. The resultant stress on the riser represented as reading at points 2 and 4 as shown in Fig. 4 and its distribution is referred to in Fig. 5. The maximum stress experienced by the riser is 107.68 MPa (compressive) at point 4 and 108.11 MPa (tensile) at point 2 when the extreme wave encountered is 10 m.

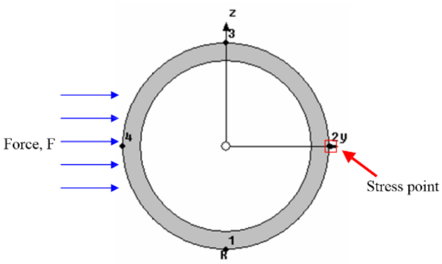

Fig. 4: Stress points on riser cross-section

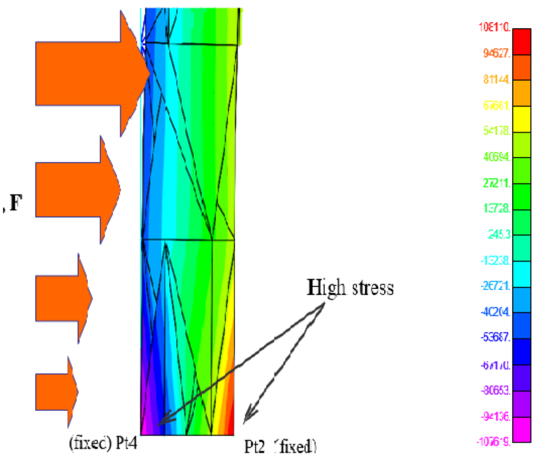

Fig. 5: Stress distribution on riser.

Dynamics analysis of the riser with respect to time gives the stress distribution as shown in Fig. 6. It shows a stress distribution along its length in association with the horizontal environmental loads when the simulation time, t = 10 seconds. Higher stress experienced by the elements near the seabed as there is a top section of the riser that is free from hydrodynamics interaction thus experienced lesser loads at its top end. Details results on dynamics analysis will be presented in other publication under preparation

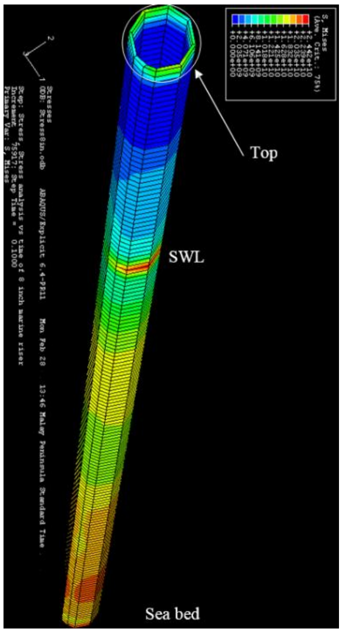

Fig. 6: Stress distribution along the span of the riser.

Riser's deformation, as well as stress-induced within the riser elements, are very much sensitive to its diameter and wave height. Fig. 7 shows the riser deformation with respect to variation in wave height, H. Maximum deformation of 190 mm occurred at the mid-span of the riser. This magnitude is still acceptable and within the save deformation over a length ratio of 0.023 percent, which is less than 0.05 percent as obtained by Niedswecki, [9].

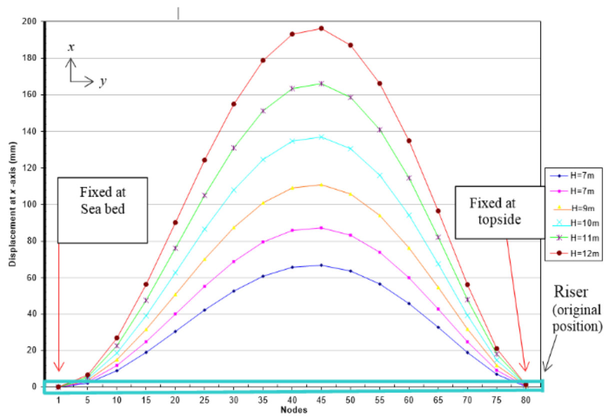

Fig. 7: Riser deformation versus wave height, H.

Highest stress and deformation are experienced by element 47 for every wave heights encountered and the lowest stresses occurred at elements 1 and 82. When subjected to an extreme wave height of 12 m, 6 inches diameter riser developed maximum stress of 108 MPa. This maximum stress gives the stress utilization within the riser of 0.2466 and indicates that the reserve strength within the riser is high. This stress magnitude does not cause failure to the riser component.

VI. CONCLUSIONS

A marine riser is a slender structure attached to the offshore platform conducting hydrocarbon from the seabed to the processing facilities above the mean sea level.

The results of this study indicate that marine riser is sensitive to hydrodynamics loads. The response of the riser to external loading shows that element no. 47 at mid-span is the most stressed with magnitude 110 MPa. The maximum horizontal displacement of 190 mm also occurred at the mid-span of the riser under extreme loads when the wave height is 12 m.

The maximum stress developed under extreme environmental loading is still very safe for the strength of the material used for the riser. The stress utilization ratio is at 0.2466, indicating that the level of reserve strength is high.

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