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Variation of Hydrodynamic Load on Vertical Riser

Iberahin Jusoh

Mechanical Engineering Department, College of Engineering and Islamic Architecture,
Umm Al-Qura University, Makkah. Kingdom of Saudi Arabia
iberahin[at]gmail.com

Abstract: ***The main purpose of risers on offshore structures is to transport hydrocarbon from the reservoir to the topside. Vertical risers are usually made of steel and vertically attached to the main structure at specific locations. In this paper, the variation of hydrodynamic load on a fixed vertical riser is studied. The main force experienced by the riser is the drag force since the riser is made of a small diameter tubular member. The largest horizontal force on the riser with a diameter of 14 inches is found to be 22.5 kN at an elevation of 76 m. Time variation effects on riser von-Mises stresses were variation was also investigated. Maximum von-Mises stress is 54 MPa on element 90 at the mean water level.***

Keywords: jacket structure, fixed verticalriser, hydrodynamic load, riser deformation, von-Mises stress

1. Introduction

A fixed vertical riser is attached to the frame structure of the jacket platform as illustrated in Fig. 1. The arrangement of the riser can be bundled into several vertical conductor tubes held together in the riser guide frame. The purpose of these risers is basically to transfer hydrocarbon from the reservoir to the topside. Its function indicates the importance of the riser within the structure. Therefore riser design and analysis must be given due consideration in terms of strength and safety stress capacity. The riser is in a shape of a slender tubular member which behaves as a drag dominant behavior when in interaction with wave and current. Several types of loading are induced mainly from hydrodynamics sources such as wave and current, buoyancy effect, riser self-weight, and internal and external pressure during this interaction [1], [2]. Other aspects of loads contributing to the total design consideration are vortex shedding and its associated vibration [3].

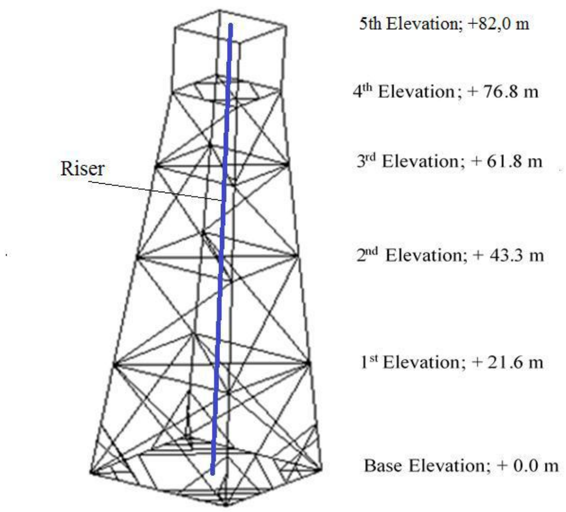

Figure 1: Riser attached to jacket platform [1]

2. Background

Fixed offshore structures are placed on their location by piling through the structure legs into the seabed. The vertical riser is made of tubular steel which is one of the most important parts of the structure. Riser or conductor pipes are attached to the jacket structure at specific levels along the structural height so that it will be having optimum support when subjected to external and internal loadings. Fig. 1 shows a level of horizontal bracings on the structure where the fixing points were located. It has to be carefully analyzed to give enough allowance for stresses due to loading that usually deformation and fatigue problems. With that analysis and considerations at the design stage, the vertical riser at its place on the structure could withstand hydrodynamic forces, wind load, its weight and buoyancy force acting on it [4], [5].

3. Structural Modelling

In this study, a vertical riser is attached to a typical offshore jacket structure installed at a water depth of 82 m as shown in Fig. 1. The properties of the riser are presented in TABLE 1. It has a range of diameters from 6 to 14 inches with a wall thickness of 0.5 inches. It is assumed that the riser has a fixed support at both ends, i.e. at the seabed and topside of the platform. The submerged section of the riser will experience hydrodynamic load due to water wave and current interaction while the exposed top part will experience the wave-induced load on the riser. Horizontal wave particles passing and interacting with the riser would create a vortex and create a vibration on it [5]. The riser will also experience stresses due to self-weight and buoyancy as well as differences in internal and external pressure [4].

Table 1: Material properties of marine riser

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

Stresses induced within the riser and its associated displacement were analyzed in response to hydrodynamic load. The static and dynamic behavior of the riser was also investigated.

4. Loading Formulation

The hydrodynamic load induced on the riser was estimated using the Morison equation. Since it is known that the force is periodic, the summation of forces is sinusoidal and cosine in nature, then the stresses experienced by the riser will also differ according to time. Fig. 2 and Fig. 3 illustrate hydrodynamics loads on the submerged section of the 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, D is the riser diameter, A is the riser projected area, C_D is the drag coefficient, C_M is the inertia coefficient.

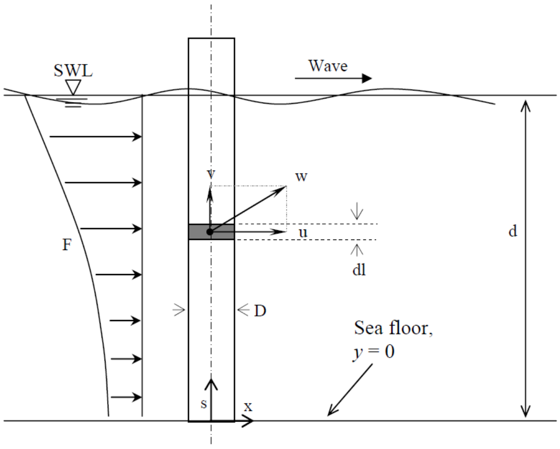

Figure 2: Hydrodynamic load on vertical riser.

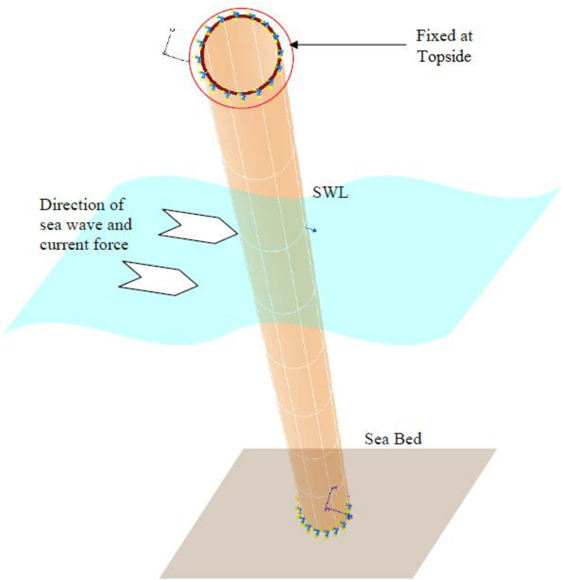

Figure 3: Riser subjected to hydrodynamic load.

A formulation for water particle's velocities and accelerations in the x-direction, u and z-direction, v at any point of time, t.

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

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

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

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 the current velocity at mean sea level, z is the distance from the surface and d is water depth. The magnitude of the current velocities was adopted from an earlier study by Jusoh [1].

Wind force exerted on the marine riser above mean sea level may be estimated using the following relationship:

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

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

5. Results and Discussion

The main finding in this study is the variation of the hydrodynamic force's magnitude that is sensitive to time variation and horizontal and vertical water particle motion. It is also affected by the water depth as illustrated in Fig. 4. Horizontal hydrodynamic loads are sensitive to the riser's diameter. The largest horizontal force is found to be 22.5 kN at a mean water level of 76 m on the riser with a diameter of 14 inches.

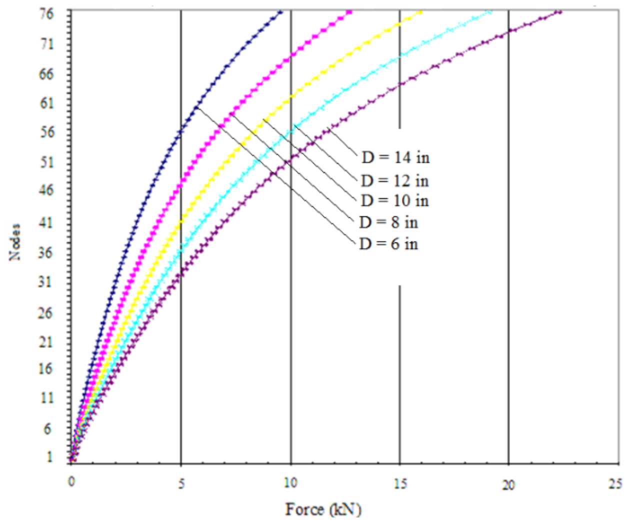

Figure 4: Hydrodynamic forces on riser with different diameters.

The distribution of bending stress due to hydrodynamic force at T=10 seconds along the riser is shown in Fig. 5 [3]. Hydrodynamic forces will cause deflection and deformation that give rise to related von-Mises stresses within the riser. Examples of time variation of von-Mises stresses on elements at selected points are shown in Fig. 6 and Fig. 7. It is found that element 90 at the top section of the riser experienced the highest stress within the riser. It was expected due to the distribution of hydrodynamic load being maximum at the top level of the riser. Hydrodynamic forces at their highest occurred at the still water level, thus associated with the highest bending moment to the base of the riser. The smaller the riser's diameter, the higher the magnitude of the riser's oscillation under hydrodynamic forces. This is due to the effect of structural rigidity, *E* as well as the slenderness ratio of the riser. Due to the complex form of riser vibration and vortex shedding excited by hydrodynamic forces. The 8-inch diameter riser has a bigger amplitude of oscillation compared with bigger diameter risers. It has a maximum stress of 54 MPa and a minimum of 13.9 MPa in tension stress.

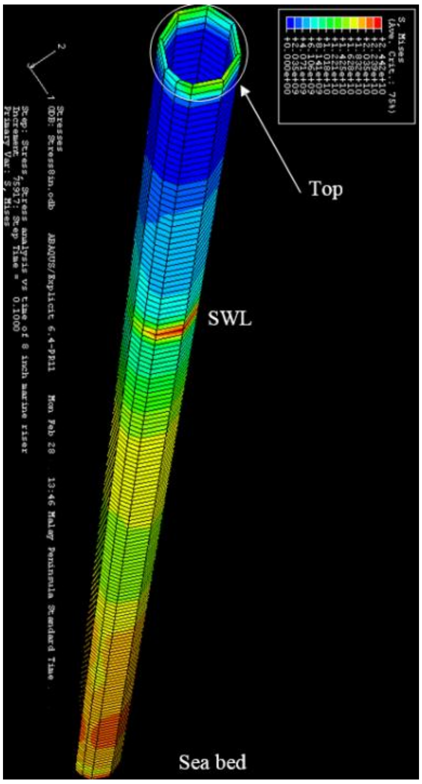

Figure 5: Distribution of Bending Stress along the riser's length at t = 10 seconds [3].

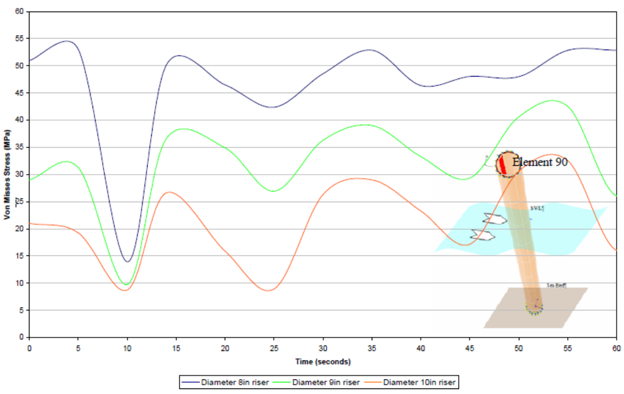

Figure 6: Time variation of von-Misses stress on element 90

Fig. 7 shows the summation of hydrodynamic forces at respective nodes as marked on the riser. Nodes were located at 10.25 m up to 61.6 m from the seabed. The results were dependent on time as shown in the Morison equation.

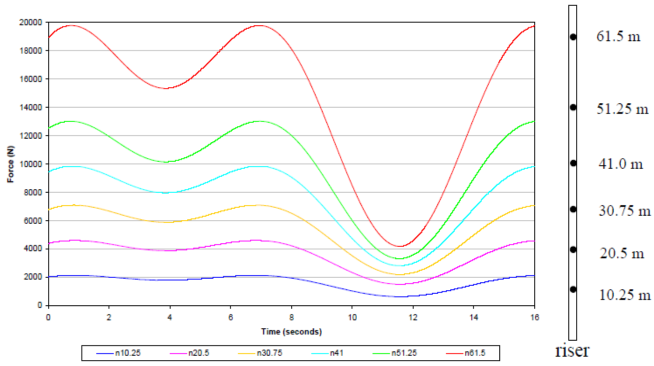

Figure 7: Summation of hydrodynamic forces on riser nodes

6. Conclusions

From this study, the following conclusions can be drawn. Hydrodynamic loads are the main source of forces and stress on the riser's element. The magnitude of the hydrodynamic load and the riser response are interacted and very much depend on the water particle motion and the riser's diameter as well as water depth elevations. The riser has an acceptable level of stress at both the bottom and top joints. Riser diameter is one the most important parameters which affect the development of stresses within the element. The bigger the diameter, the more rigid the riser and will cause it to experience less stress and smaller deformation. The force of the ocean wave is the main external excitation of the marine riser system. Maximum bending stress occurred at the base of the riser at seabed elevation. The 8-inch diameter riser has a bigger amplitude of oscillation compared with bigger diameter risers. Maximum von-Mises stress on element number 90 is found to be 54 MPa and a minimum of 13.9 MPa in tension stress.

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