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Analytical approach for the establishment of critical length criterion for the safe and economical design of the flexible jumper in deepwater applications

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ABSTRACT

The Hybrid Riser (HR) configurations based on flexible jumpers connected to a submerged buoy offer certain unique advantages over other field proven riser concepts in deepwater, and have been used successfully in industry. In particular, flexible jumpers can effectively isolate the dynamic Floating Production Unit (FPU) motions, and thus in place riser fatigue is minimized. This paper focuses on the flexible jumper issue, and aims to propose a highly effective analytical approach for setting its critical length criterion (CLC). The critical length is defined as the minimum length that can maintain the equilibrium between the de-coupled property and economics of the flexible jumper. Furthermore, the analytical approach is verified by numerical parametric studies for the flexible jumper of a Single Line Offset Riser (SLOR). The results demonstrate that there exists a CLC for the safe as well as economical design of the flexible jumper. Therefore, the usual design approach employed for the flexible jumper is not completely adequate, and should be complemented by alternative approaches. A new practical design method of flexible jumpers can be developed following the CLC presented here.

1. Introduction & problem description

In the present days, petroleum exploration and production activities proceeds into water depth close to 3000 m. Thus, technically and economically suitable offshore production systems are needed to overcome the demanding challenges presented by large water depth and harsh environments in ultra deepwater. In this context, HR configurations [1,2] offer certain unique advantages and have gained wide recognition in the offshore industry over other field proven riser concepts in deep-water. Although there are different versions of the HR and its configurations have been modified through the years, the key technical benefit remains that the major rigid vertical risers or Steel Catenary Risers (SCRs) are offset from FPU using top flexible jumpers as connection. On this basis, rigid risers or SCRs can be decoupled from direct wave loads and FPU motions. This de-coupled effect will enhance HR performance significantly.

It can be noted that the common point of all the prevailing HRs is the use of flexible jumpers connecting the submerged buoy to the FPU. In this case, both connection points are positioned at different levels. Though some fields have been proven, many problems still remain in the design and analysis of the flexible jumper, whose details are still unknown and rarely systematically disclosed in the existing literature. This fact leads us to concentrate the efforts to the study of the flexible jumper problem alone. Furthermore, the most significant problem is how to set the CLC of the flexible jumper. On the one hand, the flexible jumper length should be long enough so as to be in a slack catenary shape for the de-coupled effect. On the other hand, it is well known that flexible jumpers are considerably expensive, and therefore design length values should be as short as possible. In view of this, the critical length is defined as the minimum length that can maintain the equilibrium between the de-coupled property and economics of the flexible jumper. Fernandes et al. [3,4] performed a static analysis of the free-hanging catenary, and the results of the application of such consistent catenary concepts in analytical studies of the Highly Compliant Riser (HCR), whose connection points are positioned at the same level. As a consequence, they found that there exists a critical length that separates the dominance of the vertical loads from the horizontal loads and determines minimum feasible values for the flexible jumper length. Furthermore, they concluded that the critical jumper length just relates to its maximum span and believed that this relationship can also be expected for suspended

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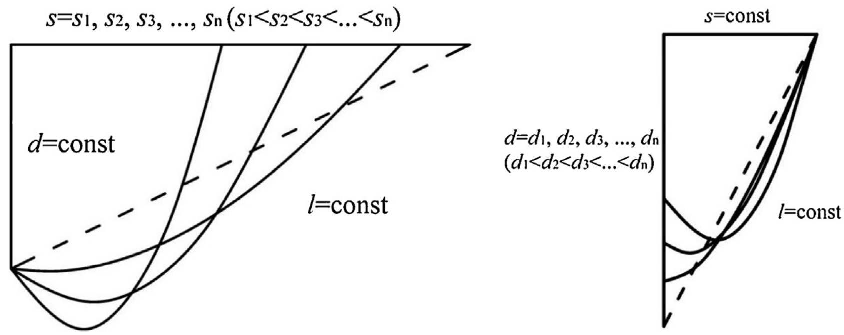

Fig. 1. Effects of the horizontal span and submerged depth on the critical jumper length.

jumpers with connection points located at different levels, such as in the Tension Leg Riser (TLR) or Riser Tower cases.

Nonetheless, it should be noted that, with respect to TLR or other HR concepts including SLOR, COR (Concentric Offset Riser), and Bundled riser towers, etc., the submerged water depth of the intermediate supporting buoy will also have a significant influence on the final determination of the critical jumper length. It lies on the design features of HR concepts. With respect to non-offset, multi-pipe bundled hybrid riser [5,6], the intermediate supporting buoy is located right below the FPU. It is obvious that the maximum span of the flexible jumper won't have a significance on its critical length determination. This HR structure has been used in Green Canyon block 29 of the Gulf of Mexico by Placid Oil in 1988 as well as the Garden Banks field by Ensearch in 1994 [1]. In addition, the subsurface development strategy for offshore petroleum production [7,8] is proposed and aiming to overcome the demanding limitations of subsea and dry tree developments in ultra-deep water. In this case, it is envisaged that the Xmas trees are located on a mid-depth facility below Mean Water Level (MWL) and the flexible jumper from the mid-depth facility would terminate at the FPU. The mid-depth facility can theoretically be located at any water depth between the seabed and surface. In particular, the location of the mid-depth facility in greater depths is potentially advantageous for the potential increase in productivity arising from reduction in static head. Given this, it can confirm primarily that the critical jumper length relates to not only its maximum span but also the submerged water depth of the intermediate supporting buoy when connection points of the flexible jumper are positioned at different levels. Fig. 1 depicts effects of the horizontal span as well as submerged depth on the critical jumper length.

This study, therefore, focuses on the flexible jumper issue, and aims to present a highly effective analytical approach for setting its CLC. The validity of the analytical approach are confirmed by numerical parametric studies for the flexible jumper of a SLOR.

2. Analytical approach for setting critical jumper length criterion

Referring to Fig. 2, the flexible jumper in a static equilibrium can be considered as a plain catenary with end points at different levels (end A & end B). The tension T of the flexible jumper at the top connection can be written as:

$$T = w \cdot a \cdot \cosh\frac{x_A}{a} \tag{1}$$

$$a = \frac{T \cdot cos\theta}{w} \tag{2}$$

where w is the distributed submerged weight, x_A is the horizontal ordinate of the top end point, θ is the departure angle at the top, and a is the catenary coefficient defined by the ratio between the horizontal projection of T and w.

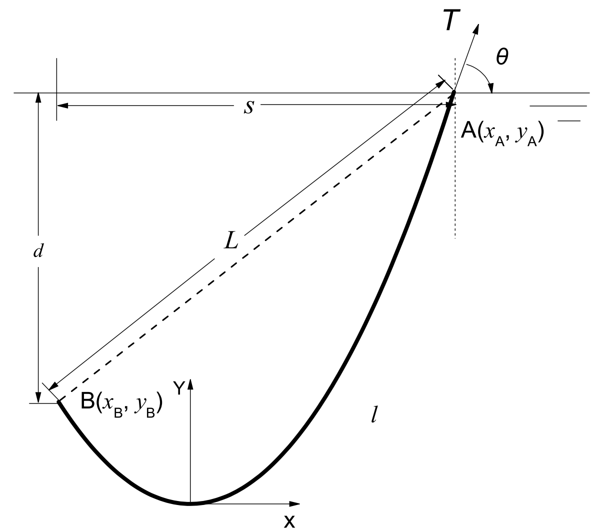

Fig. 2. Equilibrium configurations of the flexible jumper.

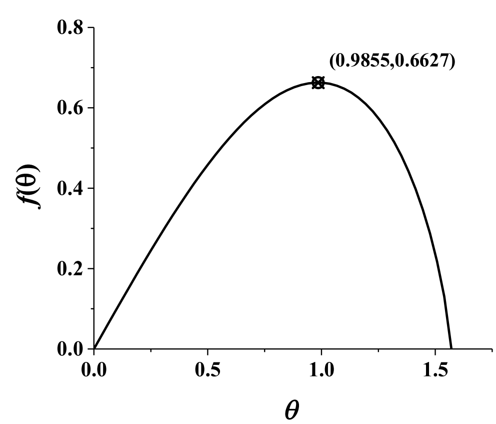

Fig. 3. The relationship between $f(\theta)$ and θ.

Combining Eqs. (1) and (2), the following relation between T and θ can be derived:

$$T = \frac{w \cdot x_A}{\cos\theta \cdot \mathrm{arcosh}\left(\frac{1}{\cos\theta}\right)} \tag{3}$$

Let $f(\theta) = \cos\theta \cdot \mathrm{arcosh}(1/\cos\theta)$, the plot of $f(\theta)$ in Fig. 3 reveals that when $\theta = 0.9855$ rad, $f(\theta)$ gets the maximum value as 0.6627, which also implies that there exists the minimum tension:

$$T_{min} \cong \frac{w \cdot x_A}{0.6627} \tag{4}$$