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A nonlinear mechanical model for deepwater steel lazy-wave riser transfer process during installation

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ABSTRACT

To meet the increasing applications of the deepwater steel lazy-wave riser (SLWR), its installation is a great challenge for SLWR which affects its service performance. This paper is focused on the transfer process during the SLWR installation which is of great importance to the installation feasibility and analysis. A comprehensive mechanical model based on the nonlinear large deflection beam theory for the deepwater SLWR transfer process is developed. The presented model is able to deal with three different stages analysis of the transfer process and the length and tension of the two cables used to lift the riser's pull-head: A&R cables of installation vessel and pull-in cable of production platform. Numerical analysis is conducted to investigate the riser configurations and some important mechanical parameters which exert influences on the riser's performance. The proposed model can be a basic reference to the design and dynamic analysis of deepwater SLWR installation.

1. Introduction

The exploration and production activities of oil and gas have increased dramatically in deepwater areas in recent years [1]. The steel catenary riser (SCR) has been selected for an increasing number of deepwater developments with the advantages of lower manufacturing cost, resistance to high temperature and high pressure, good adaptability to the floating structure's motion, and so on. However, as submerged fields become deeper, catenary configurations present high top tension levels once the suspended length is large. It is generally considered as a crucial challenge for the riser and the flexible joint connecting the riser and the vessel which must sustain a high level hang-off tension transferred from SCR [2,3]. By installing several buoyancy modules to the middle section of a SCR, creating an upward buoyancy force to eliminate partial tension, a steel lazy-wave riser (SLWR) is thus generated and employed as a viable solution in deepwater applications. Compared with the free-hanging catenary configuration, there are a sag bend and an arc bend at the middle section of a typical SLWR, offering substantial riser motion decoupling between the riser top section and the touchdown zone to reduce the top loads and improve fatigue life.

A lot of workers have conducted extensive studies on the SCR including static response, dynamic behavior, pipe–soil interaction and the installation analyses [4–13]. The installation of the pipeline makes influence of the riser's service life and is an important research direction. Many calculations are undertaken to ensure safety before the installation is carried out [14] and then the optimal installation path is chosen. Some experts have done many researches on the installation of the SCR. Duan and Chen [15] performed a comprehensive study of a mechanical model for deepwater SCR transfer process during installation. Duan and Wang [16] developed a new lifting system device for SCR installation used on S-lay vessels and proposed a corresponding installation method.

However, the nonlinear behavior and installation analysis of SLWR have not been exhaustive studied and it still needs to be better and comprehensively analyzed. Li and Chau [17] modeled the suspended part of SLWR as three catenary segments, and focused on the study of dynamic responses which ignored the effect of bending stiffness. Santillan and Virgin [18,19] have presented a systematic study on the lazy-S and steep-S, steep-wave risers and did some experiments to validate the numerical results for varying configurations and conditions. Wang and Duan [20] obtained the numerical solutions of deepwater SLWR behavior based on the nonlinear large deflection theory and some factors are taken into the parametric analysis. Thomas and Benirschke [21] have described the installation engineering challenges for the SLWR and used the commercial analysis tool to simulate the installation, pre-abandonment, recovery and transfer process, but they did not provide the detail model

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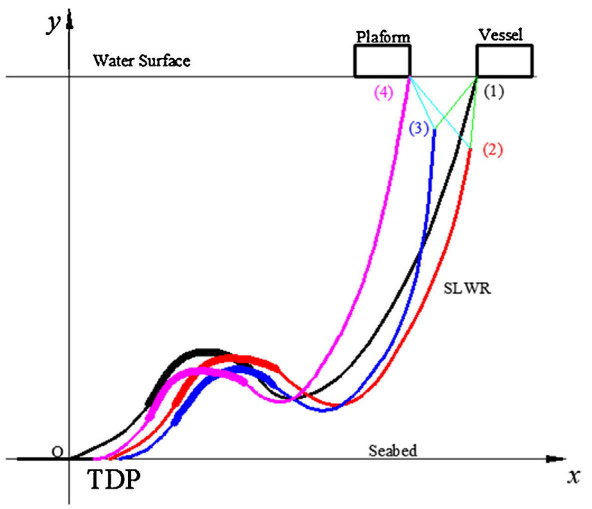

Fig. 1. A schematic presentation of SLWR in transfer.

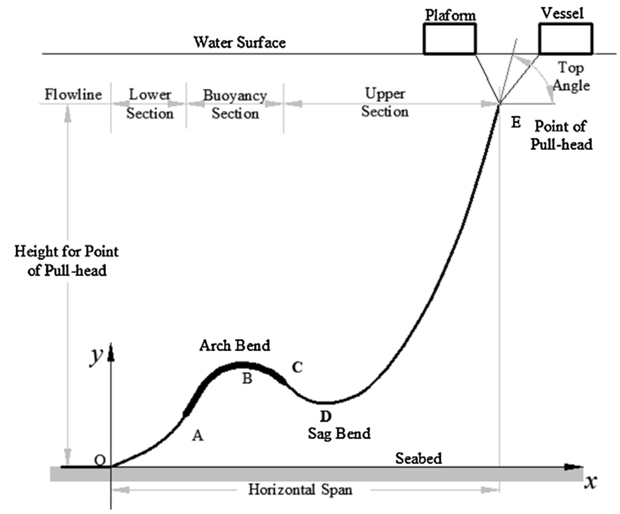

Fig. 2. A schematic presentation of the SLWR model.

of SLWR. Yue and Campbell [22] presented some different kinds of configurations of SLWR, and had researched the empty J-lay installation feasibilities of all configurations.

Transfer process of SLWR (as shown in Fig. 1) is a complex operation in SLWR installation, and the transfer system contains: SLWR, the A&R cable and its installation vessel, the pull-in cable and its production platform. There are three typical stages in a typical transfer process. The three typical stages are as follow: (1) lowering stage (as shown in stages (1) and (2) of Fig. 1): the SLWR's pull-head is hanging on the installation vessel initially, connecting the A&R cable of the installation vessel and pull-in cable of the production platform. Reel out the A&R cable of the installation vessel to lower the SLWR pull-head to the predefined water depth while the riser is lifted merely by the A&R cable. (2) Tension transfer stage (as shown in stages (2) and (3) of Fig. 1): keep the length of A&R cable constant while reel in the pull-in cable of the production platform. The tension transfer process starts while the tension is shared by both cables. Reel in the pull-in cable until the riser is completely lifted by the pull-in cable of the production platform. During the entire tension transfer process, the SLWR is lifted by both cables. (3) Recovery stage (as shown in stages (3) and (4) of Fig. 1): reel in the pull-in cable of the production platform until the pull-head recovers to the platform hang-off point while keep the A&R cable of the installation vessel loosen. The riser is merely lifted by pull-in cable the production platform during this stage.

This paper focuses on the mechanic model of the SLWR transfer process from the installation vessel to the production platform. The nonlinear large deflection beam theory is applied for simulate the SLWR. A MATBLA language numerical program based on the mechanical model is developed to obtain the numerical solutions based on finite difference method. A typical transfer example is been calculated and some conclusions are derived.

2. Nonlinear mechanical model for SLWR transfer process

The following assumptions and simplifications are made for the riser and cables in this work: (1) the analysis is conducted within 2-D plane without considering the torsion. (2) The riser is assumed to be non-extensible, and no rotation is considered at the connection with vessel. (3) The installation weather window is mild in the real installation activities, so it does not consider the wave and current loading. (4) Based on the previous research [20], the pipe–soil interaction mainly affects the fatigue at TDP and the nearby sections while it makes slight influence on the global riser configuration and mechanical parameters. Therefore, the seabed is assumed to be horizontal and rigid without considering the relative slide between the pipeline and seabed. (5) The installation vessel and production platform are at the water surface and the same height from seabed. (6) During transfer process, the A&R cable of the installation vessel and pull-in cable of the production platform are very short, thus their weight and catenary shape are not considered and assumed to be straight. Both the two cables connecting riser's pull-head are suspected to tension without bending moment. (7) The transfer process is very slow, so the entire process can be approximately modeled as many different steps which is in the static condition.

The model will be introduced in detail in the following sections including the mechanical model with governing equations, the geometrical models and associated boundary conditions during different transfer stages.

2.1. Mechanical model for deepwater SLWR transfer process

A SLWR is a special and advanced SCR with a segment of its length equipped with external buoyancy modules, where the distributed upward buoyancy force is greater than the downward gravity force and thus an arch bend is generated, as shown in Fig. 2. A mathematical model for the SLWR installation refers to the methods used in the static analysis of its configuration.

The model is established in the global coordinate system (x, y) with the three sections: lower section, segment O–A; buoyancy section, segment A–B–C and the upper section, segment C–D–E. The origin of the global coordinate system (x, y) is set at point O, which is the TDP. The bottom endpoint O connects to the flowline section which is assumed to be horizontally laid on the rigid seabed at the touchdown zone, while the top endpoint E (namely point of pull-head) is hung by the cables of the installation vessel and the production platform through pull-head. The point B is the peak of the arch bend, namely arch bend point, and its elevation from the seabed is called arch bend point height Y_{arch}. The segment C–D–E, the upper section, presents a catenary shape and a catenary segment is generated around the point D. The point D is the lowest point of the sag bend, namely sag bend point, and its elevation from the seabed is called sag bend point height Y_{sag}. The height from the sag bend point to the arch bend point is the arch bend height $Y_{sag\text{-}arch}$. The higher the value of the arch bend height, the greater the degree of bending of this section. The top angle θ_{top} is defined as the intersection angle between the tangent line and the horizontal line at the pull-head point E. The horizontal span x_{span} is the horizontal distance from TDP to the point of pull-head.