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Response of submarine pipelines to impacts from dropped objects: Bed flexibility effects

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ABSTRACT

Effects of soil–pipe interaction on the response of continuously supported offshore pipelines subjected to transverse impacts caused by dropped objects are studied. For this, the impact on an internally pressurized pipeline resting on a flexible bed has been numerically simulated. The numerical model has first been validated against different sets of experimental data from the authors and a number of researches. A relatively extensive parametric study has then been carried out to examine effects from variations in the pipe geometry, internal pressure, boundary conditions, indentor shape and orientation, embedment depth of the pipe into the soil bed and subsoil mechanical properties on the pipeline response. It has been noticed that the presence of internal pressure results in substantial increase in the impact force. It, however, reduces the denting length, causing the deformation to become spatially more localized. It has also been shown that the flexibility of pipe bed plays an important role in the impact energy dissipation. This effect becomes more pronounced when the internal pressure is relatively low.

1. Introduction

Pipelines are often referred as "lifelines" which indicates that they play an important role in human's life [1]. Over the past 10 years, energy demands have greatly increased, and recent estimates denote that the world energy consumption will rise rapidly over the next 20 years. It means that many additional miles of transmission pipelines will be needed. Thus, the safety of pipelines is likely to become even more important. Pipes might become subjected to heavy accidental transverse loads, which may cause significant damages. The pipes' ability to absorb the applied load/energy and transform it into plastic deformation is of the particular interest in many practical engineering purposes. The response of submarine oil and gas pipelines under transverse load conditions is of particular importance. This is because they are usually laid unburied and an impact could produce catastrophic consequences [2]. Typical examples of transverse impacts on a submarine pipeline, such as those caused by trawl gears, anchors or other dropped objects, are illustrated in Fig. 1.

The subject of transverse impacts on tubular members has received attentions in the literature. Two-dimensional response of metal tubes under transverse (lateral) compressive loads has first been investigated experimentally and analytically in 1963 [3–5]. The transverse load was applied through rigid plates and remained constant along the tube. Reid and Reddy [6] conducted additional research to improve the previous works by taking into account the strain hardening effects. Reid and Bell [7], experimentally investigated the response of steel rings under two diametrically opposed concentrated loads. They also proposed an analytical model to evaluate major parameters which affect the capacity of tubes under transverse compressive loads [8]. Ghosh et al. [9] extended this work to investigate the response of short-length tubes and rings under opposed concentrated loads. Leu [10] examined the two-dimensional collapse of aluminium tubes of various diameter-to-thickness ratios (D/t) under lateral compression between two rigid plates. He considered a nonlinear finite element simulation approach.

Wierzbicki and Suh [11] examined the steel pipe response under a concentrated transverse load in the presence of axial load and bending, through a simplified three-dimensional shell model. They proposed analytical expressions for the denting deformation of the pipe. Hoo Fatt and Wierzbicki [12] analysed tubular members under localized transverse loading, and presented a methodology that converts the problem into an equivalent one-dimensional issue. Zeinoddini et al. [13] numerically investigated the response of free-spanned tubular steel members against static and dynamic transverse loads. In a separate work [14], they adopted a modified

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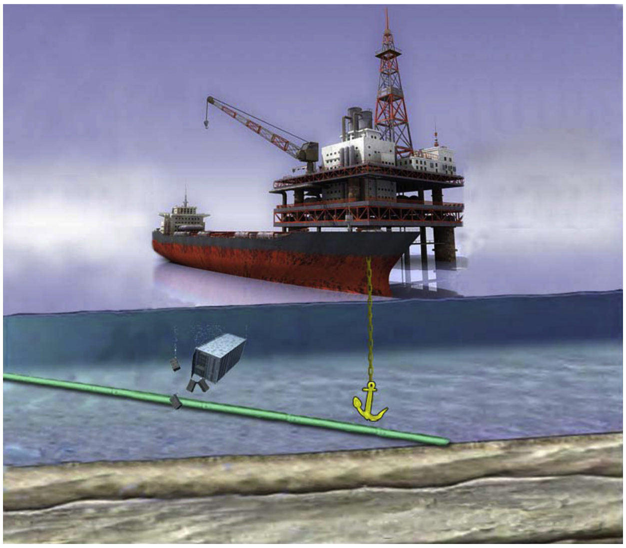

Fig. 1. Transverse impacts on offshore pipelines.

version of the simplified model proposed by Wierzbicki and Suh [11], to analyse pipe response under a single transverse load. Karamanos et al. [2,15] expanded this work to investigate the influence of internal pressure in the collapse of steel tubes due to transverse loads. Interface forces in transversely impacted steel tubes in the presence of axial pre-compressing were also experimentally and numerically investigated by Zeinoddini et al. [16–18]. An experimental study and numerical simulations of pipe-on-pipe impacts were conducted by Yang et al. [19]. Effect of geometrical parameters, material properties and the impact velocity were evaluated. Recently, Zeinoddini [20] has provided an extensive experimental/numerical/analytical review into the dynamic and quasi-static behaviour of steel tubular members under lateral impacts.

Most previous studies either consider a free-span [for example see 8,19,21,22] or a rigid bed [for example see 2,10,15,23,24] condition for the impacted tube. To the best of the authors' knowledge, the effects of the bed flexibility on the response of pressurized tubular members against transverse impacts have not been previously addressed by other researchers. In this study, transverse impact problem in continuously supported offshore pipelines in the presence of internal pressure has been investigated. Quasi-static lateral impacts on tubular members are numerically simulated. Transverse loads are applied through a wedge-shaped indentor. The model has first been verified against different sets of experimental data from the authors and a number of researches. The validated model has then been employed to carry out a relatively extensive parametric study to examine effects from variations in the pipe geometry, internal pressure, boundary conditions, indentor shape and orientation, bed flexibility, embedment depth of the pipe into the soil bed and subsoil mechanical properties on the pipeline response.

2. Model description

Transverse impact problem in the pressurized tubular members has been studied using a 3D finite element model, considering geometrical and material nonlinearities. A general purpose advanced finite element program, ABAQUS [25] has been used. Different parts such as the pipe, the indentor and the pipe bed (Fig. 2) are included in the numerical model. Four-noded reduced integration shell elements are used for modelling of the pipe body. Eight-noded first order solid elements are employed for modelling the indentor, the rigid and flexible beds.

Geometry of the problem is defined based on parameters such as the pipe outer diameter (D), the pipe wall thickness (t), length of the pipe (L), embedment depth of the pipe in the sea bed (e), shape and alignment of the indentor and size of the modelled part of the sea bed. Different shapes, as defined by DNV-RP-F111 [26] are considered for the indentor.

Material properties and geometries of the submarine steel pipe are in the common ranges for the oil and gas offshore pipelines. A linear isotropic strain hardening model has been considered in the plasticity model of the steel material. This proves to be more suitable for quasi-static monotonic loadings. The related yield function is dependent to the equivalent pressure stress. This model has been used with a von Mises yield surface criterion. It has a non-associated flow rule. A constant hardening modulus equal to 1% of the steel elasticity modulus has been considered for the pipeline steel in the parametric studies (Section 4). The yield stress and the hardening modulus for the validation models (Section 3) have been selected based on the test data reported and the steel grades. These are reported later in each case. Based on a parametric study, the element size in the longitudinal direction and around the impact area is chosen equal to approximately 0.12 of the pipe diameter. This was found to provide an economical and reasonably accurate simulation for the impact problem. Details of the model validation are presented in Section 3. A coarser mesh is employed for other areas of the tubular member.

A frictionless contact algorithm is employed to simulate the interactions between the pipe outer surface and the wedge-shaped

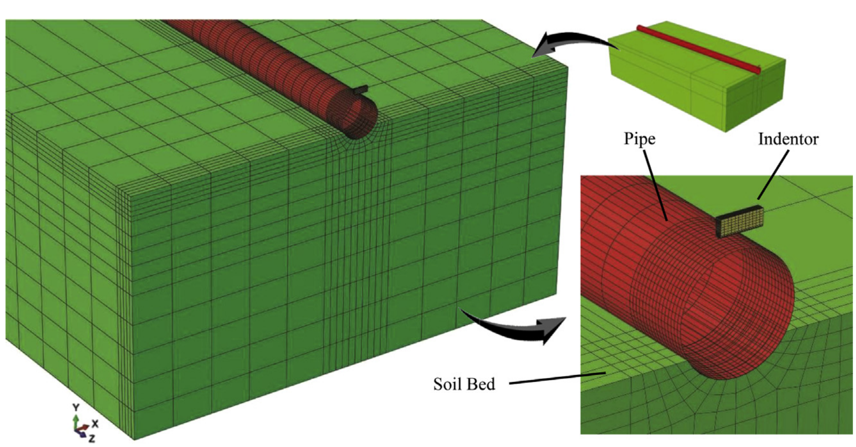

Fig. 2. General configuration of the numerical model.