Ocean Engineering 152 (2018) 26–35

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Determinate dimension of numerical simulation model in submarine pipeline global buckling analysis

Run Liu *, Chengfeng Li

State Key Laboratory of Hydraulic Engineering Simulation and Safety, Tianjin University, Tianjin 300072, China

ARTICLE INFO

Keywords:
Submarine pipeline
Pipeline global buckling
FEA method
The critical length
Pipe model length

ABSTRACT

Numerical simulation is an effective method to study the global buckling of submarine pipelines under high temperature and high pressure. The length of the pipeline model has a significant effect on the global buckling during the numerical simulation. This paper outlines the global buckling regularity of different pipes of various lengths and proposes a method to determine the pipe model length for the numerical simulation of pipe buckling by using theoretical analysis and the FEA method. A method of calculating the pipeline's critical length and upper-limit critical length is proposed based on the characteristics of the short pipe and long pipe. The numerical analysis results indicate that the global buckling amplitude of the short pipe increases with the length of the pipeline model. Therefore, the model length of a short pipeline in the numerical simulation should be equal to the actual length of the research object. In contrast, the buckling amplitude of pipes with a length greater than the critical length does not vary with the pipe length. Thus, the model length only needs to be equal to or slightly larger than the critical length. A method to determine the length of the pipe model for the numerical simulation of pipe buckling is proposed for various pipelines with different laying modes in practical engineering.

1. Introduction

Submarine pipelines are widely used in the development of offshore oil and gas resources and they are increasingly required to operate under high temperatures and pressures, which are prone to cause the global buckling deformation of pipelines. Scholars have performed a considerable amount of research on the global buckling of submarine pipelines. As early as Hobbs (1984) deduced the classical analytical solution for the vertical and lateral global buckling of an ideal submarine pipeline. In Taylor and Gan (1986) derived an analytical solution to the global buckling of pipes with single-arch and double-arch geometric initial imperfection based on Hobbs (1984) analytical solution. The analytical solution can accurately reflect the global buckling mechanism in theory but can only be applied to the analysis of pipeline buckling for a small deformation, as it presents many limitations in the study of post-buckling with a large deformation in the non-linear pipeline because a small slope angle and linear elasticity are assumed. With the rapid development of computer technology in the past 40 years, the finite element analysis (FEA) method based on PIPLIN-III, PlusOne, ABP, UPBUCK and ABAQUS finite element software has been applied to the global buckling of submarine pipelines. The large-scale commercial software (ABAQUS, 2008) has been most widely used; many valuable calculation results have been obtained using this software. Several researchers have described the pipe buckling mechanism using the FEA method based on ABAQUS such as Miles and Calladine (1999), Bruton and Carr (2005), Klæbo and GiertsenSævik (2008), Li (2011) and Karampour et al. (2013). Numerical simulations based on the Pipeline Project of the Gulf of Mexico and the South China Sea were carried out by Jukes et al. (2008), Ramaiah and Bong (2013) and Carpenter (2015). Several investigators Sriskandarajah et al. (2001), Peek and Yun (2009), Jukes et al. (2009), Sun et al. (2011), and Liu et al. (2014) have used many different methods to numerically simulate global buckling; the static method, the Riks method and the dynamic method are the main methods used to study the global buckling of a subsea pipeline when using ABAQUS.

Many results of FEA study on the global buckling of subsea pipelines demonstrate that FEA method is critical for the theoretical research and engineering guidance of pipeline. Accurately predicting the pipeline global buckling and its responses relies on the FEA model being constructed correctly. Therefore, a well-developed FEA model should incorporate the physical and mechanical parameters of the pipeline and subsoil, as these parameters have a significant influence on the global buckling deformation. The effects of various parameters on the numerical simulation of pipeline global buckling have been studied. Several researchers investigated the influence of a geometric initial imperfection

* Corresponding author.
E-mail address: liurun@tju.edu.cn (R. Liu).

https://doi.org/10.1016/j.oceaneng.2018.01.014
Received 11 April 2017; Received in revised form 29 September 2017; Accepted 3 January 2018

on the buckling of a submarine pipeline when using the FEA method Sriskandarajah et al. (1999), Suzuki et al. (2006), Chaudhuri et al. (2008), Arjomandi and Taheri (2009), Hong et al. (2015). Bruton et al. (2006, 2008, 2009) noted the significant effect of the pipe-soil interaction on the numerical simulation of pipeline global buckling, as it is the most uncertain parameter in pipeline design. In Haq et al. (2013) analysed the influence of various parameters, such as the ratio of the outside diameter and the wall thickness of the pipeline (D/t), pipe out of straightness (OOS), internal and external pressure, lateral and axial friction, operating temperature and installation depth, on the numerical simulation of pipeline global buckling.

Because an accurate simulation of pipeline global buckling relies on correct parameters, many studies have focused on the parameters relevant to pipeline global buckling when using the FEA method. This article focuses on the impact of the pipe model length on the numerical simulation of pipeline buckling and proposes a method to determine the length of the pipeline model, as few studies have systematically investigated this topic. In Christensen (2005) first proposed the concept of a "short" pipeline and noted that the result is conservative for short pipelines when using the Hobbs equations for "very long" pipelines to assess the global buckling. Walker et al. (2010) assessed the influence of the material properties, friction coefficient and the virtual anchor spacing (VAS) length on the axial strain of the buckling pipeline using the FEA method based on ABAQUS. He concluded that the pipeline buckling strain increases with the VAS length by analysing the relationship between axial strain and VAS length with different materials and under different friction coefficients. The cases of short flowlines, medium flowlines and unbounded pipe in pipe systems were presented by Maoût et al. (2011), as he holds the view that the infinite mode buckle shape does not accurately reflect the lateral buckling mechanism. The buckling axial force of an unbounded pipe and medium and short flowlines was given, and the expression of the axial force at the anchor was deduced. An equation for the summation of the pipe buckling length and pipe sliding length was deduced by Liu et al. (2015) in 2016 using the energy method. The derivation of the equations is illustrated through an example of a pipeline with a single arch initial imperfection undergoing third-order global buckling. These studies show that several researchers have investigated the effects of the pipeline length on the global buckling and found that pipeline buckling is quite sensitive to the pipeline length. Therefore, it is critical to propose a method to determine the length of the pipe model for numerical simulations of pipe buckling.

This paper includes three main sections. The first section provides the definitions of "critical length", "long pipe" and "short pipe" by analysing the law of the axial force distribution of the pipeline proposed by the classical analytical solution and establishes a method for calculating the critical length and upper-limit critical length. The second section focuses on the buckling regularity of the long pipe and short pipe by simulating several different pipeline models with various lengths based on the 3D-Explicit Method. The last section proposes a method to determine the length of the pipe model for the numerical simulation of pipe buckling and demonstrates how it can be used for pipelines with different laying modes.

2. Definitions of the "critical length", "long pipe" and "short pipe"

The Hobbs equation (Hobbs, 1984), which has been used for years to evaluate the susceptibility of pipelines to global buckling, assumes that the pipeline is infinitely long. The deformation length of the pipe is assumed to be divided into two parts: the buckling length L and sliding length L_s. As shown in Fig. 1, the axial force at the end of the sliding section to infinity is p_0, which is the axial pressure of the pipe in the fully constrained state at the design temperature. The axial force of the pipe buckling section is p.

The infinite model introduced by Hobbs is infeasible when using the FEA method to study the global buckling of the pipeline. The length of the pipe model can be determined by difference in the axial forces of buckling pipelines of different lengths. Next, a pipe with two free ends and an initial imperfection in the middle is used as an example to analyse the relationship between the pipe length L_m and axial force distribution. Three basic forms of pipe axial force are shown in Fig. 2. For the first basic form of the pipe axial force, as shown in Fig. 2(a), the pipe is sufficiently long. The buckled pipe can be divided into four parts based on the axial force distribution: the buckling section L, slip section L_s, fully constrained section L_d and free-end of the axial force releasing section L_c. The maximum axial force p_m, equal to p_0, appears in the fully constrained section. When the pipeline length decreases from sufficiently long, the length of the fully constrained section L_d decreases equivalently, and the length of the other three sections does not change. The pipe axial force becomes the second form when the length of the fully constrained section L_d decreases to zero, as shown in Fig. 2(b). The buckled pipe can be divided into three parts: the buckled section L, slip section L_s and free-end axial force releasing section L_c. The maximum axial force p_m is equal to p_0. When the pipe length is reduced further, the lengths of the pipe buckling section l, slip section l_s and free-end axial force releasing section l_c decrease, and L_d is equal to zero. As shown in Fig. 2(c), the maximum axial force p_m is less than p_0.

From the analysis above, the axial force form in Fig. 2 (b), characterized by $L_d = 0$ and $p_m = p_0$, is the critical form of the axial force distribution of pipelines with different lengths. Therefore, this paper defines this length as the "critical length", denoted as L_t. A pipe with a length greater than the critical length is designated a "long pipe," and a pipe with a length less than the critical length is designated a "short pipe". The maximum axial force p_m of the long pipe is equal to p_0 and appears at the end of L_s (e, f), which is defined as the anchor. The distance between the two anchors is referred to as the anchor spacing. The maximum axial force p_m of the short pipe is less than p_0 and appears at the end of l_s (e, f), which is defined as the virtual anchor. The distance between the two virtual anchors is referred to as the virtual anchor spacing.

3. Methods to determine the pipeline's critical length and upper-limit critical length

Critical length is an important basis for assessing whether a pipeline is considered a long pipe or short pipe. The method for determining the critical length is illustrated through an example of a single insulation pipe

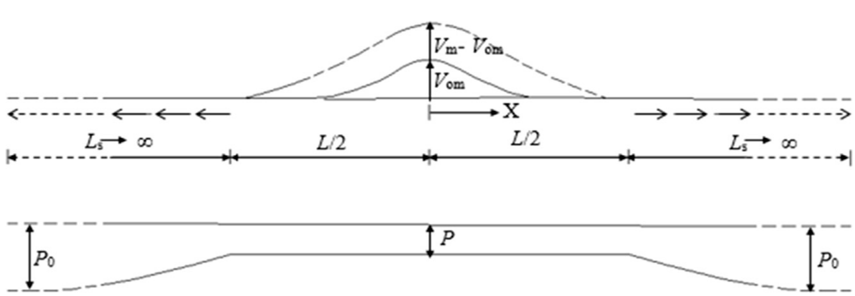

Fig. 1. Axial force distribution of an infinite pipeline by classical analytical solutions.