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Evaluation for Allowable Span Length of a Submarine Pipeline Considering VIV Hysteresis Effect

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Vortex-induced vibration (VIV) is one of the main causes of fatigue failure of submarine pipelines under the action of ocean currents. A reasonable evaluation for the allowable (maximum) length of a pipeline span is vital for the avoidance of VIVs. The length of a pipeline span can alter its natural frequency and further influence the corresponding critical reduced velocity for the onset of VIVs. Nevertheless, the experimental observations indicated that the VIV hysteresis could be significant under the natural flows with increasing/decreasing velocity cycles, especially under the wall-proximity conditions. A case study is then performed to examine VIV hysteresis effects on the allowable span length of submarine pipelines. A dimensionless parameter is proposed and derived for characterizing such hysteresis effect on the allowable span length. It is indicated that lower-critical span lengths are much smaller (up to more than 20%) than those estimated with the commonly used upper-critical flow velocity. As such, the VIV hysteresis effect should be taken into account for determining the allowable span length of submarine pipelines.

INTRODUCTION

Submarine pipelines have been widely employed for transporting offshore oil and gas from subsea wells to platforms or onshore processing facilities, thereby being regarded as the lifelines of offshore oil and gas industries. An uneven seabed is always encountered for long-distance laid pipelines, especially while oil and gas exploitation is currently moving toward deep waters. Meanwhile, a partially embedded pipeline could be suspended as a result of tunnel erosion under the action of ocean currents (Sumer et al., 1988; Gao and Luo, 2010; Gao, 2017). As such, free-spanning pipelines—that is, some sections of a long pipeline untouched with the underlying seabed—are frequently occurring and even inevitable in the subsea environments (see Det Norske Veritas and Germanischer Lloyd, 2017).

Structural failure may occur because of overstress from static loads, fatigue failure from dynamic loads as a result of vortex-induced vibrations (VIVs), and severe damage as a result of third-party activities (such as ship anchoring operation, trawling for fishing, etc.) (Rezazadeh et al., 2010; Xing, 2011; Shittu, 2012). In the case of a heavy object falling onto a free-span pipeline, both the impulse impact and the ramp impact while the object staying on the pipe would dramatically affect the structural responses, which was modeled and analyzed by nonlinear three-dimensional finite element method (Chung and Cheng, 1996). There are quite a few records of structural failures related to pipeline free spanning, necessitating an increasing attention to VIV analyses. The schematic diagram of a pipeline free spanning is given in Fig. 1. As illustrated in this figure, the pipeline free span features with some scenarios, such as the span length L, the gap between the pipeline and the seabed e, etc. Under the action of ocean currents, the submarine pipeline may vibrate as a result of vortex shedding (see Gao et al., 2006; Yang et al., 2008). The natural frequency of pipeline span is a key factor for identifying the allowable or critical spanning length for the onset of VIVs (Choi, 2001; Sumer and Fredsøe, 2006; Shittu et al., 2019). This study aims to reexamine the existing practice on the allowable length of free spanning, which can be referenced in the DNV-GL recommended practice "Free spanning pipelines" (see Det Norske Veritas and Germanischer Lloyd, 2017).

The critical flow velocity for the onset of VIVs can be described with the reduced velocity (Vr) (see Blevins, 1990). $Vr = U/f_n D$, in which U is the flow velocity normal to the pipeline, f_n is the natural frequency of the pipeline span, and D is the outer diameter of the pipeline. A reasonable evaluation for the allowable span length can efficiently prevent the frequency of hydrodynamics forces from approaching the corresponding natural frequency and thereby avoiding the onset of VIVs. The allowable span length was occasionally evaluated for the case of in-line VIVs (Guo et al., 2014); nevertheless, the potential risk to the pipeline structure failure of cross-flow VIVs is generally much more severe than that of in-line VIVs (King, 1977; Tsahalis, 1984; Shittu et al., 2019). As such, the critical span length has been commonly evaluated for the occurrence of cross-flow VIVs.

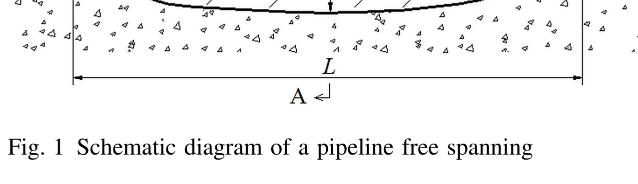

Fig. 1 Schematic diagram of a pipeline free spanning

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KEY WORDS: Submarine pipelines, vortex-induced vibration, critical reduced velocity, hysteresis effect, allowable span length.