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Unburied Offshore Pipeline Stability Analysis Based on Non-linear Relationship Between Pipeline and Carbonate Soil

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ABSTRACT

The purpose of this paper is to investigate the stability of an unburied offshore pipeline resting on carbonate soil under severe storm condition. Pore pressure accumulation and pipeline movement during cyclic loading caused by waves and currents are numerically investigated. Both drag and lift forces are numerically obtained for 100 years return period storm condition using the Fourier decomposition method. Non-linear spring element is used to simulate a slip phenomenon between pipeline and seabed. The effects of both bi-linear and tri-linear spring element models on the pipeline movement and pore pressure response are numerically investigated. Pipeline movement during cyclic loading greatly depends on the mechanical properties of non-linear spring element.

KEY WORDS: Pipeline stability analysis; non-linear spring element; pipeline movement; carbonate soil; 2-D non-linear FEM; 100 years return period storm condition.

INTRODUCTION

It is very important in pipeline design to investigate the stability of an unburied offshore pipeline under severe storm condition. The cyclic movement of pipeline due to drag and lift forces caused by waves and currents will lead to pore pressure build up in the seabed around the pipeline. The pore pressure accumulation will reduce the effective strength of the seabed soil and degrade its bearing capacity. In particular, an increase of horizontal displacement of the pipeline may lead to a sudden break-out, which has a serious influence on the safe operation of the pipeline. It is therefore very important for design engineers to evaluate the stability of an unburied offshore pipeline by considering pore pressure accumulation in the seabed soil around the pipeline under severe storm condition. This can be achieved by carrying out numerical analyses (Taiebat and Carter, 2000; Zhang et al., 2001; Takatani, 2005a; 2005b; 2006; 2007) and simulations (Zhang et al., 2002; Takatani and Randolph, 2003) based on experimental data of pore pressure build up during horizontal cyclic loading.

The purpose of this paper is to investigate the stability of an unburied offshore pipeline resting on carbonate sand under severe storm condition in consideration of the seabed characteristics such as the stiffness of seabed. It is well known that a carbonate soil has so complicated characteristics because of high compressibility and crushability due to high void ratio. In this paper, the mechanical properties for carbonate soil with the relative density Dr=60% are evaluated from the liquefaction intensity curve, that is, the effective stress ratio vs. the number of cycles.

In general, a non-linear relationship between pipeline and seabed plays an important key role in a pipeline-seabed interaction analysis. Takatani (2005a; 2005b; 2006; 2007) has conducted some pipeline-seabed interaction finite element analyses by using a joint element to simulate a slip phenomenon between pipeline and seabed. Verley et al.(1994) has proposed a force-displacement model of non-linear relationship for pipeline–seabed interaction problem. In this paper, non-linear spring element is employed for a non-linear relationship between pipeline and seabed, because there seems to be a need for the comparison study concerning the non- linear spring element model and the joint element one. The stiffness of spring element may be replaced by tangential stiffness between pipeline and seabed, which is used in the joint element model.

An advanced two-dimensional non-linear finite element method is used for a pipeline-seabed interaction problem. The pipeline with 1.0m diameter is assumed to be located at 60m water depth and 0.25m for its initial depth, while the seabed is assumed to be a carbonate sandy soil. Using the Fourier decomposition method, both drag and lift forces acting on an unburied offshore pipeline are numerically obtained for 100 years return period storm condition whose maximum significant wave height and wave period are 13.2m and 13.5s, respectively. Pore pressure accumulation and pipeline movement during cyclic loading in the long time are numerically investigated through some numerical examples taking account of a force-displacement relationship of non-linear spring element.

Although it is well known that the wave-induced cyclic shear stress directly affects the seabed liquefaction, the pore pressure accumulation is assumed to be caused by only cyclic pipeline movement due to wave currents under severe storm condition, and the effect of the wave-induced cyclic shear stress on the seabed liquefaction is neglected in this paper because the pipeline is assumed to be located at 60m water depth.