Sensitivity Analysis on Key Parameters of Deep-sea Pipeline with Sleepers

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ABSTRACT

The thermal additional stress generated in the pipeline heating process cause large lateral global buckling deformation. Excessive lateral displacement will harm the safety of pipeline systems. For controlling the lateral buckling, the sleepers are laid under the deep-sea pipelines to in practice. This paper analyzed the sleeper treatment method and proposed key parameter sensitivity analysis. Different sleeper’s height, initial pipeline offset and the distance between sleepers were simulated.¹

INTRODUCTION

Taylor and Gan [1] considered soil resistance in the pipeline deformation process and deduced the analytical solution for the first - and second - order buckling models of submarine pipeline, which had geometric initial imperfection in the vertical or lateral direction. Taylor [2] provided three different models of pipeline imperfection based on the theory and experimental research on vertical buckling and obtained the calculation equation for critical buckling load, but didn’t take the influence of residual stress caused by geometric initial imperfection on the global buckling. Junes [3] established nonlinear finite element models for buried pipelines and simulated the vertical buckling of submarine pipeline with geometric imperfection considering nonlinear constraints of soil foundation. David [4] revealed the global buckling mechanism based on nonlinear finite element analysis and

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emphasized that the axial force on internal pipeline, geometric initial imperfection of pipeline, and soil resistance are the main factors controlling the buckle shape.

Base on the pipeline project of Angola oil field in West Africa Sea, the paper simulated the implementation effects of signal sleeper method. A reliable simulation model calibrating was established. And the influence of key parameters on controlling effect, sleeper’s height, initial pipeline offset and the distance between sleepers, were analyzed respectively.

BUCKLING CONTROLLING WITH SLEEPERS

The lateral global buckling controlling with sleepers takes effect by laying several sleepers at the pre-set site in the design pipeline routine before pipeline installation. The sleepers create a un-touch-down pipeline part and reduce the soil resistance. The critical global buckling force of this upheaval pipeline part will be much smaller than the untreated pipeline parts. Figure 1 shows the configuration of pipeline lying on sleeper. The vertical height of sleeper is \( H \), and the distance between sleepers is \( a \). In order to trigger lateral buckling and avoiding triggering vertical buckling, the pipelines are usually set with an initial offset. The initial lateral offset of pipeline is \( L \).

The upheaval part added initial offset can trigger the lateral global buckling, avoiding the unexpected buckling at uneven seabed, and reduce the pipeline damage risk.

CASE STUDY

Details of Engineering Case

The oil field locates at Angola in West Africa Sea, and the water depth is from 1150 m to 1500 m. The detail pipeline parameters are displayed in Table 1.
TABLE I. PIPELINE PARAMETERS.

<table>
<thead>
<tr>
<th>Outer diameter ($D_0$) (mm)</th>
<th>Wall thickness ($t$) (mm)</th>
<th>Elastic modulus ($E$) (GPa)</th>
<th>Pipeline density ($\rho_s$) (kg/m$^3$)</th>
<th>Thermal expansion coefficient ($\alpha$) ($^{\circ}$C)</th>
<th>Poisson's ratio ($\nu$)</th>
<th>Soil resistance coefficient ($\phi$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>323.9</td>
<td>19.1</td>
<td>206</td>
<td>7850</td>
<td>1.1×10$^{-5}$</td>
<td>0.3</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Key Parameters Sensitivity Analysis

Numerical simulation models with different values of key parameters, sleeper’s height $H$, pipeline initial offset $L$ and distance between sleepers $a$, are calculated to reveal the influence of each key parameter on the buckling deformation.

1) Sleeper’s height $H$

Figure 2(a) shows the impact of sleeper’s height on critical buckling force. The pipeline with single sleeper at one pre-set site and pipeline with double sleepers at one pre-set site are considered.

Figure 2(a) shows that the critical buckling force decreases with the increasing sleeper’s height and increases with the increasing wall thickness. The critical buckling forces for all pipelines with sleepers are less than pipeline without sleepers. That is to say, the sleepers can effective trigger the lateral global buckling and increasing the sleeper’s height properly can enhance the effect of sleepers. While the pipeline with excessive high sleeper has larger free span length, the free span will produce structural vibration under the action of ocean currents, threatening the pipeline safety.

2) Pipeline initial lateral offset $L$

The relationship between critical buckling force and the initial offset is shown in Figure 2(b).

(a) different sleeper’s heights

(b) different initial offsets

Figure 2. The critical buckling force of pipeline with different sleeper’s heights and initial offsets.
Figure 2(b) shows that the critical buckling force decreases with the increasing pipeline initial offset, increases with the increasing wall thickness. Pipeline with large initial lateral offset and small wall thickness is much easier to exhibit lateral global buckling.

(3) Distance between sleepers

The distance between two sleepers at one pre-set site (as the Figure 1 (b) shows) is a. Figure 3 shows the relationship between critical buckling force and the distance between two sleepers.

Figure 3 reveals that the critical buckling force reduces with the enlarging sleepers’ distance and the reducing rate is relative constant. The critical buckling force rises with the increasing wall thickness, and the rising rate is little affected by the sleepers’ distance. Pipelines with three different sleepers’ distances have almost the same rising rate. Like the sleeper’s height, excessive sleepers’ distance also may cause the structural vibration, and the reasonable sleepers’ distance value should be chose.

CONCLUSIONS

This paper analyzed the global buckling controlling method based on an engineering case. The pipelines with sleepers of different key parameters are simulated, and the main conclusions are as followed.

(1) The critical buckling force reduces with the rising sleeper’ height, but for all pipelines simulated in this paper, the critical buckling force of all pipelines with sleeper are smaller than pipeline without sleeper.

(2) The critical buckling force reduces greatly with the increasing initial lateral offset. The influence of wall thickness on critical buckling force reduces with the increasing initial lateral offset.
(3) The critical buckling force reduces with the enlarging sleepers’ distance, and
the rising rate is little affected by the sleepers’ distance. Pipelines with three
different sleepers’ distances have almost the same rising rate.

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