Study of sleeper’s impact on the deep-water pipeline lateral global buckling

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Abstract. Pipelines are the most important transportation way for offshore oil and gas, and the lateral buckling is the main global buckling form for deep-water pipelines. The sleeper is an economic and efficient device to trigger the lateral buckling in preset location. This paper analyzed the lateral buckling features for on-bottom pipeline and pipeline with sleeper. The stress and strain variation during buckling process is shown to reveal the impact of sleeper on buckling.

1. Introduction
Pipeline system is widely used in offshore oil development. In operation, pipelines are applied high temperature and pressure (HP/HT) to transport the oil. Due to the restricted of seabed soil, the pipeline cannot expand freely under HP/HT. As a consequence, large additional stress accumulates in the cross-section of pipelines, and finally pipeline occurs lateral global buckling. Unexpected and uncontrolled lateral global buckling may harm the safety of pipeline systems, and this kind of global buckling should be avoided.

There are two major kind of buckling control method, to prevent the global buckling or to trigger global buckling in preset location. The former one which can also be called prevention method is usually implemented by (1) precooling the transported substance to reduce the additional stress; (2) enhancing the flexural rigidity of pipeline by using pipe-in-pipe or increasing the tube bundle; (3) adding traction devices to produce the pretension. The other method controlling the buckling in a reasonable lateral displacement mainly has three implements: the sleepers, snaked-lay pipeline and distributed buoyance devices. The latter buckling control method is low-cost but facing more design challenge in practice than the former prevention method, and it has more potential in deep-water oil development.

This paper analyzed the lateral global buckling for on-bottom pipeline and pipeline with sleeper based on the data from an engineer case locating in Western Africa. The distribution and variation of stress is shown to reveal the influence of introducing the sleepers into pipeline systems.

General situation of the engineer case
This case locates in the Western Africa, and the operation water depth is about 1150 - 1500 m. The specific parameters of pipeline are shown in Table 1.
Table 1 Pipeline design parameters

| Outer diameters D/mm | Wall thickness t/mm | Modulus of elasticity E/GPa | Steel’s density $\rho$/kg-m$^{-3}$ | Thermal expansion coefficient $\alpha$ / C$^{-1}$ | Poisson's ratio $\nu$ | Soil resistance coefficient $\varphi$ | Steel’s yield strength $\sigma_s$/MPa |
|---------------------|---------------------|----------------------------|------------------------------------|---------------------------------|----------------|---------------------------------|---------------------------------|
| 323.9               | 19.1                | 206                        | 7850                               | 1.1×10$^{-5}$                  | 0.3            | 0.4                             | 520                             |

The variation of pipeline’s temperature and pressure since the pipeline system is put into use is displayed in Figure 1 and Figure 2.

![Figure 1](image1.png)  
**Figure 1** Variation of temperature

![Figure 2](image2.png)  
**Figure 2** Variation of pressure

The single sleeper method is used in practice. Every preset buckling triggering location places one large diameter (usually 1 m) tubular sleeper. The sketch of sleeper is shown in Figure 3.
The symbol $H$ represents the vertical height of the sleeper. The symbol $L$ is the lateral offset of pipeline, and $L_0$ is the length for the pipeline segment which does not touch seabed.

2. The data monitoring for pipeline with sleeper and on-bottom pipeline
The relative data is monitored and analyzed since the pipeline is put into use. Figure 4 shows the buckling form of pipeline applied a sleeper. The yellow structure is the sleeper, and the gray line is the pipeline laying routing. The profile of the post-buckling pipeline is the red one.

The distribution of axial strain of pipeline with sleeper and on-bottom pipeline are shown in Figure 5.
Figure 5 shows the monitoring data for pipeline with a sleeper and on-bottom pipeline. Comparing the two figures, we can see that the axial strain of on-bottom pipeline is larger than pipeline with a sleeper. The peak value of on-bottom pipeline and pipeline with a sleeper are -0.137 % and -0.125 % respectively. The axial strain of on-bottom pipeline is 9.6% larger than the pipeline with a sleeper.

The distribution of stress along the pipeline for the two kinds of pipeline under several heating-cooling cycles is shown in Figure 6.
From Figure 6 we can see that the peak stress for pipeline with a sleeper is 232 MPa in operation. The stress of pipeline with sleeper under incomplete shut-down state is far more less than pipeline under complete shut-down. The peak stress for on-bottom pipeline is 321 MPa, much larger than pipeline with a sleeper, increasing about 38%.

3. Conclusion
The monitoring data reveals that the stress and strain for pipeline with a sleeper is smaller than on-bottom pipeline. The reasonable installation of the sleeper triggers lateral global buckling accurately in the pre-set location, and obviously reduces the stress and strain after occurring lateral buckling at the same time. The sleeper can control lateral global buckling effectively.

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