Study on snaked laying method and the influence to control lateral buckling

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Abstract. The snaked laying is an effective method to control the submarine pipeline lateral buckling and widely used in the pipeline projects. In order to control the lateral buckling, the snaked lay method is investigated theoretically and numerically. Because of the special configuration of the snaked laying pipeline routine, the lateral global buckling can be easily triggered with a small compressive stress and the bending stress on the pipeline cross-section can be maintain at a low level. This paper analysed the impact factors of snaked laying pipeline on the lateral global buckling especially the laying wavelengths, amplitudes of curve and curve shapes. And the comparison between snaked laying and regular laying pipeline are discussed.

1. Introduction

Submarine pipelines play an important role in offshore oil development engineering. High temperature and pressure are applied on the pipeline to keep the oil flowing in the pipeline. High temperature and pressure cause large additional stress, and lead to the lateral global buckling. Excessive bending moment will harm the integer of pipeline system [1].

Uncontrolled lateral buckling displacement will harm the safety of pipeline systems. In order to control the lateral global buckling, the snaked laying method was proposed. Preston et al. (1999) [2] summarized the methodology adopted and the analysis performed to define an acceptable as-laid pipeline geometry. The snaked laying method has succeeded in practice in many projects such as the Penguins project (Matheson et al (2004) [3]). Further development of the snaked laying concept is presented by Run sag et al (2008) [4], Li et al. (2008) [5] compared snaked laying method with other laying techniques to reveal the benefit of snaked laying method. Rathbone et al (2008) [6] carried out a parameter study to investigate the influence of snake laying geometry on the critical buckle initiation force and post-buckling responses. LIU (2012) [7] proposed a new shape of snaked-lay pipeline based on numerical analysis with ANSYS software. Wang et al. (2015) [8] proposed a new shape of snaked laying curve based on combining genetic algorithm (GA) and finite element analysis. LIU (2015) [9] discussed the effect of distance between two snaked-lays on lateral deflection, bending moment and strains.
The special configuration of the snaked laying pipeline routine brings the benefit of releasing additional stress and controlling global buckling bending stress at the same time. Thus, studying the snaked laying pipeline configuration can optimized the pipeline system design. This paper analyzed the impact factors of snaked laying pipeline on the lateral global buckling especially the laying wavelengths, amplitudes of curve and curve shapes. And the comparison between snaked laying and regular laying pipeline are discussed.

2. Snaked Laying Method

The snaked laying pipeline is designed to lay with several zigzag horizontal imperfections. This laying method can avoid pipeline from laying on the severe seabed zone, such as uneven seabed or seabed erosion area, and trigger the lateral global buckling at the crown of the zigzag horizontal imperfections to release the large compressive stress. The configuration of the zigzag imperfection is the key influence factor for the stress and deformation distribution of the post-buckling pipeline. Figure 1 shows the typical snaked laying pipeline routine.

As the Figure 1 shown, the snaked laying pipeline can be divided into two categories: the straight segment and the arc segment. Part ab, part cd and part ef are the straight segment; Part bc and part de are the arc segment. The straight distance between point a and point f is named as the laying wavelength L. The distance normal to the symmetry axis of laying routine (straight line af) for the endpoints of the arc (point b, point c, point d and point e) is named as the amplitudes of curve V. The straight distance between two point on a same arc (such as distance between point b and point c, or distance between point d and point e) is named as the laying chord length β. Based on these three basic parameters (laying wavelength L, amplitudes of curve V and laying chord length β), the configuration of the snaked laying pipeline could be determined. The parameter sensitivity analyses are carried out to reveal the influence of the three parameters. Pipeline parameters are shown in Table 1.

| Outside diameter D/m | Wall thickness t/m | Density ρ/kg·m⁻³ | Elasticity modulus E/N·m⁻² | Thermal expansion coefficient α/°C⁻¹ | Poisson's ratio ν | Temperature difference Δt/°C | Yield strength σy/MPa |
|----------------------|-------------------|------------------|--------------------------|-------------------------------|---------------|-----------------------------|------------------|
| 0.3239               | 0.0127            | 7850             | 2.06×10¹¹                | 1.1×10⁻⁵                     | 0.3           | 200                         | 448              |

ABAQUS/Explicit method was used for simulation. The pipeline was modeled with PIPE 31 elements, and the soil was simulated with S4R elements. The bottom of soil is fixed. The vertical interaction between pipeline and soil is simulated with “hard” contact, allowing separating but cannot
penetrate into each other. The lateral interaction between pipeline and soil is simulated with “penalty” method. The soil resistance on the pipeline is calculated as the product of the penalty coefficient and the vertical contact force. The typical lateral buckling displacement plot contour is shown in the Figure 2.

3. The Impact Of Key Configuration Parameters
The parameter sensitivity analyses are carried out to reveal the impact of the three key configuration parameters (laying wavelength $L$, amplitudes of curve $V$ and laying chord length $\beta$) on the post-buckling pipeline.

3.1. The impact of laying wavelength $L$
The snaked laying pipeline with 3200 m laying wavelength and 4000 m laying wavelength were simulated, and the bending moment and the axial force of the cross-section with largest lateral displacement are shown in Figure 3.

![Figure 2. The lateral buckling displacement plot contour for snaked laying pipeline](image)

![Figure 3. Deformation for snaked laying pipeline with different laying wavelengths](image)
Figure 3 shows that the snaked laying pipeline with large laying wavelength exhibits more severe lateral deformation. When the temperature difference of pipeline is 200 °C, the bending moment and axial force of snaked laying pipeline with 4000 m laying wavelength is 20 % and 7 % larger than those of pipeline with 3200 m laying wavelength.

3.2. The impact of amplitudes of curve V
The snaked laying pipeline with 40 m curve amplitude and 50 m curve amplitude were simulated, and the bending moment and the axial force of the largest lateral displacement cross-section are shown in Figure 4.

![Graph showing bending moment and axial force](image)

**Figure 4.** Deformation for snaked laying pipeline with different curve amplitudes

Figure 4 shows that the snaked laying pipeline with large curve amplitude exhibits less severe lateral deformation. When the temperature difference of pipeline is 200 °C, the bending moment and axial force of snaked laying pipeline with 40 m curve amplitude is 12 % and 7 % larger than those of pipeline with 3200 m laying wavelength.

3.3. The impact of laying chord length β
The snaked laying pipeline with 40 m laying chord length and 50 m laying chord length were simulated, and the bending moment and the axial force of the largest lateral displacement cross-section are shown in Figure 5.
Figure 5 shows that the snaked laying pipeline with large laying chord length exhibits less severe lateral deformation. When the temperature difference of pipeline is 200 °C, the bending moment and axial force of snaked laying pipeline with 40 m laying chord length is 28 % and 200 % larger than those of pipeline with 50 m laying chord length.

4. The comparison between snaked laying pipeline and regular laying pipeline

A regular laying pipeline is simulated to compare with the snaked laying pipeline to reveal the benefit of snaked configuration in triggering global buckling and controlling deformation stress and strain for post-buckling pipeline. The two models are shown in Figure 6.

The snaked laying pipeline has 3200 m laying wavelength, 40 m curve amplitude and 50 m laying chord length. The snaked laying pipeline is marked as M1 pipeline. The regular laying pipeline is 3200 m long with 4 initial imperfections located at the corresponding location with the arc segment in snaked laying pipeline. The imperfection amplitude of regular laying pipeline is 1.5 m. The regular laying pipeline is marked as M2 pipeline. The simulation element types, boundary conditions, interaction condition and load condition of M2 pipeline is the same with the M1 pipeline. Figure 7
shows the axial force along the pipeline for M1 and M2 pipeline experiencing 200 °C temperature difference.

![Critical buckling force (M1) and (M2)](image)

**Figure 7.** The axial force of cross-section along the pipeline

Figure 7 shows that the axial force of M1 and M2 pipeline is far more less than the ideal pipeline (pipeline exhibiting no global buckling), the M1 and M2 pipeline release large compressive force through the global buckling deformation. The critical buckling force of M1 pipeline is about 30 % less than the M2 pipeline. The M1 pipeline exhibits 4 global buckling segments, while the M2 pipeline only exhibits 2 buckling segments. M1 pipeline trigger global buckling more efficiently.

5. Conclusion

The snaked laying pipeline is good for controlling the global lateral buckling. In this paper, the influence of configuration parameters of snaked laying pipeline on the lateral global buckling and the comparison between snaked laying and regular laying pipeline are discussed. The main conclusions are as followed.

1. The snaked laying method changes the routine of the pipeline, helping to avoid severe seabed condition. When pipeline was heating and exhibiting global lateral buckling; only the arc segments of pipeline deformed, and the straight segments of pipeline occurs no lateral displacement. This could be benefit for maintaining the stable of pipeline routine.

2. The configuration parameters of snaked laying pipeline influence the state of deformed cross-section after buckling. The snaked laying pipeline with larger laying wavelength, less curve amplitude exhibits and less laying chord length exhibits more severe lateral deformation. The influence of laying chord length is the greatest among the three parameters.

3. Comparing with the regular laying pipeline, the snaked laying pipeline can trigger global buckling at a lower axial force level, and reduce the disadvantageous factor towards the pipeline safety (such as bending moment, axial force and axial strain) after buckling. That is to say, the snaked laying method ensures success rate of triggering global buckling at the pre-set location and increases safety margin at the same time.

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