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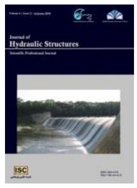

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Effect of Scour Hole on Lateral Buckling of Offshore Snaked Lay Pipeline

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Abstract

Submarine pipeline is one of the most popular research filed that many researchers focus on solving the issue of buckling of pipeline. The snaked laying is an effective method to control the lateral buckling. The scour below offshore pipeline may affect the efficiency and performance of the snake lay pipeline. The objective of this study was to investigate the effect of scour hole on the buckling of seawater pipelines. A three-dimensional numerical model developed to investigate the effect of scour below offshore pipeline subjected to wave and current by using Abaqus software and Aqua Module. The results indicated that vertical deformation of straight pipeline increased by increasing scour hole depth. This value changed 4.85 cm to 32.87 for holes 11 to 200 cm respectively, but these parameters of the snake lay pipelines were not affected by the presence of scour hole. Moreover, the effective axial force of snacked lay pipelines reduced 5 times in comparison to straight pipeline by applying wave and current. The results indicated that the value of stress of snaked-lay pipeline was independent on scour hole depth. Therefore, this pipeline was effective method to limit and control buckling even in the presence of scour below it.

Keywords: Submarine Pipeline; Snaked Lay Pipeline; Scour Hole; Lateral Buckling

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1. Introduction

Submarine pipelines are widely adopted to transport the oil gas and other liquids in ocean engineering [1-2]. But any damage to this equipment may result in great losses in material and can cause environmental disasters. The safest way for export of chemicals or petroleum products in the form of liquid or gas is through the pipelines [3]. However, pipelines are also susceptible to failure in some cases. Where pipelines are laid on seabed the extreme axial compressive stress caused by temperature and pressure generated by the way they are placed could result into lateral

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buckling of the pipes. This could endanger the integrity of a pipeline and result into plastic deformation of the pipeline [4-6].

Pipelines laid in a free span could buckle downward, and when placed on the seabed, they may buckle horizontally or they could buckle vertically upward when they are in buried condition [7].

Lateral and upheaval buckling in pipelines have been studied by many researches applying the analytical [8-14] and experimental [15] methods. Andreuzzi and Perrone [16], taking into account varying axial resistance in the bucking process could present a mathematical model for upheaval buckling. Sharifi et al [17] assess reliability of pipeline located in south Pars Gas Field against latera buckling.

Recent researchers have applied theoretical modelling and FEM to study the lateral and upheaval buckling of seabed pipelines [18-27]. Shi et al. [18] and Wang et al. [22] studied upheaval buckling for pipelines when they are laid in ideally straight position or with imperfect supports laid on the plastic soft seabed. Wang et al. [28] performed perturbation analysis applying pipe-soil interaction to study the upheaval buckling of imperfectly buried pipelines. Seth et al [29] investigated the dependency of the pipe buckling direction on the seabed features and burial condition. Also, Zhuet al. [30] analytically studied localised lateral buckling of straight pipelines. Furthermore Zeng and Duan [25] and Wang and Van der Heijden [31] investigated localised lateral buckling of partially embedded subsea pipelines applying the nonlinear soil resistance. To avoid buckling of subsea pipeline some methods have been incorporated namely trenching, burying and rock dumping, also using the in-line expansion spools attempt is made to relive the induced stress [32-33]. However, these methods are not cost effective and costs increase with increasing temperature and pressure also with evolution of hydrocarbon moves into deeper waters [34]. Therefore, a more cost-effective method is proposed here named controlled lateral buckling to relieve thermal and pressure induced compressive stress. In this method thermal expansion is accommodated by causing controlled buckling of pipeline at a number of pre-planned points instead of allowing an uncontrolled excessive buckling in one point [35-36]. Snake-lay and residual curvature lay methods are methods incorporated to create controlled buckling in pipeline. Rundsaget al. [37] investigated the effect of snake laying geometry on the critical buckle initiation force and post-buckling responses through a parameter study. Li et al. [38] presented the advance of snaked lay method by comparing with other laying method. Wang et al. [39] combining genetic algorithm (GA) and FE methods proposed a new shape for snake -lay curve. Liu [40] investigated the influence of two snake-lays distance on the lateral deflection, strain and bending moment. Liu [41] studied the impact factors associated with various snake-laying methods including the laying wavelengths, curve shapes and their amplitudes.

Furthermore, the scouring phenomenon around the sea pipelines is one of the important issues in the destruction of these type of structures [42].

Therefore, estimating the maximum scour depth is one of the important concerns of engineers. Some important parameters in the scouring around the sea water pipelines are including; the property of the pipe, the sediment of the bed and the surrounding flow.

Fredsøe [43] presented a comprehensive review of pipeline-seabed interaction under the effect of waves and/or currents. He involved the three factors of scour, liquefaction and lateral stability of pipelines in his study. According to him the scour around a pipeline is affected by seabed which is in turn influenced by pipeline movement due to bending during the scouring. Leckie et al. [44] and Draper et al. [45], studied the scour hole length effect on the pipeline deformation. They concluded that with long holes the pipe sinks locally into the hole which causes strains over the pipe length, but with shorter holes sinking occurs in a more uniform way. Myrhaug et al. [46] provided a practical stochastic method by which the maximum equilibrium scour depth below a pipeline exposed to random waves plus a current on mild slopes can be derived.

As stated, the snaked laying pipeline is one of the safest and the most efficient method for controlling the buckling in marine pipelines. During operation the probability of occurring the scouring hole may reduce the safety of using this method, that this issue is not well considered by researchers. This research investigated on the effect of scouring holes on the buckling of the snaked laying pipelines. The effect of scour hole on the buckling of pipelines was investigated by numerical modelling and using Abaqus software. Moreover, the behaviour of the pipeline with different diameters for different values of flow and depth of the hole was evaluated.

2. Numerical Modeling

According the research of Palmer [47] and Zhang et al. [48] the finite element analysis is a convenient and effective tool to calculate the buckling of pipelines. The present paper was aimed to investigate a three-dimensional finite element analysis of submarine pipeline using Abaqus software.

2.1. Pipeline and Seabed Elements and Materials

The geometry of the problem involves pipeline geometry (a circle member), sea bed and a scour hole geometry. Firstly, to investigate and compare the behavior of the snaked laying pipeline with straight pipeline, a 1000 m long straight pipeline was modelled. Laying chord length (R), laying wavelength (L) and amplitudes of the curves (V); those are three basic parameters of the snacked laying pipeline [41]. In this study, these values were 1000, 1000 and 50 meters for snaked laying pipeline modelling, respectively based on Bahari and Motamed nejhad [49]. The dimensions of the sea bed for the straight and snaked laying pipelines were different. For the straight pipeline, the length of the bed was 1100 meters and its width was 50 meters, while for the snaked laying pipeline, the length of the bed was 1200 and its width was 100 meters.

The length and depth of the scour hole were calculated using the relationships provided by Yasa and Etemad Shahidi [50] and Ary and Shingan [51], which were different for the pipe with different diameters, according to Table 1. Moreover, not only four depths that indicated in Table 1 but also two extra depths, 50 cm and 200 cm, were considered to evaluate the effect of pipeline collision with the seabed.

Table1. Length and depth of scour hole

point	Pipeline diameter (cm)	Scour hole length (m)	Scour hole depth (cm)
1	25.4	50	11
2	50.8	64	20
3	76.2	75	28
4	101.6	86	36

API5L X65 material grade are used for submarine pipeline. The concrete coating is applied to the pipeline outer diameter to protect it from seawater. The geometry and properties of pipeline are tabulated in Table2. According to DNV standard recommendation, the length should typically be in the order of one diameter where the buckle is expected to occur and may be longer in straight portions [52]. Therefore, based on different pipe diameter, four different elements with 0.25m, 0.5m, 0.7m and 1m length were considered in modelling. PIPE31 element is used for the pipes. This element is a two-nodal three-dimensional element. It has thin-walled circular cross- section, which has the capability to apply internal pressure [53].

Table 2. Pipeline, seabed and hydrodynamic design parameters

Mechanical property of pipeline

Pipe diameter (cm)	Pipe thickness mm	Concrete thickness mm	Yield stress MPa	Steel young's module GPa	Concrete young's Module MPa	Steel density Kg/m³	Concrete density Kg/m³	Poisiion ratio	Coefficient of thermal expansion C^{-1}
25.4 50.8 76.2 101.6	12 16 20 25	51 68 68 68	450	207	20	7850	3040	0.3	$11,7 \times 10^{-6}$

Seabed property

Soil type	Soil density Kg/m³	Soil shear strength KPa	Submerged density of soil KN/m³	Vertical friction coefficient	Lateral friction coefficient
Sand Clay	2000	25	9.5	0.5	0.79

Hydrodynamic Property

Water depth m	Density of seawater Kg/m³	Wave height m	Wave Period	Drag coefficient	Lift coefficient	Inertia coefficient
70	1030	2	1.3	0.7	0.9	1.5

The seabed type is considered as three dimensional discrete rigid (R3D4). However, it should be noted that the soil properties have to be assigned to seabed mesh. The soil bearing capacity and coefficient of frictions are the most important factors that have to be included into the analysis. Soil vertical stiffness and coefficient of friction along the pipeline and transverse to the pipeline are listed in Table 2. For more illustration, a section of the seabed and pipeline is depicted in (Fig 1).

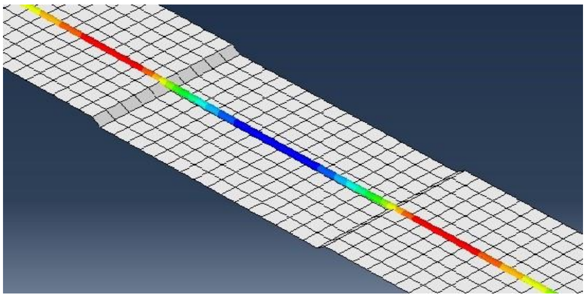


Fig 1. Three dimensional seabed demonstration

2.2. Pipe/Soil Interaction

The interaction between pipeline and soil simulated by setting up contact elements. The contact of pipeline and soil was assumed to be the surface to surface and dynamic contact type. The soil restriction to the pipeline depends on frictional resistance between pipeline and soil [54]. According to the subsoil properties, the vertical and lateral frictional coefficient on the contact surface was chosen to be 0.5 and 0.79 respectively, and penalty function was utilized to determine the soil frictional resistance to the pipeline. The normal force appears when the pipeline moves towards and compresses the soil foundation. In order to consider the normal contact, the pressure /penetration relationship recommended by Bai Y and Bai Q [55] was used.

2.3. Boundary and Loading

Degree of freedom is constrained at both ends of the pipeline in order to apply loading. The analysis was performed in two parts: in the static analysis of the pipeline under self-weight buoyancy, internal and external forces and temperature, whilst the response due to wave action was of interest in the dynamic analysis. The initial pipe temperature is assumed 13°C and it is increased up to 90°C. Also, the internal and external pressure was 13.9 and 0.8 MPa respectively.

The final step of multi-step analysis was a direct integration non-linear time domain analysis in which the pipeline was exposed to the effect of wave loading calculated by Morrison equation in Abaqus. Airy wave theory was used for this analysis, as it is considered to be accurate for low amplitude wave in deep water. Abaqus/Aqua software was used to analyse the pipeline for sea-state given in Table2.

3. The Reliability Verification of Modelling

For reliability verification of the model, the research carried out by Bahari and Motamed nejhad [49] was used. Bahari and Motamed nejhad simulated the straight pipeline with free end boundary condition to identify buckling locations. The physical specification of their problem was according to Table 3.

Table 3. Modeling Specifications [49]

Side-friction factor	Longitudinal friction Factor	Water depth (m)	Yield Stress (MPa)	Modulus of Elasticity (MPa)	Temperature C^0	Design Temperature C^0	Internal Pressure (MPa)	Internal Pipeline Diameter (m)	Outer Pipeline Diameter (m)
0.79	0.5	70	420	207000	13	88	13.9	0.77	0.813

The result from Bahari and Motamed nejhad modelling was compared with the result of this study, as illustrated in Fig 2. As shown in this Fig, the results of their modeling are exactly in line with the effective axial force diagram of the present research modeling. The biggest difference is located in the midpoint of the pipeline and it is less than 10%.

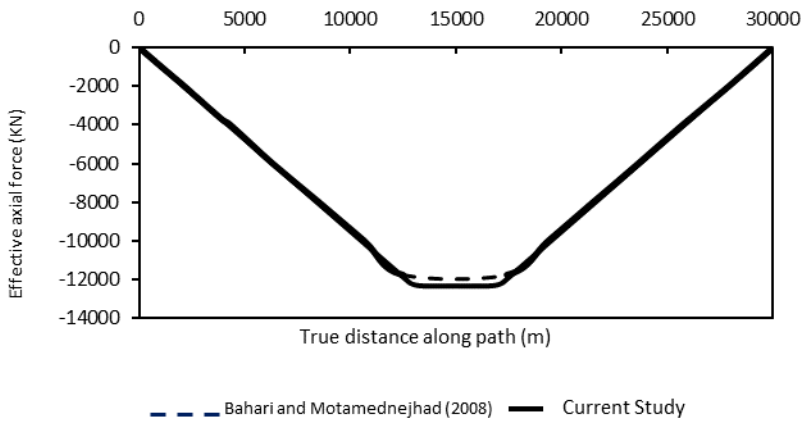


Fig. 2. Effective axial force variation in straight pipeline

Moreover, using the relationships provided by the DNV RP F110 standard, the axial force was 12072176 N. The percentage of the difference with the results of this research was 2% (Eq 1). Therefore, the FEA result based on this study modeling is reliable.

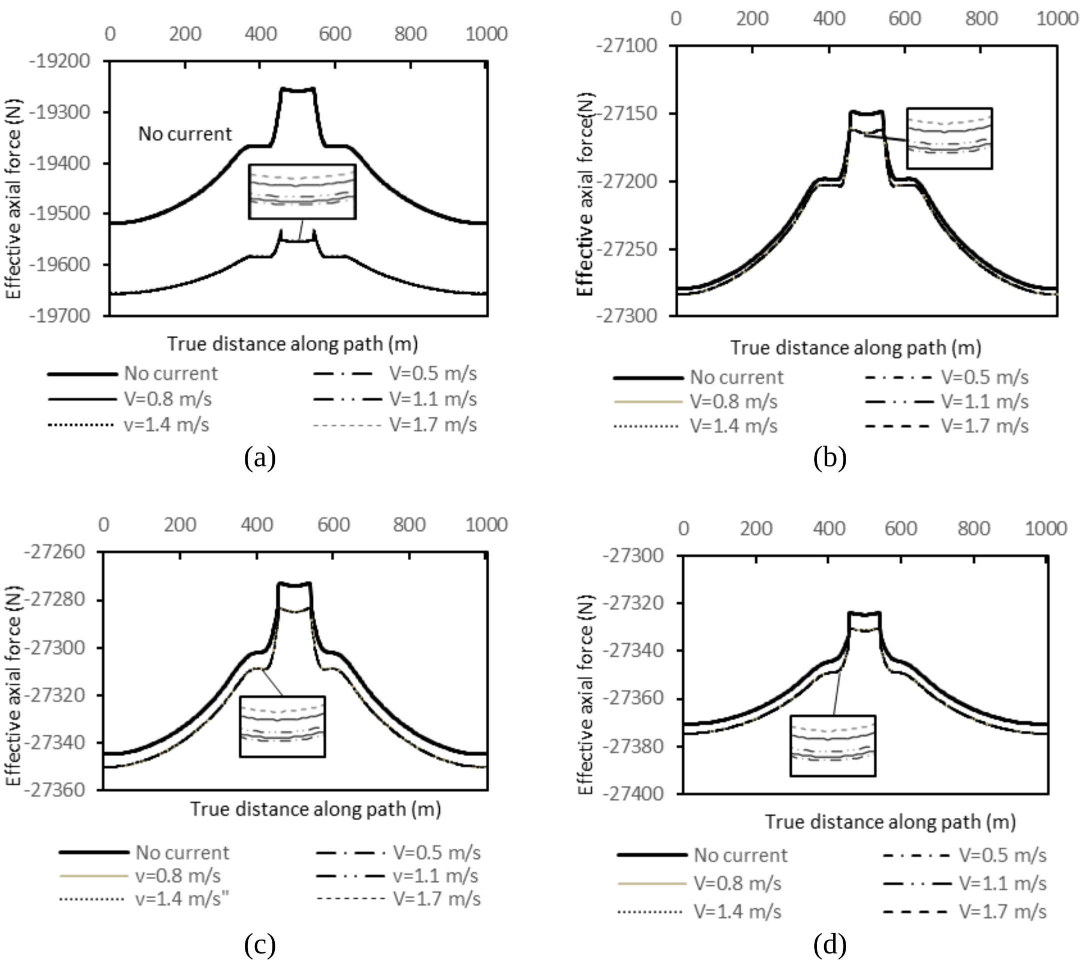
$$difference\ percentage = \frac{|real\ amount - analysis\ amount|}{real\ amount} = \frac{|12072176 - 12337600|}{12072176} \times 100 = 2\% \qquad (1)$$

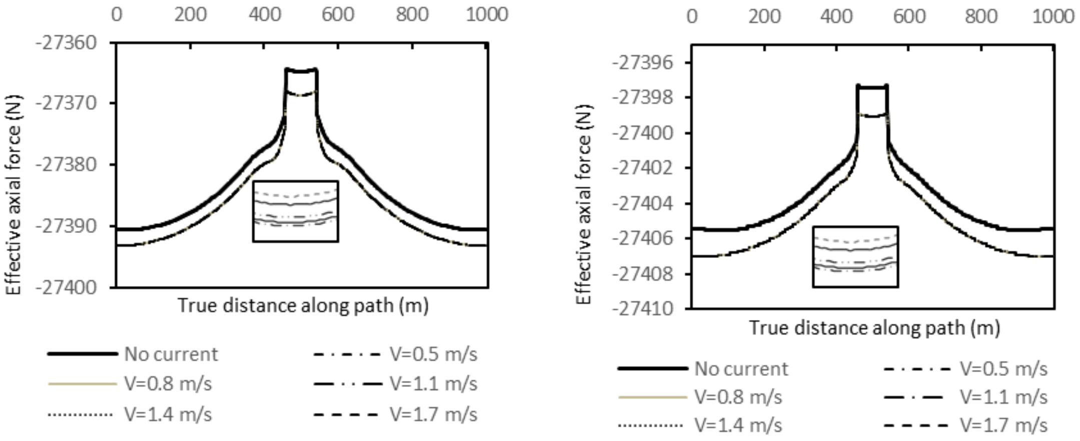
4. Result and Discussion

The effect of scour hole depth on the lateral global buckling and comparison between snaked laying pipeline and regular laying pipeline are discussed in this section. The location of scour hole was exactly under the middle point of pipeline.

4.1. The Impact of the Scour Hole Depth on the Axial Force of Offshore Pipeline

The results of straight and snaked-lay pipeline analysis for different scour hole depths are presented in this section. The diagrams of axial forces for pipelines of various diameters were overlapped; therefore, only the result of pipeline 40 inches in diameter is presented in Fig 3. The results showed that the axial force was not significantly affected by the value of current velocity. Fig 3 illustrates this issue clearly.





(e) (f)

Fig. 3. The axial force distribution along the whole straight pipeline with various scour hole depth: a)200 cm depth, b) 50 cm depth, c) 36 cm depth, d) 28cm depth, e)20 cm depth, f) 11 cm depth

As shown in Fig 3(a), the maximum axial force was observed at both ends of pipeline. It might attribute to the rigid supports of pipeline. The axial force decreased to a distance of 360 m from the support. In fact, the pipeline released the axial force until the value became equal to friction force. This value remained constant along pipeline to a distance of 420 m. Therefore, this segment of curve is horizontal (360 m to 420 m). Thereafter, the axial force was reduced again to the beginning of the scour hole .

According to Fig 3, the axial force of pipeline for various scour hole depths had same trend. But the horizontal segment of graph decreased as the hole depth declined. This horizontal segment was 60 m for a 200 cm hole depth and it was reduced to zero for 11 cm and 20 cm hole depths, as shown in Fig 3(a) to Fig 3(f). The horizontal section of diagram reveals the equalization of the frictional force with the effective axial force of pipeline. The effective axial force increased as the contact surface of pipeline and seabed increased (decrease of scour hole depth); therefore, the frictional force was equal to the effective axial force in almost no part of the pipeline for shallow scour holes. Moreover, by reducing the depth of hole, the axial force amplitude decreased. For instance, for a 200 cm scour hole depth, the axial force variation ranged from 19200 KN to 19700 KN (Fig. 3a) and for a 11 cm hole depth, these values ranged from -27408 KN to -27396 KN (Fig 3f).

According to Fig 3, the axial force curve was sharp at the beginning and ending of the score hole due to resting of pipeline on the seabed. The axial force increased and reached to the maximum value in the middle of scour hole.

Table 4 shows the effective axial force for different scour hole depths. The contact surface between the pipeline and the seabed increased by reducing the depth of scour hole. As the contact surface increased, the effective axial force increased because of releasing the compressive stress. Also, by reducing the depth of the hole, the effective axial variation range decreased.

Table 4. Effective axial force of straight pipeline for different scour hole depths

Scour hole depth	Effective axial force (KN)		Difference percentage
	With current	Without current	
200	19555	19258	1.54
50	27164	27150	0.05
36	27285	27274	0.04
28	27331	27324	0.025
20	27368	27364	0.014
11	27399	27397	0.007

As shown in Table 4, the difference in effective axial force in with and without current states was reduced by decreasing scour hole depth. For example, for a hole 200 cm in depth, the difference in axial force with and without current was 1.54%. While, for a hole 11 cm in depth, the value of difference was 0.007% which was not significant. This issue indicated that by decreasing the depth of scour hole, the impact of the current on the effective axial force was reduced.

The variation of effective axial force in the snaked-lay pipeline is illustrated in Fig 4. The graph clearly shows that the velocity of current was important parameters which had a significant effect on effective axial force of snaked-lay pipelines.

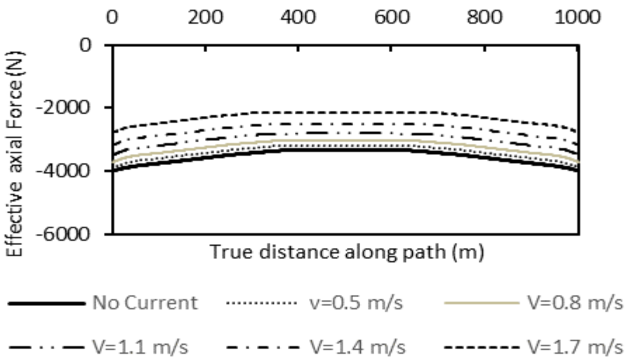


Fig. 4. The effective axial force variation of snaked laying pipeline

The axial force in snaked-lay pipeline was considerably less than the axial force in straight pipeline. The result showed that the segment of snaked-lay pipeline laid on the seabed might be raised a few centimetres above the bed by considering the impact of wave and current; therefore, the pipeline released the axial force easily. Moreover, in the snaked-lay pipeline, the axial force of pipeline decreased by increasing the current velocity. The reason of decreasing the axial force might be attributed to the displacement of pipeline which rose by increasing the current velocity; therefore, the effective axial force decreased. This phenomenon is in contrast with straight pipeline.

Moreover, the result showed that the effective axial force of snaked-lay pipeline was the same for different score hole depths. This issue indicated that the scour hole depth had no effect on axial force of snaked-lay pipeline.

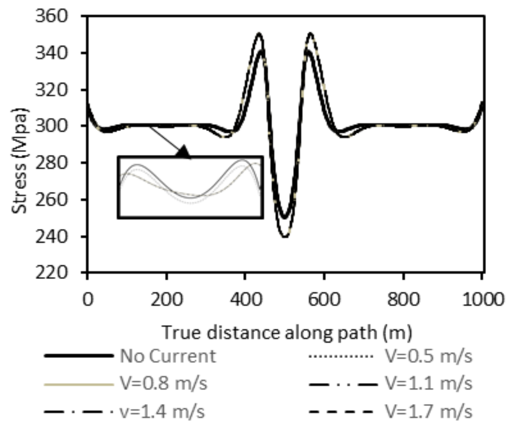
4.2. The Impact of Scour Hole Depth on Pipeline Van Maiss Stress

The stress at different sections of pipeline should be lower than allowable stress. According to the DNV RP F110 standard, the maximum acceptable stress is 80% of the yield stress; therefore, in this study, the allowable stress was limited to 360 MPa because the yield stress was 450Mpa.

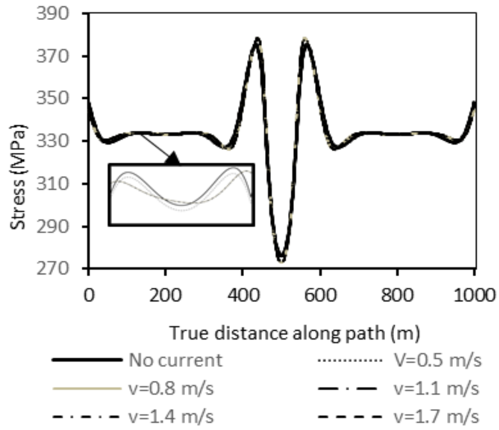
Fig 5 shows the Van Maiss stress for the straight pipeline. As seen in Fig 5, the maximum stress was found in prior to the scour hole and its lowest value was in the middle of the hole. This phenomenon was independent of current and wave.

For 200 cm scour hole depth, the difference in stresses with and without current was 2.85% and 4.40% in the prior and middle of the scour hole, respectively (see Fig 5(a)). Also, the stress in whole part of pipeline remained in allowable stress range.

For a scour hole 50 cm in depth (Fig. 5(b)), the difference between the maximum and minimum stress was approximately 100 MPa. This value was 10% less than the amount for 200 cm scour hole depth. This decreasing trend continued by decreasing the depth of scour hole. Further, this value (the difference between the lowest and highest stresses) for the holes with depths of 36, 28, 20 and 11 cm was 73, 58, 42 and 22 MPa, respectively (Fig 5(c) to 5(k)).



(a)



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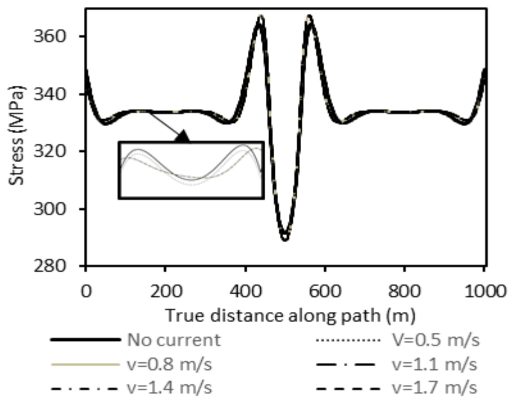

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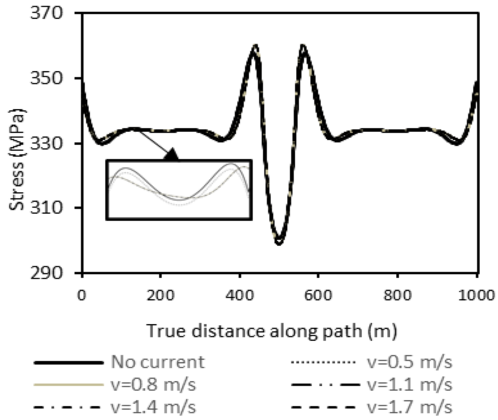
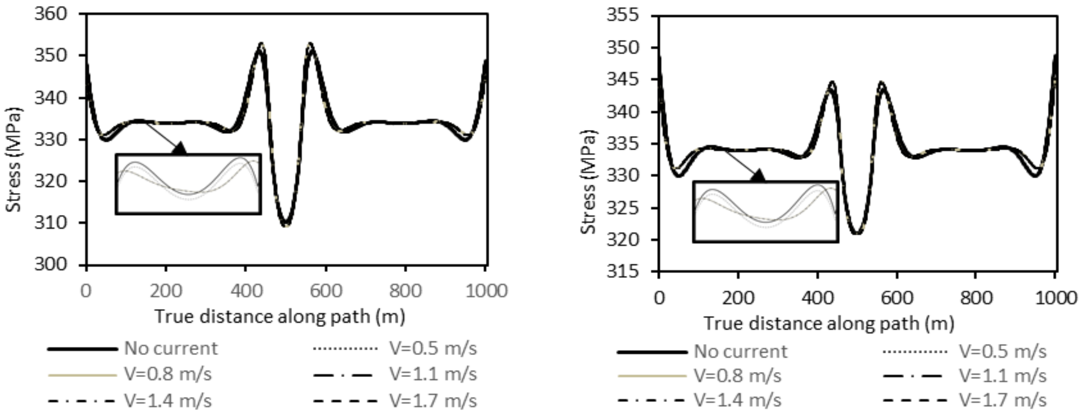


(d)



(e) (f)

Fig. 5. Van Miass stress variation in straight pipeline for different scour hole depth a)200 cm depth, b) 50 cm depth, c) 36 cm depth, d) 28cm depth, e)20 cm depth, f) 11 cm depth

However, the variation of stress interval was decreased as the depth declined, but the minimum stress increased by decreasing the depth of scour hole. Therefore, the minimum stress for the scour hole 11 cm in depth had the highest value compared to the minimum stress of other hole depths (Fig 5(k)).

As seen in Figs 5(b) and 5(c), for the scour hole depth of 50cm and 36cm, the stress at the beginning and at the end of the scour hole exceeded the allowable stress. Therefore, it is necessary to consider a solution for this problem. In contrast, the stress remained in allowable value for whole part of pipeline for 11 and 20 cm scour holes.

Table 5 shows the variation of the stress for straight pipeline for two different modes (with and without current). As shown in this table, decreasing the depth of the scour hole resulted in a decrease in variation of stress percentage for both modes. This issue demonstrated that the reduction of scour hole depth might reduce the impact of current on the value of stress.

Fig 6 shows the variation of stress in the snaked-lay pipeline. As seen in Fig 6, the stress in whole part of snaked-lay pipeline remained in the allowable stress range.

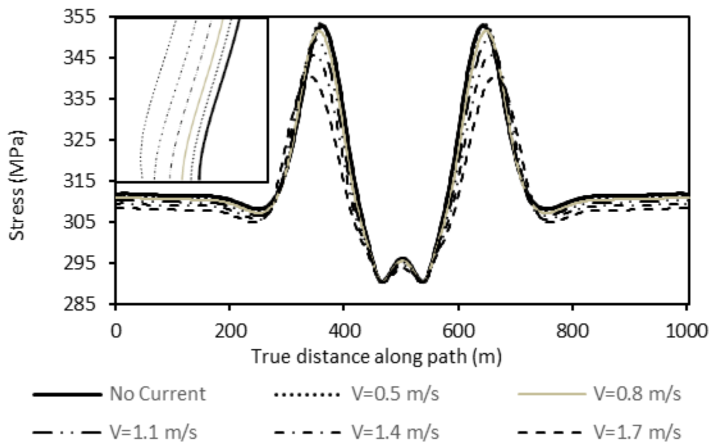


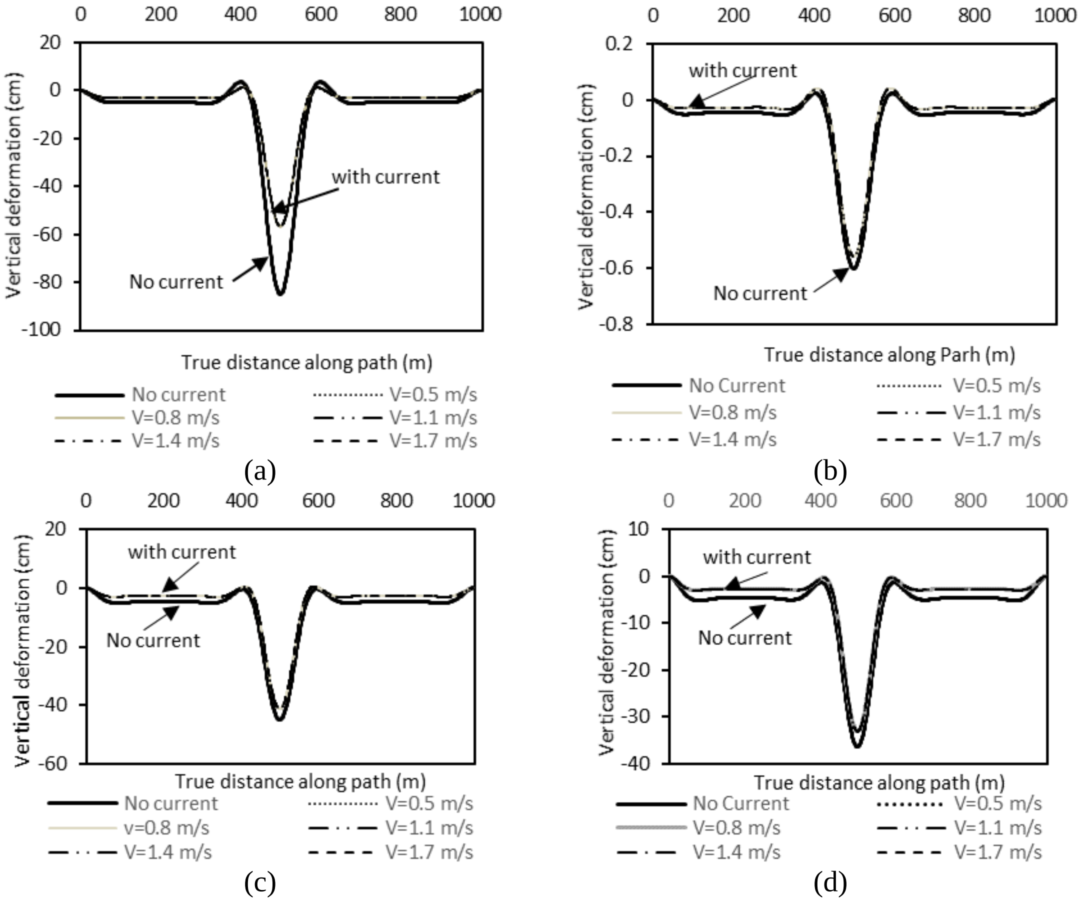
Fig. 6. Van Miass stress variation in snaked laying pipeline in present of scour hole with 200 cm

As shown in Fig 6, the stress of pipeline decreased by increasing the current velocity. The decreasing trend of stress occurred for the part of pipeline located on seabed as well as the part of pipeline located on scour hole. But the decreasing rate of stress in the part of pipeline located on scour hole was lower than other parts of pipeline.

The result showed that the difference between the maximum and minimum values of stress was approximately 65 MPa and this issue was repeated for different depths of scour hole. It indicated that the value of stress of snaked-lay pipeline was independent on scour hole depth. However, the result showed that the percentage of stress variation was decreased by increasing the wave velocity.

4.3. The Impact of the Scour Hole on the Vertical Deformation of the Pipeline

Fig 7 shows the vertical deformation in the straight pipeline on scour holes with different depths. As shown in Fig 7, the pipe deformation for different wave velocities (0.5, 0.8, 1.1, 1.4 and 1.7 m/s) were overlapped.



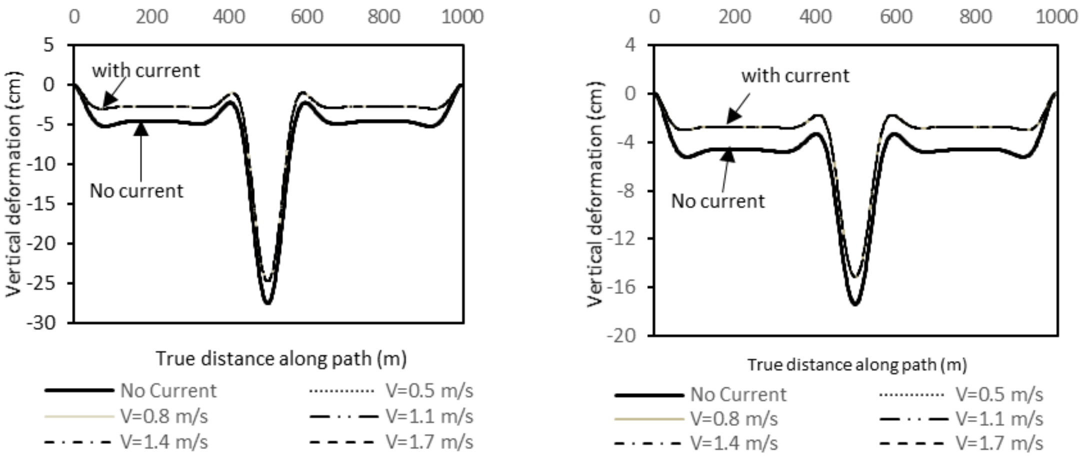


Fig. 7. Vertical deformation variation in straight pipeline with different scour hole a)200 cm depth, b) 50 cm depth, c) 36 cm depth, d) 28cm depth, e)20 cm depth, f) 11 cm depth

Fig 7 shows that the maximum vertical displacement occurred in the pipeline located on the scour hole for all depth variations. The pipe hit the hole bed for all variations of score depth, except for 200 cm scour hole depth.

As shown in Fig 7, the vertical deformation of the pipeline decreased by reducing the depth of the hole. Furthermore, the variation of pipe displacement with and without current increased by enhancing the scour hole depth. These values for holes 200, 50, 36, 28, 20 and 11 cm in depth are 32.87, 35.8, 8, 35.5, 5 and 4.85 cm, respectively.

The pipeline penetrated in the seabed from the beginning of the pipeline to the beginning of the scour hole as well as after the hole to the end of the pipeline. Moreover, the pipeline rose slightly from the seabed at the beginning and end of scour hole.

Fig 8 shows the vertical deformation for the snaked-lay pipeline. The results showed that the vertical deformation of the pipeline was the same for the holes of different depths. It indicated that the displacement of pipeline was not impacted by the scour hole.

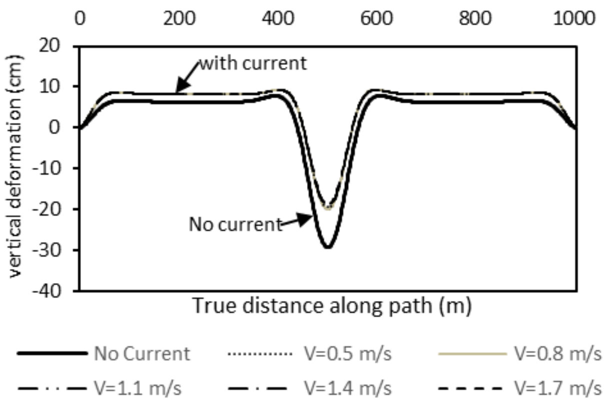


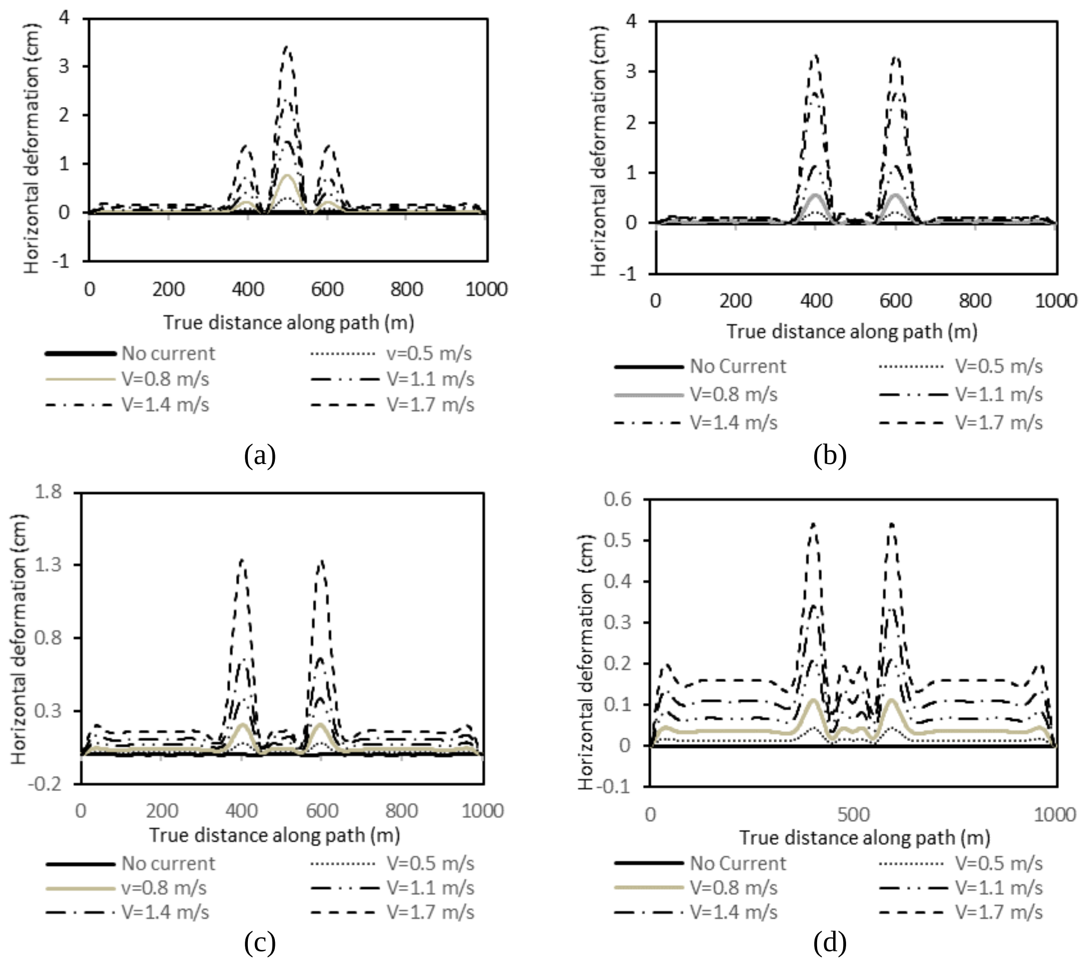
Fig. 8. Vertical deformation variation in snaked laying pipeline in present of scour hole with 200 and 50 cm

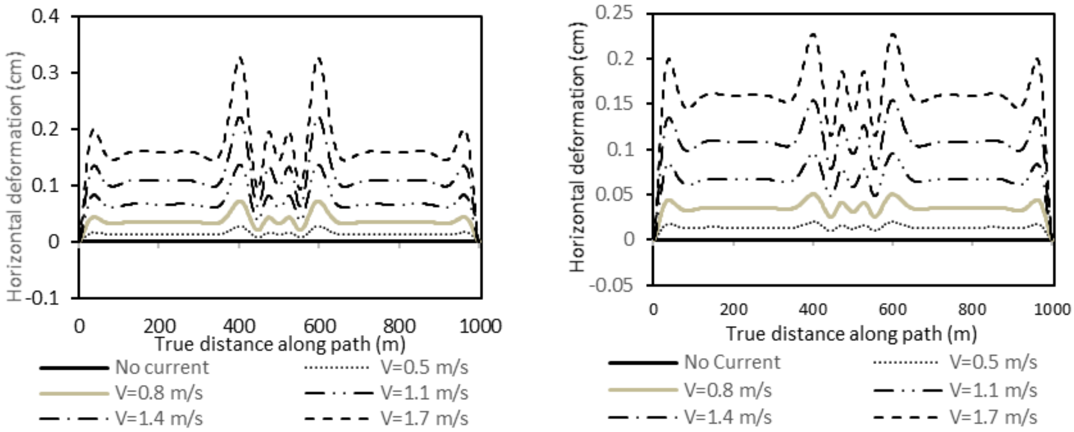
The snaked-lay pipeline was raised from the seabed, before and after the scour hole. The value of vertical deformation increased before and after the scour hole by increasing the flow velocity. These results indicated that the vertical deformation of the snaked-lay pipeline might be influenced by some parameters such as current and wave.

Also, the vertical deformation of pipeline in the middle of scour hole decreased by increasing the current velocity. This is because of buoyancy force of current that induced vertical pressure on pipeline. Furthermore, the vertical displacement variations of pipeline increased for both cases with and without current. For example, for a wave velocity of 1.7m/s, the vertical displacement variation was 19% before scour hole, while this amount was 35.27% in the middle of scour hole.

4.4. The Impact of the Scour Hole Depth on the Lateral Deformation of Pipeline

Fig 9 shows the lateral deformation curve for the straight pipeline. It shows the maximum deformation of pipeline occurred in the middle of the scour hole 200 cm in depth. The amount of this deformation was not significant. For example, for a flow velocity of 1.7 m/s, the deformation was only 3.5 cm.





(e) (f)

Fig. 9. Lateral deformation variation in straight pipeline for scour hole with a)200 cm depth, b) 50 cm depth, c) 36 cm depth, d) 28cm depth, e)20 cm depth, f) 11 cm depth

As shown in Fig 9b and 9c, the displacement in the middle of scour hole 50 cm and 36 cm in depth was approximately zero due to the penetration of the pipeline in the seabed. Maximum lateral deformation occurred at the distance between 400 m and 600 m from the beginning of the pipeline.

The value of lateral displacement was insignificant for straight pipeline. According to Fig 9d, when the depth of the scour hole was reduced to 28 cm, the maximum amount of lateral displacement was 5 mm, which was 60% of lateral displacement of pipeline located on scour hole 36 cm in depth. The decreasing trend of lateral deformation was greatly reduced by decreasing the scour hole depth. For instance, the greatest lateral deformation was about 2 mm for a scour hole 11cm in depth, which was insignificant.

Fig 10 shows the lateral deformation of the snaked-lay pipeline. The result showed that the variation of scour depth had no impact on the lateral displacement. Therefore, only the lateral deformation curve for the snaked-lay pipeline located on 200 cm scour hole was shown and the deformation curve for other scour hole depths was discarded.

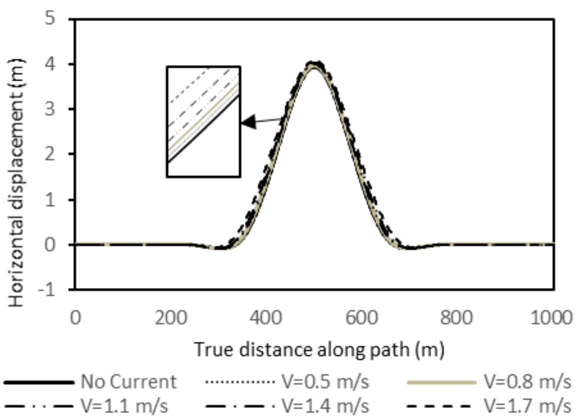


Fig. 10. Lateral deformation variation in snaked laying pipeline for scour hole in present of scour hole with 200cm

The results showed that the snaked-lay pipeline had a considerable lateral deformation in comparison with the straight pipeline. Maximum lateral deformation was 3.5 cm for the straight pipeline, while this value was about 4 meters for the snaked-lay pipeline.

In contrast, the change in current velocity did not have much effect on the lateral deformation of the snaked-lay pipeline. For the maximum current velocity, i.e., 1.7 m/s, the difference value was 3.51% for the pipeline with and without current.

Fig 11 shows the lateral deformation curve at a distance of 450 to 550 m along the pipeline. As shown in this Fig, the lateral deformation increased by enhancing the velocity. It should be noted that by increasing the current velocity, the buckling length of the snaked-lay pipeline was increased.

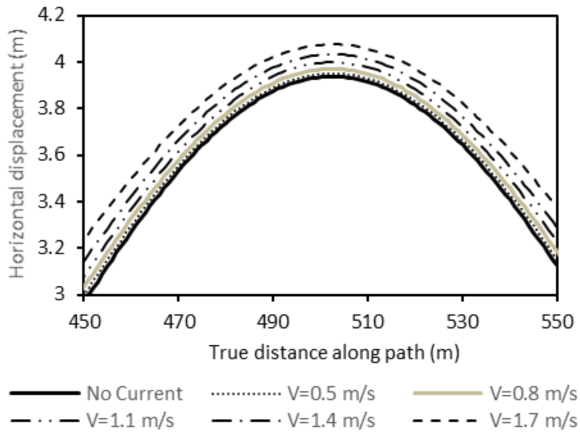


Fig. 11. Lateral deformation variation in snaked laying pipeline at distance of 450m to 550m

5. Conclusion and recommendation:

In this research, the effect of scour hole on the lateral buckling of offshore pipeline was investigated. For modeling, ABAQUS software was used and four diameters of 10, 20, 30 and 40 inches were considered. The main results are as follows.

1- The depth of the scour hole affected the vertical deformation of straight pipeline and the pipeline penetrated into the scour hole bed, but this penetration was limited because of the restriction of pipe-soil interaction considered in modeling. Therefore, the pipeline was not penetrated more than a few centimeters into the seabed.

2- The result showed that the difference etween the maximum and minimum values of stress was approximately 65 MPa and this issue was repeated for different depths of scour hole. Moreover, the result showed that the effective axial force and deformation of snaked-lay pipeline was the same for different score hole depths. It showed that the depth of the scour hole did not affect the axial force, Van Misses stress and lateral deformation of the snaked-lay pipeline Therefore, it was reasonable to ignore the effect of uneven seabed or seabed erosion area for analysis of this kind pipeline.

3- The axial force increased by considering the effect of current on straight pipeline, the difference in effective axial force in with and without current states was reduced by decreasing scour hole depth. For a hole 200 cm in depth, the difference in axial force with and without current was 1.54%. While, for a hole 11 cm in depth, the value of difference was 0.007% which was not significant. Therefore, considering the current or eliminating it in the buckling analysis did not affect the buckling of the straight pipeline.

4- By applying the current and wave to the snaked-lay pipeline, the axial force decreased, and the value of reduction was significant. Therefore, it was reasonable to disregard the effect of current on the analysis of snaked-lay pipe buckling.

5- A reduction of axial forces by at least 5 times in the snaked-lay pipeline in comparison with the straight pipeline indicated the efficiency of snaked-lay method for the control of buckling, even in the presence of scour hole under pipeline.

For further studies it is recommended to:

1- Study the effect of location and number of scour holes on buckling of submarine pipeline.

2- Evaluation the effect of seabed soil type and scour hole on buckling of submarine pipeline.

3- Investigate the effect of scour holes on buckling of submarine snaked lay pipeline with two or more arc.

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