Longitudinal Pipeline Scour Propagation Induced by Wave-Current Interaction For the South Sumatra-West Java Submarine Pipeline

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Abstract. Scouring process around subsea pipelines could reduce the soil bearing capacity which affected to the pipe stability. Scouring initial process against time should be known to discover scouring propagation. This paper aims to analyze the time scale calculation of 32 inch diameter in-trench pipe, until meet the maximum-scouring-depth stage. Embedment (e/D) variation is given to know the impact to the scour propagation. Wave and current condition presented to meet the real condition. Wave orbital particle velocity (U_w) is calculated to obtain the non-dimensional factors (U_c/(U_c+U_w)) and KC. The results showed according to the deeper pipe embedment, it takes longer time to reach the maximum scouring depth.

Keywords: Pipeline Scour Propagation, wave-current interaction, embedment ratio

1. Introduction

One of the important aspects to be considered in designing and planning of submarine pipelines is scouring process phenomenon. Pipeline existence would affect the flow pattern and characteristic, thereby inducing sediment scouring around pipe structure. Scouring process towards the longitudinal (along the pipe) on long run could form free spans. Based on DNV OS-F101 [1], formed free span has a certain safety standard level to avoid the failures such as local buckling, fatigue, and fracture.

The interaction between pipe, seabed, and flow (wave and current) is a complex phenomenon that results in local scour as shown in [2]. The occurrence of scours begin with a small span occurred by constant wave and current force or pipe is held on an uneven surface. Scour occurs when current flows and wave accelerate below pipe so it widen and deepen the free span. Some scouring development researches against current and wave condition has been studied, e.g. [3, 4, 5, 6, 7, 8, 9].

Scouring depth analysis over time needed to monitor the development of scouring depth. There are a few researches which study the time scale scouring propagation. [6] showed that the shield parameter has a role on the scouring process and it shows how long a scouring process occurs where the greater Shields parameter value would affect the smaller time scale. The larger the Shields parameter cause the larger the sediment transport which influence the higher scour propagation. The sediment transport studies under various wave motions has been done by [10, 11, 12, 13, 14]. While [9] mentioned that current gives increasing time scale scouring time scale significant impact when it combines with wave. In this paper, the time scale of longitudinal scouring propagation will be discovered until it reaches the maximum scouring depth. This research conducted on in-trench pipe condition and given three different embedment depths, so it can be known the influence of different embedment depth (e/D) to the time scale of scour propagation on in-trench condition.
2. Theoretical Background

2.1. Governing Parameters

In this case, pipe obtains force from two sides caused by the bottom flow due to wave and unsteady current flow due to tides. Parameters in scouring calculations which important due to wave and current influences are particle velocity ratio, KC number, and the Shields parameters. Particle velocity ratio could be defined by Equation (1)

\[ m = \frac{U_c}{U_c + U_w} \]

where \( U_c \) is the current velocity in 100% depth (m/s) and \( U_w \) is the velocity of the wavelength particle (m/s).

Wake-pattern formation and extension is determined by KC parameter (Keulegan-Carpenter number). When KC number is small then the orbital motion also small against the total pipe width, if it comes to greater KC number, then affected water particle is farther than the total pipe width. KC is defined by

\[ KC = \frac{U_w T_w}{D} \]

where \( T_w \) is period of wave (s) and \( D \) is the pipe diameter (m).

To express the Shield parameter due to the wave-current interaction given in Equation (3) proposed by [15], as follows

\[ \theta_{cw} = \left( \frac{\theta_c^2 + \theta_w^2 + 2 \theta_c \theta_w \cos \phi}{\theta_c^2 + \theta_w^2} \right)^{1/2} \]

where, \( \phi \) is the angle between current and wave. Where shield parameters of current use the following formula

\[ \theta_c = \frac{U_f}{\sqrt{g(s-1)d}}, \quad U_f c = \frac{\tau_\infty}{p} \]

where \( U_f \) is the current friction velocity, and \( \tau_\infty \) is the shear stress for undisturbed flow. Shield parameters of wave use the following formula

\[ \theta_w = \frac{\tau_w}{\rho g (\rho_s/\rho - 1) d_{50}} \]

where \( \tau_w = \frac{1}{2} \rho f_w U_w^2 \), \( f_w = 0.237 r^{-0.52} \), \( r = \frac{U_w T}{2 \pi k_s} \), \( \tau_w \) represents shear stress flow undisturbed under wave action, \( k_s \) is the nikuradse equivalent sand grain roughness, and \( f_w \) is wave friction factor.

2.2. Time Scale Scouring

At a certain period, scour depth will reach the equilibrium condition. The time scale is taken into calculation in this study. The formula used to calculate the time scale is as follows

\[ S_t = S \left( 1 - \exp \left( -\frac{t}{T} \right) \right) \]

where \( S_t \) is the equilibrium scouring depth; \( T \) is the predicted time of the scour depth and the time it takes (usually calculated with a slash drawn from \( t = 0 \)). Time scale on steady currents calculated by Equation (7) and time scale on wave conditions defined by Equation (8)
2.3. Scouring Propagation Rate along the Pipe

In two-dimensional modeling, scoured part is centered until it reaches the equilibrium. So that bed shear stress is equal to the undisturbed value $\tau_\infty$. However, bed shear stress increase as it moves at the end of span which occurs along $\beta D$ as shown in Figure 1. Occurred erosion on the span angle is determined by the difference of sediment transport that come out from the corner and which come in to the corner area. The erosion rate determined by sediment properties, bed shear stress, pipe embedment, and $\alpha - \beta$ coefficients. However, by assuming $\beta = 1$ then erosion volume rate can be calculated by this following formula

$$c = \frac{q_{co} - q_o}{e(1-n)}$$

(9)

Where $q_{co}$ as sediment transport in support free span area (corner), $q_o$ is transport sediment in flat bed area, $e$ is embedment, and $n$ defined as porosity. While $q_o$ can be determined using Equation (10), as follows

$$q_o = 8\sqrt{(s-1)g\bar{d}_{50}(\theta - 0.047)^{3/2}}.$$  

(10)

2.4. Study Area and Environmental Data

The location of South Sumatera – West Java Gas Pipeline (SSWJ) offshore pipeline used as a case study in the present paper given in Figure 2. The SSWJ pipeline gas transmission transport natural gas from the Grissik gas production field in South Sumatra Province to Rawa Maju in West Java Province to meet the rising energy demand in West Java. The capacity of the Project pipeline is 460 million standard cubic feet per day [16]. The water depth, soil type, wave and current data for Zone 17 and 18 with Kilometer Points (KP) from 139 up to 162 were used to evaluate the longitudinal pipeline scour propagation given in Table 1, Table 2 and Table 3, respectively. In which, it has the pipeline diameter (D) 32 inch laying on seabed and in-trench condition. While the embedment depth set on 15% of pipe diameter ($e = 0.15D$).
Figure 2. Offshore Pipeline Route of South Sumatra-West Java (SSWJ) [16]

Table 1. The Water Depth in Zones 17 and 18 for KP 139.6 to 161.3

| Zones | KP from | KP to | min depth (m) | max depth (m) |
|-------|---------|-------|---------------|---------------|
| 17    | 139.6   | 155.7 | 5.80          | 21.80         |
| 18    | 155.7   | 161.3 | 0.00          | 5.80          |

Table 2. Soil Type for KP 149.6 to 161.3

| KP Range From  | To   | Soil Type | Bulk Density (kg/m³) | Zone |
|----------------|------|-----------|----------------------|------|
| 149.6          | 161.3| Sand      | 1258                 | 17-18|

Table 3. Wave and Current Data for Zone 17 and Zone 18

| Zone | Hs (m) | Ts (sec) | 0% of depth | 50% of depth | 100% of depth |
|------|--------|----------|-------------|--------------|---------------|
| Z17  | 3.8    | 7.88     | 1.28        | 0.69         | 0.38          |
| Z18  | 3.46   | 7.52     | 1.42        | 0.83         | 0.52          |
3. Result And Discussion

3.1. Time Scale Propagation of Pipeline Scour

The modelling results of time scale propagation pipeline scour at zone 17 and 18 for the pipeline diameter(D = 32 inch) with variation of the embedment i.e. e=-0.05 D, e=-0.15 and e=-0.25 given in Table 4 and Figure 3. It can be shown that the maximum scour depth ($S_{\text{max}}$) and the time ($t_{\text{max}}$) needed to reach the maximum scour depth increase with the increase the water depth (d) and the embedment. For all the variation of the embedment e=-0.05 D, e=-0.15 and e=-0.25 when the water depth (d) = 15.30 m was obtained $t_{\text{max}}$ and $S_{\text{max}}$ higher than others water depth as shown in Figure 3. The result shows $S_{\text{max}}T_{\text{max}}$ for e=-0.25D slightly longer than $T_{\text{max}}$ for e=-0.15D & e=-0.05D.

Table 4. Time scale propagation of pipeline scour for Zone 17 and Zone 18 with the pipeline diameter(D) = 32 inch in variation of the embedment value (e=-0.05 D, e=-0.15 and e=-0.25)

| No | d (m) | $U_c/(U_c+U_w)$ | e = -0.05D | e = -0.15D | e = -0.25D |
|----|------|-----------------|------------|------------|------------|
|    |      | $T_{\text{max}}$ (h) | $S_{\text{Max}}$ (m) | $T_{\text{max}}$ (h) | $S_{\text{Max}}$ (m) | $T_{\text{max}}$ (h) | $S_{\text{Max}}$ (m) |
| 1  | 7    | 0.15            | 5.44       | 0.208      | 5.49       | 0.22       | 5.55       | 0.234      |
| 2  | 8.66 | 0.183           | 4.86       | 0.216      | 4.9        | 0.229      | 4.95       | 0.243      |
| 3  | 10.32| 0.2             | 4.9        | 0.212      | 4.95       | 0.226      | 5          | 0.239      |
| 4  | 11.98| 0.211           | 5.3        | 0.205      | 5.35       | 0.217      | 5.41       | 0.231      |
| 5  | 13.64| 0.219           | 5.93       | 0.195      | 6.01       | 0.208      | 6.07       | 0.22       |
| 6  | 15.3 | 0.225           | 6.85       | 0.186      | 6.92       | 0.197      | 6.98       | 0.209      |

Figure 3. Time scale propagtion of pipeline scour for Zone 17 and Zone 18 with the pipeline diameter(D) = 32 inch in variation of the embedment value (e=-0.05 D, e=-0.15 and e=-0.25)

Figure 3 showed how the scouring propagation process against time starts from the initial time until it reaches the maximum scouring time. It can also be seen that the steep slope of the graph is a time scale value (T) which is a progressive scouring process (63.14% of maximum scouring depth). The deepest depth (15.30 m) has the longest time of maximum scouring as well as the larger the embedment (e) values lead to a slightly longer scouring time.
3.2. Longitudinal Scour Propagation

The longitudinal scour propagation was simulated based on 2D numerical model proposed by [6] in which the propagation along the pipeline occurs after equilibrium depth scouring ($S_{Max}$) was reached. The results showed that the increasing of embedment depth, scouring propagation rate goes slower. The longitudinal scouring rate is determined by sediment property, bed shear stress ($\tau_\infty$) and the Shields parameter ($\theta_{cw}$) induced by wave-current interaction on flat bed, the embedment depth ($e$), and $\alpha - \beta$ coefficient. According to [6] shear stress amplification ($\alpha$) decreases by the increasing embedment. The value of $\alpha$ is obtained by put it into the graph so that the result is $e=-0.05D$ for $\alpha=2$, $e=0.15D$ for $\alpha=1.72$, and $e=-0.25D$ for $\alpha=1.58$. So it can be concluded for the greater value of embedment condition will cause the rate of propagation scouring takes longer. The results obtained have been in accordance with research that has been done by [6,17].

Table 5. Longitudinal scour propagation for Zone 17 and Zone 18 with the pipeline diameter(D) = 32 inch in variation of the embedment value (e=-0.05 D, e=-0.15 and e=-0.25)

| No | d (m) | $\theta_{cw}$ | $e$ = -0.05D | $e$ = -0.15D | $e$ = -0.25D |
|----|-------|--------------|--------------|--------------|--------------|
|    |       | $\theta_{co}$ | D=32inch c (m/h) | $\theta_{co}$ | D=32inch c (m/h) | $\theta_{co}$ | D=32inch c (m/h) |
| 1  | 7     | 0.28         | 0.562         | 4.45         | 0.484         | 1.01         | 0.444         | 0.48         |
| 2  | 8.66  | 0.42         | 0.834         | 8.2          | 0.717         | 1.87         | 0.659         | 0.88         |
| 3  | 10.32 | 0.4          | 0.794         | 7.61         | 0.683         | 1.73         | 0.627         | 0.81         |
| 4  | 11.98 | 0.33         | 0.663         | 5.76         | 0.57          | 1.31         | 0.524         | 0.62         |
| 5  | 13.64 | 0.25         | 0.501         | 3.71         | 0.431         | 0.84         | 0.396         | 0.4          |
| 6  | 15.3  | 0.18         | 0.37          | 2.29         | 0.318         | 0.52         | 0.318         | 0.24         |

The slowest propagation rate exists at 15.30 m and it gradually increases to 8.66 m, while at water depth (d) = 7.00 m it goes back to decrease. This caused by the larger Shields parameter ($\theta_{cw}$) indicating that the propagation rate is getting bigger. The results also show that greater embedment values gave smaller propagation rate values.

As the result it can be discovered that Shields parameter ($\theta_{cw}$) becomes the determinant of longitudinal pipeline scour propagation characteristics. Shield parameters are representative of the shear stress and flow velocity. So the greater value of shield parameters, obtained greater stress and its velocity.

4. Conclusion

The numerical modelling of the longitudinal pipeline scour propagation induced by wave-current interaction for the South Sumatra-West Java Submarine Pipeline (SSWJ) has been done, It can be concluded that the Shields parameter ($\theta_{cw}$) becomes the determinant of longitudinal pipeline scour propagation characteristic as representative of the shear stress and flow velocity. So the greater value of shield parameters, obtained greater stress and its velocity. The Shields parameters have an important role in determining propagation scouring where the greater the value of the Shields parameters obtain the faster of longitudinal scouring propagation. And the pipeline scour propagation decreases (decelerates) as the increases of the embedment ratio (e/D).
Acknowledgements
Authors would like to thank the LPPM-ITS and DRPM-RI for supporting. This research partially supported by grant of DRPM Ministry of Research, Technology and Higher Education of the Republic of Indonesia (No 135/SP2H/LT/DRPM/IV/ 2017) related with the research grants of PUPT, 2017.

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