Resubmission

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SCOUR BELOW SUBMARINE PIPELINE DUE TO CURRENTS[*]

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The paper describes the results of an experimental investigation of scouring under a pipe and self-burial process due to currents. Two kinds of experiments were carried out. (1) The experiments which are related to the scour process below pipeline and main effective parameters on it. (2) The experiments include investigation of adding a spoiler to the pipe section to increase self-burial potential of the pipelines. In this research, the influence of major parameters on scour caused by current has been investigated by a physical model. The graphical mod results showed reasonable relationship between dimensionless parameters in pipeline scour.

1. Introduction

Pipelines are installed in marine environments either for transportation of gas and crude oil from offshore platforms or for transportation of the water, and for the disposal of the industrial and municipal waste water into the sea. Due to the need of human for more hydrocarbons, development of offshore oil and gas fields has rapidly increased and the construction of submarine pipelines for transportation of crud oil and gas to onshore refineries increased. Following the score process around a pipeline, the vortex shedding is formed around the pipe and this will cause oscillatory loads on the line. Then fatigue damage will be happened due to these oscillatory loads.

The first part of present study addresses the two case of experiments, namely: (a) the mechanism of the scour process around single pipeline and the main parameters affected it, and (b) the scour pattern around multiple pipelines and comparisons with previous cases. In the second part a spoiler was longitudinally added to the crest of pipe section and the properties of scouring were again measured.

2. Experimental set-up and procedure

Two kinds of experiments were conducted: (1) the experiments related to the scour process around single and multiple pipelines, (2) those related to self-burial potential of pipelines during scour process.

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The experiments were conducted in an open flume, 0.275 m in width, 0.35 m in depth and 6 m in length. The water depth maintained at 0.23~0.26 m. A 2 m long and 0.10 m deep sand-bed section was established in the flume, protected at tow ends by section of polymer with 1:2 slopes. The upstream and downstream ends of sand-bed section were 2 m from the inlet and outlet section of flume. A vertical guiding wall (made of Aluminum and polymer) was used to fix the water depth in working section. Sixe pipe diameter sizes were used in the experiments, namely D=110.5, 62.75, 50, 40, 30 and 20 mm. The pipe was rigidly fixed in the section to the side walls of the flume at its ends. The junction between the pipe and the side wall may be a critical section for the onset of scour. To avoid this, the junction between the pipe and the side walls was filled by two polymers cylinders which added to the ends of pipe. In the next stage, tests have been carried out by two pipes with the different space being set from one to another.

In second part, in order to increase of scouring and following that increasing the self-burial of pipe, a spoiler of 30 mm in width was longitudinally added to the crest of the pipe section with D= 62.75 mm.

Two kinds of sand were used in the experiments: d_{50}=0.42, and 0.53 mm Specific weight of sand was 26545 N/m^3.

The test conditions regarding these experiments are given in Table 1.

In Table 1, U is the undisturbed flow velocity at the top of the pipe which determined by measured the discharge of flow and assuming the logarithmic velocity profile and U_f is the undisturbed friction velocity in the case of the steady current that obtained by the Colebrook-White formula

$$\frac{U}{U_f} = 8.6 + 2.5\ln\left(\frac{D}{2k_b}\right) \tag{1}$$

In which D is the pipe diameter and the bed roughness k_b is taken as $2.5d_{50}$.

θ is the shields parameter defined by (Sumer et al., 2001)

$$\theta = \frac{U_f^2}{g(s-1)d_{50}} \tag{2}$$

In which s=2.7 is the specific gravity of sand grains, g is the acceleration due to gravity. Also, Re is the Reynolds number

$$Re = \frac{UD}{\upsilon} \tag{3}$$

In which D is the pipe diameter and υ is the cinematic viscosity.

Also, Fr is the Froude number

$$Fr = \frac{U}{\sqrt{gh}} \tag{4}$$

In which U is the fellow velocity, h is the local depth of water and, g is the acceleration due to gravity.

In order to measure the equilibrium scour profile, the profile was tracked visually (and by video camera) and after a period of time, it was seen that the scour depth has become unchanged. Then, the profile measured every 1cm distance in length by a coils vernieh which has 0.05mm precision. This equipment installed in top of the channel and it has two degree of freedom in length and depth directions of the channel.

Table 1. Test conditions.

Test no.	d50 (mm)	h (mm)	D (mm)	U (cm/s)	Uf (cm/s)	θ	Re	Fr
O1	0.53	70	20	36.7	2.688	0.0817	7,340	0.44
O2	0.53	70	30	45.8	3.122	0.1103	13,740	0.55
O3	0.53	70	40	61.1	3.97	0.1783	24,440	0.74
O4	0.53	70	50	91.7	5.75	0.3741	45,850	1.11
O5	0.42	150	62.75	1.88	0.11	0.0002	1,180	0.02
O6	0.42	150	62.75	9.7	0.567	0.0046	6,087	0.08
O7	0.42	140	62.75	19.95	1.167	0.0194	12,519	0.17
O8	0.42	150	110.5	16.97	0.917	0.0120	18,752	0.14
O9	0.42	170	110.5	8.56	0.463	0.0031	9,459	0.07
O10	0.42	170	110.5	10.7	0.578	0.0048	11,824	0.08
O11**	0.42	140	62.75	15.58	0.911	0.0118	9,776	0.13
O12***	0.42	140	62.75	11.32	0.662	0.0063	7,103	0.10
O13****	0.42	140	62.75	16.36	0.957	0.0131	10,266	0.14
O14*	0.42	140	62.75	18.18	1.064	0.0162	11,408	0.16
O15*	0.42	140	62.75	14.96	0.875	0.0109	9,387	0.13

* Pipe with spoiler.

** Spacing between the pipes is zero.

*** Spacing between pipes is equal to the pipe diameter.

**** Spacing between pipes is equal to the two pipe diameter.

3. Mechanism of scouring process around pipeline

The mechanism of scouring process around the pipeline is same as following: By increasing the velocity of flow, the pressure gradient is increased. Then a point is reached where the surface of the sand at the immediate downstream of the pipe begins to rise. This stage continues for some period of time (about 5 s), and is subsequently followed by the process where a mixture of sand and water breaks through. The onset of scour is followed by the stage called tunnel erosion. During this stage, a substantial of scour depth is derived. In the case of the two-dimensional scour below the pipeline, tunnel erosion is followed by the stage called the lee-wake erosion. Basically the scour at the stage of lee-wake erosion is governed by the vortex shedding, and the scour characteristics are controlled by the lee-wake of the pipe eventually: When the gap between the pipeline and the bed reaches a certain value (due to scour), the vortex shedding will begin to occur. The vortices shed from the bed side of the pipe sweep the bed, as they are convected downstream. The sediment transport at the lee side of the pipe will increase tremendously due to this action. This will presumably result in the lee-wake erosion. The scour process finally reaches a steady state, the equilibrium stage (Sumer and Fredsoe 2002).

4. Experimental results and verification

4.1. Scour around single pipeline

Figure. 1 shows the variation of physical model results in dimensionless scour depth with the Reynolds number. Therefore the model results reveal that the scour depth at most varies weakly with the Reynolds number. From the model results shown in Figure. 1, the mean value of the normalized scour depth and its standard deviation are found to be as follows:

$$\frac{S}{D} = 0.352\,, \quad \text{With } \frac{\sigma}{D} = 0.10 \tag{5}$$

Which is valid for clear water $\left(\theta \leq \theta_{cr}\right)$.

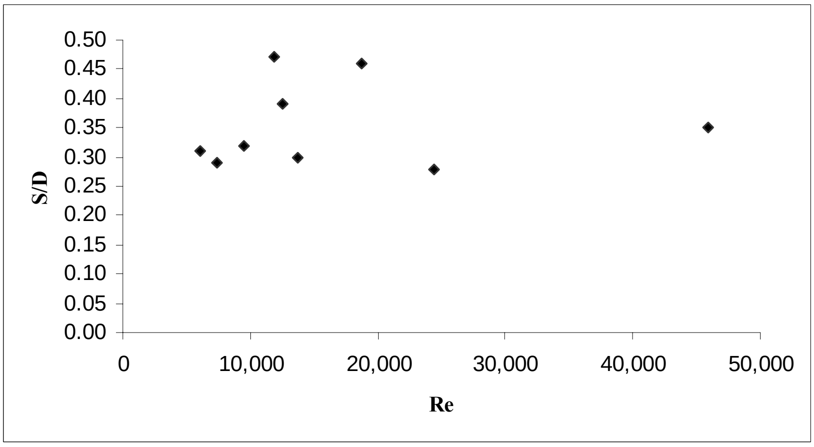

Figure 1. Physical model results for equilibrium relative scour depth. Current. Clear water.

Also, figure 2 shows the effect of water depth on relative scour depth. As can be seen from the figure, the relative scour depth increases linearly with Froude number (Fr). This is because the flow velocity in the gap between the pipe and bed will increase with Fr and following this, large tunnel erosion will occrue. The effect of water depth on scour may be important when the water depth becomes comparatively small (for example in the case of river crossing).

Finally, figure 3 illustrates the effect of shields parameter on relative scour depth. As can be seen, the effect of shields parameter is quite weak when $\left(\theta > \theta_{cr}\right)$. However, it becomes increasingly important when $\left(\theta < \theta_{cr}\right)$. As can seen be, the effect of θ should be taken into account when it is smaller than critical value of shields parameter (i.e., in the case of the clear water scour) (as parspused by sumer 2002).

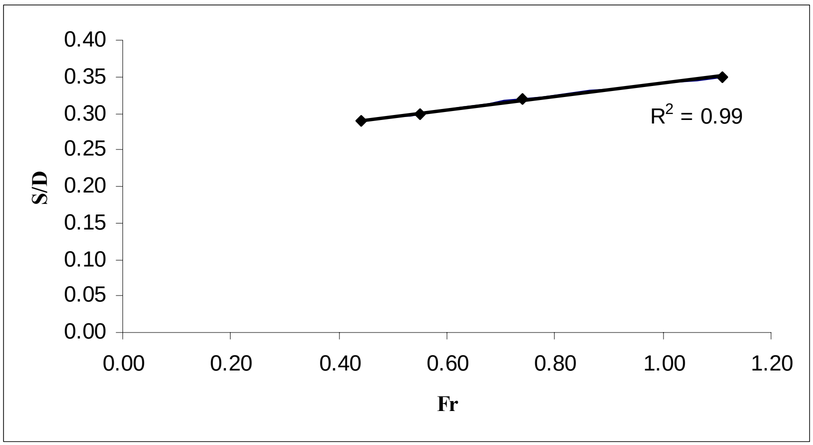

Figure 2. Effect of water depth on equilibrium scour depth.

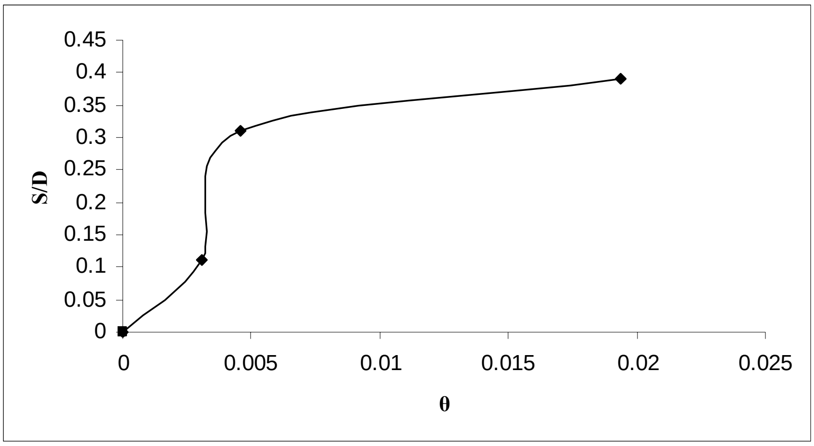

Figure 3. Effect of shields parameter on equilibrium scour depth.

4.2. Scour pattern around multiple pipeline

As mentioned before, the experiments are carried out with two pipes. When more than one pipeline is laid on seabed, depth of scour (as well as the maximum scour depth) may change, depend on the number of pipelines and the spacing between them.

Figure 4 shows the model results of two case studies for single and double pipelines (with spacing equal to pipe diameter). Comparing the equilibrium scour profiles of tese two cases reveal that the depth and width of scour were increased in the case of multiple pipelines.

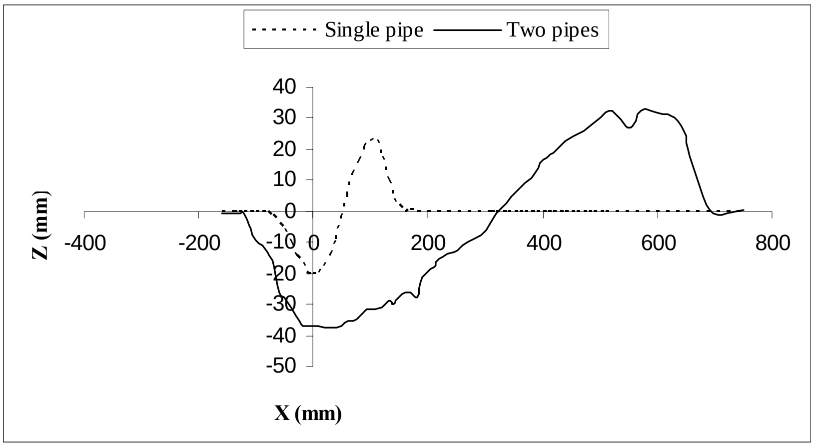

Figure 4. Equilibrium scour profiles of single and two pipes. Spacing between pipes is equal to pipe diameter.

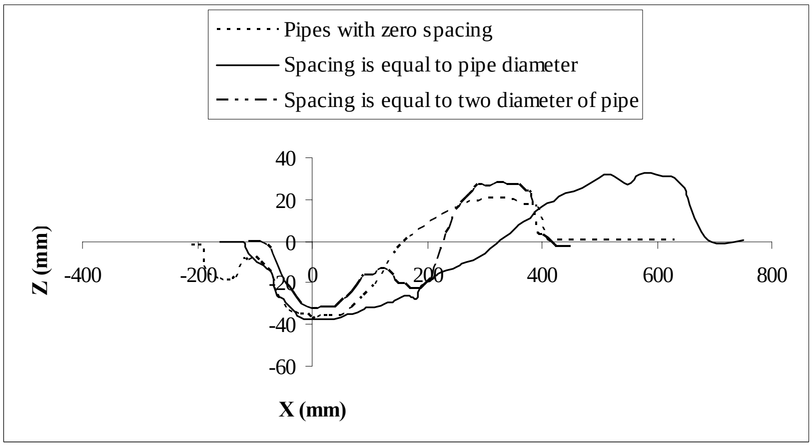

Figure 5. Effect of pipe spacing on equilibrium scour profiles in the case of two pipes.

In figure 5 similar equilibrium scour profiles for different spacing between pipes were compared with each other. This figure indicated that when the spacing between the pipes is over than the pipe diameter, the effect of one to another was reduced.

Also the scour depth in the case of zero spacing is smaller than that of 1D between them.

4.3. Effect of spoiler on scour profile

Due to scouring underneath pipelines, pipelines laid on the seabed may bury themselves in the seabed by various mechanisms. Where pipelines would not bury themselves fast enough (or they would not bury themselves at all), other tools must be used to stimulate the self-burial of pipelines. For this purpouse a spoiler attached to the pipeline longitudinally which is shown in figure 6. In figure 6 the equilibrium scour profiles of two pipes with and without spoiler are compared.

As seen from this figure, the maximum scour depth in the case of pipe with spoiler is approximately three times greater than that of the pipe without spoiler.

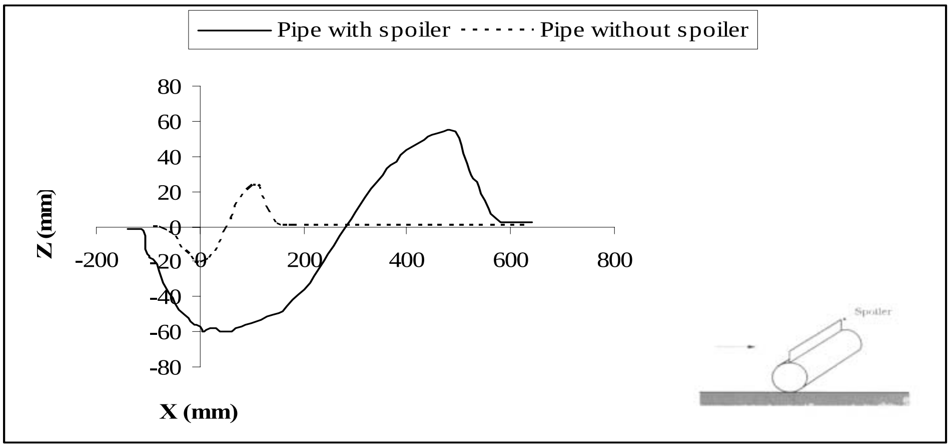

Figure 6. Effects of spoiler on equilibrium scour profile.

5. Conclusion

(1) The present physical model considers the interaction between the unidirectional flow, pipeline, and changing bed topography for various cases.

(2) In this model in order to avoid armoring and locking the grains, uniform grain sizes were used.

(3) With increasing pipe diameter the maximum scour depth, scour hole volume, and distance from crest and trough of the scour profile for central pipe axis are increased.

(4) Eq. (1.3) may be used to assess the equilibrium scour depth in the case of clear water.

(5) The scour depth hase increased linearly with Fourde number. Also by decreasing water depth the scour depth hase been increased.

(6) The effect of the shields parameter is quite weak when $\left(\theta > \theta_{cr}\right)$. However, it becomes increasingly important when $\left(\theta < \theta_{cr}\right)$. As can be seen, the effect of θ should be taken into account when it is smaller than critical value of shields parameter (i.e., in the case of the clear water scour).

(7) In the case of multiple pipelines the scour depth and width of scour profiles were increased. When the spacing between the pipes is over than the pipe diameter, the effects of them to each other were reduced.

(8) In order to increase self-burial potential of the pipe a spoiler can be added longitudinally to the crest of pipe section. This method in large depth seas will be economically. The final scour depth of the self-burial in the spoiler case will be larger than that of the pipe without spoiler.

(9) The spoiler reduces the time necessary to accomplish a given self-burial depth with respect to a plain pipeline.

(10) As can bee seen form the physical model results, equilibrium scour depth, scour hole volume, and the distance from crest and trough of the scour profile to central pipe axis, are together changed simultanously. Because the angle of slop of scour hole couldn't more than angle of internal friction of sand, therefore increasing scour depth depend on the increasing scour volume and this depends on the increasing the distance from crest and trough of the scour profile to central pipe axis.

(11) In all cases scour hole hase a jentel slope in downstream and steep slope in upstream.

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