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STUDY OF SCOUR AT DOUBLE SUBMARINE PIPELINES DUE TO WATER CURRENTS

دراسة النحر لخط انابيب بحرى مزدوج نتيجة للتيارات المائية

By

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ملخص البحث :

يقدم البحث دراسة معمليه لظاهرة النحر الموضعى أسفل خط انابيب بحرى مزدوج . فى هذا البحث تم اجراء اكثر من مائة تجربة معمليه لدراسة تأثير العوامل المختلفة لهذه الظاهرة مثل قطر خط الانابيب ، المسافة بينهما ، عمق المياه ومعدل سريانها وذلك فى قناة معمليه ذات قاع من مواد غير متماسكه (رمال) . أوضحت النتائج كيفية حدوث هذه الظاهرة وتطورها والشكل النهائى لها . لتحليل النتائج المعملية تم تمثيل العوامل المختلفة لهذه الظاهرة على شكل منحنيات غير بعدية بالاضافة الى استنباط ثلاث علاقات رياضية للتنبؤ بأقصى نحر ممكن وذلك باستخدام الاساليب الاحصائية كدالة فى رقم " فراود ".

ABSTRACT

The main objective of this study is to improve the influence of spacing between double submarine pipelines on local scour. Experiments have shown how local scour develops around double submarine pipelines in noncohesive sediment. Based on experimental results, a number of curves are illustrated to represent the relationship between maximum scour depth and Froude number for pipeline diameters, spacing between pipelines, flow depth and flow rate per unit width. It highlights the limitations of Froude number to estimate maximum scour depth at submarine pipelines. According to Froude number limitations, three formulae for prediction of maximum scour depth at submarine pipelines are presented.

INTRODUCTION:

The rapid development of offshore oil fields has increased the construction of submarine pipelines for transport of crude oil to onshore refineries. Interaction between the pipelines and an erodible bed under current and/or wave conditions tend to undermine part of the pipe causing it to be suspended in water. If the free span of the pipe is long enough, the pipe may experience resonant flow-induced oscillations, leading to structural failure.

Most research investigations, Bijker and Leeuwestein [2]; and Chiew [4], were conducted on scour due to the presence of a single submarine

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pelines. The present study illustrates the effeet of spaeing between uble suhmarine pipelines on scour hole depth and length. In present periments, pipes were placed just on top of an initial horizontal d, see Fig. (1). Fnr each set of water depths and discharges, acing between pipelines were 1.5, 2, 3, and 4Φ. Three pipeline ameters, Φ, were considered (2.7, 3.35, and 4.2 cm).

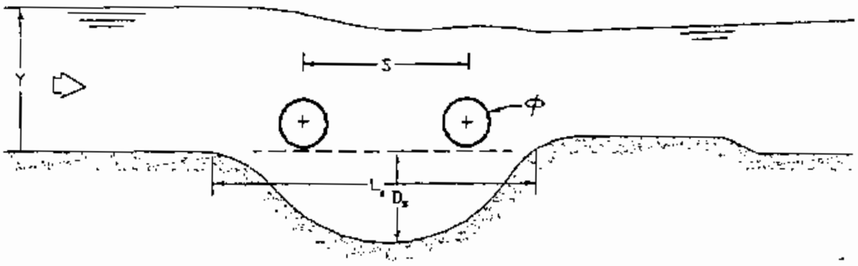


Fig.1- Layout of the problem under considration.

VIEW OF PREVIOUS INVESTIGATIONS

The number and variety of formulas proposed for prediction of cal scour depth around bridge piers is numerous, but comparatively w are found for estimating scour depth at single submarine pelines. In general, these equations relate the depth of scour to rameters, such as velocity, pipe diameter, grain size, and flow pth. These equations were derived from experimental data, Ibrahim], collected them at the University of New-Castle upon Tyne in gland. Chao and Hennessy [3] proposed an analytical method for timating maximum scour depth under pure current condition. Herbich al. [7] advocated use of this method and reproduced it with little ange in several publications. The fourth investigation containing veral research projects, Bijker [1]; Bijker and Leeuwestein [2]; and euwestien et al. [5], was conducted at Delft University of Tech- logy in the Netherlands. The last research work in this list was nducted at the Technical University of Denmark (Fredsøe and Hansen]; Mao [8]). Besides establishing an empirical relationship between our depth and other parameters. Bijker and Leeuwestein [2] also entified three forms of erosion around single submarine pipeline:

- *Luff erosion, which occurs at the upstream side of the pipe and is caused by an eddy formation upstream of the pipe.*
- *Lee erosion, which occurs at the downstream side of the pipe and is caused by reemergence of the main flow over and the turbulent wake downstream of the pipe.*
- *Tunnel erosion, which occurs under the pipe and is a direct consequence of the increased velocity underneath the pipe compared with the undisturbed velocity.*

Bijker and leeuwestein [2] stated that the fundamental cause of osion around a pipeline is a local increase in transport capacity of e flow around the pipeline, while deposition takes place where this *capacity decreases. This argument is, nevertheless, a necessary corollary of their observation, rather than an explanation.*

Mao [8] reported the formation of three types of vortices around a single submarine pipeline resting on a plane bed. As illustrated in Fig. 2(a), one of the vortices, A, formed at the nose of the pipe, the other two vortices, B and C, formed downstream of the pipe. The onset of scour is thus, according to Mao, due to the combined action of the vortices and under flow, which leads to the formation of a small opening under the pipe as more and more sand particles are carried away. Figure (2) clearly illustrates the process of the onset of scour.

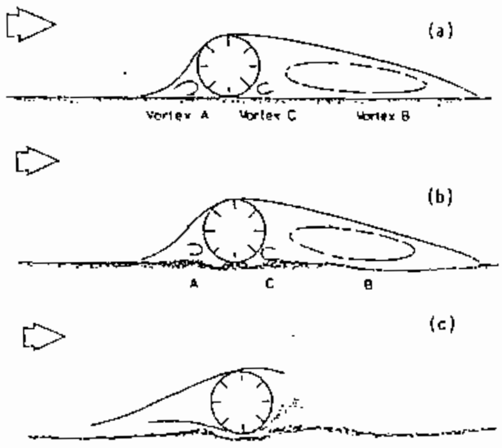


Fig.2- Three-vortex system and onset of scour.(after Mao)

Chiew [5] proposed an empirical function relating the amount of gap flow through the scour hole for given flow conditions. He proposed an iterative method for estimating maximum scour depth at single submarine pipelines.

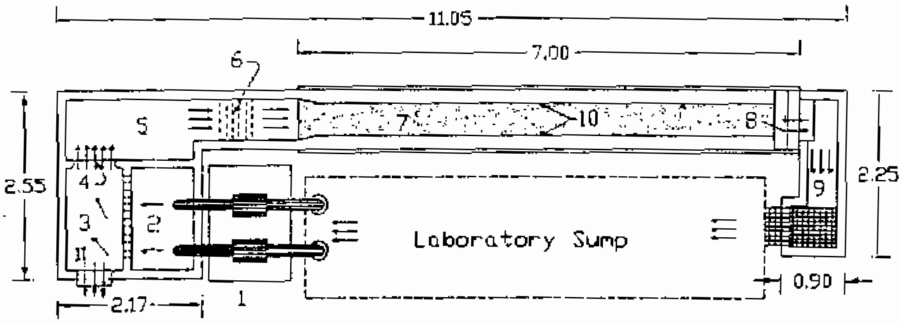
EXPERIMENTAL SET-UP

The experiments in this study were carried out in a flume 7.0m long, 0.4 m wide and, 0.4 m deep. Three different pipe diameters 27, 33.5, and 42 mm were used. For each test, the cylinders those extended the entire width of the flume were used to represent the pipes. The cylinders, fixed at both ends, were just lying on a horizontal sand bed. It must be pointed out that the grain size used in the experiment for verification had a mean value of 0.35 mm.

Equilibrium of scour hole profile was achieved within three hours duration in average. After equilibrium of scour, the flow was stopped and the profile of scour hole was recorded.

Three different approach flow depths, at 2.0, 2.5, and 3.0 ⌀ were ed in the experiments. To simulate submarine pipelines, the flow pth is always greater than the pipe diameter. The mean flow velocity s determined by dividing the flow rate per unit width by the depth flow.

The flume mainly consists of head and tail tanks and the flume self through which the flow is conveyed, see Fig.(3). Water stored the laboratory ground sump is transported by a centrifugal pump to e head tank. The head tank consists of two adjacent tanks connecting gether through holes. The delivery of the pump supplies the first nk with the pumped water, consequently, the level of the adjacent nk rises. The aim of using two tanks is to damp water fluctuations. e second tank has two weirs, one of them is to measure the flow, the her is to allow excess water overflow and to be drained into the ound sump. Thus the water head over the calibrated weir can be maintined at the constant value despite any fluctuations in the pump flow te. Water acting head over the weir is measured with a vertical ale.



1- Centrifugal pumps
2- First head tank
3- Second head tank
4- Flow measuring weir
5- Approach basin
6- Inlet screen
7- Sand bed
8- Tail hinged gate
9- Tail tank
10- Flume sides
11- Escape weir

Fig.3- Experimental set-up

The flow passes into the flume through an inlet screen to absorb ny water eddies. Water depth in the flume is controlled using a inged gate fixed at the flume end. Water were drained into the tail ump that leads to the ground sump. The depth of water could be easured with a probe which is mounted on the X-Y carriage. The carrige travels on two sets of rails.

Coarse adjustment of the probe is accomplished by sliding the inted rod up or down inside the long guide cylinder and securing it ith thumb screw. Fine adjustment is done by turning clockwise or *counter clockwise a large wheel on the probe, which in turn engages the guide cylinder. Guide cylinder is linked to the scale, which allow precise readout of the water height.*

THE EXPERIMENTAL PROCEDURE

In this study, three discharges were considered, (q = 138.25, 217.35 and 311.41 cu.cm/sec/cm.) with mean velocities ranged from 10.97 to 45.8 cm/sec). Flow depths were 2.0, 2.5, and 3.0 Φ *(5.4 to 12.6 cm).*

Spacing between pipelines are 1.5, 2.0, 3.0, and 4.0 Φ*, respectively. One hundred and eight runs were conducted. In all runs, if scour was not in a symmetry w.r.t. the centerline of the flume, the test would be repeated to ensure that the onset of scour was not due to side wall effects.*

The following are some problems that were faced during the work process and how they were overcomed;
1 - Pipelines are not fully rested on bed that has non-horizontally surface. This problem has been overcomed using water balance to adjust both of bed surface and pipelines.
2 - Starting the run while downstream side of pipelines is dry leading to false scour. Before the commencement of a run, the flume was filled from both ends, to a level slightly higher than the predetermined flow depth. The pump was then switched on and the downstream gate lowered simultaneously. This procedure was followed strictly to ensure that the onset of scour was caused by the predetermined flow condition rather than the instability other wise induced.
3 - Pipelines are not perpendicular to the flow and spacing between them is not constant. To overcome this problem, a right angle was used to fix the line and to define spacing between pipelines, a bar with certain thickness may be used.
4 - Distortion of scour hole at the end of the run due to switch off the pump and sudden change in water depths in the flume. To overcome this problem, before switching off the pump, water depth is slightly increased, the pump switched off and emptying the flume from its ends gradually with small rate.

RESULTS AND ANALYSIS

From experiments, it was observed that, there were different forms of scour holes which depend on the conditions of flow, pipe diameter, and spacing between them. Figure (4) shows the recorded deformations of scoured beds. The main cause of scour around pipelines is the change of flow pattern around the pipes and the subsequent response of the sediment.

Experiments include measurements of maximum scour depth, Ds, and scour length, Ls, for pipeline diameters, Φ *= 2.7, 3.35, and 4.2 cm. The considered pipeline spacings were S=1.50; 2.0; 3.0 and 4.0* Φ *and flow depths were Y=2.0; 2.5; and 3.0* Φ *with flow rate per unit width, q=138.25; 217.35 and 311.41. Experimental results are illustrated in dimensionless forms as shown in Figs. (5) to (10).*

a) Wide scour hole
$F = 0.37$, $y=3\phi$, $S = 3\phi$

b) Narrow scour hole
$F = 0.35$, $y=2\phi$, $S=3\phi$

c) Narrow with an attached
downstream scour hole
$F = 0.35$, $y=2\phi$, $s=4\phi$

d) Wavy scour hole
$F = 0.25$, $y=2\phi$, $S=4\phi$

d) Wavy scour hole with an apex in between
$F = 0.19$, $y=3\phi$, $S=2\phi$

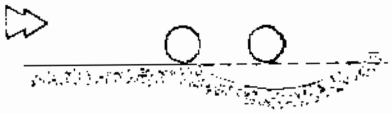
Fig.4a- Scour under the two pipes.

a) Scour under the first line only
$F = 0.18$, $y=2.5\phi$, $S=3\phi$

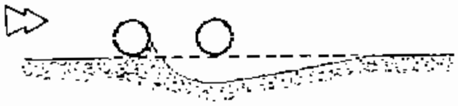
b) Scour under the first line with deposition on the second one.
$F = 0.19$, $y=3\phi$, $S=1.5\phi$

c) Scour under the first line, deposition on the second one and an attached downstream scour hole. $F = 0.25$, $y=2\phi$, $S=3\phi$

Fig. 4b- Scour under the first pipeline only



a) Scour under the second line only
F =0.285, y=2Φ, S=4Φ



b) Scour under the second line, front erosion for the first one. F =0.30, y=3Φ, S=4Φ

Fig. 4c- Scour under the second line only

Fig. 4d- Downstream scour hole with front erosions for both lines
F = 0.40, y=2.5Φ, S=3Φ

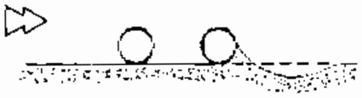


Fig. 4e- Immediate downstream scour hole with no scour under pipelines
F =0.285, y=2Φ, S=1.5Φ

Figures (5) and (6) are illustrated for pipeline diameters, flow depth ratio, ϕ/Y= 0.33; 0.4; and 0.5.Figure (5) shows the relationship between Froude number, F, and the ratio of scour depth to the spacing between lines, Ds/S. Figure (6) shows the relationship between Froude number, F, and the ratio of scour length to the spacing, Ls/S. In the above mentioned figures, it is evident that, as Froude number increases, both maximum scour depth, Ds, and scour length, Ls, increase.

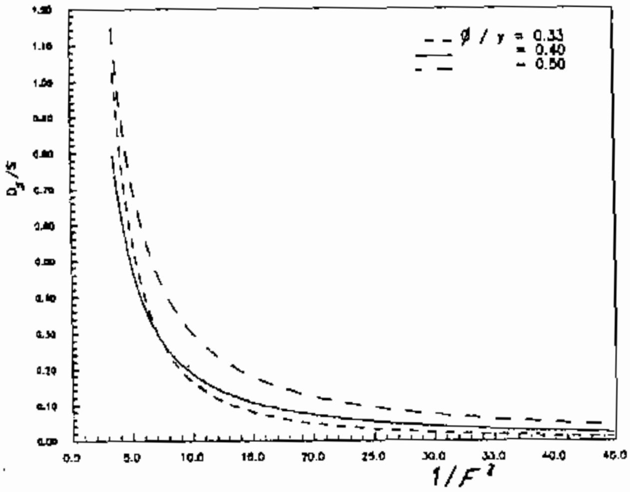


Fig.5- 1/ F^2 versus Ds/S

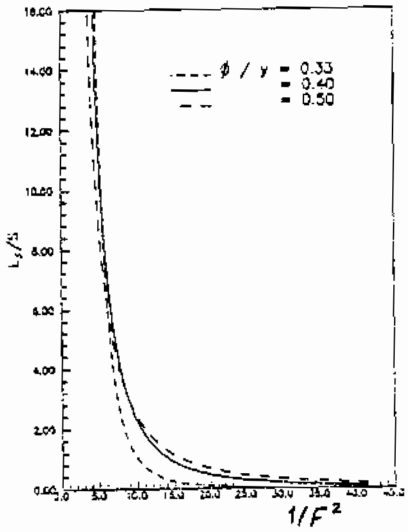


Fig.6- 1/ F^2 versus Ls/S

Figures (7), (8), and (9) illustrate the relationship between $1/F^2$, *and the ratio of scour depth to the diameter of pipelines,* (Ds/Φ) *for spacing ratio,* $S/\Phi = 1.5$, 2.0, 3.0, *and* 4.0. *From these figures, it is noticed that as* $1/F^2$ *increases as the relative scour,* (Ds/Φ), *decreases. Therefore, scour depth, Ds, is related to flow velocity, V, water depth, Y; gravitational acceleration, g; pipe diameter,* Φ, *and spacing between pipelines, S.*

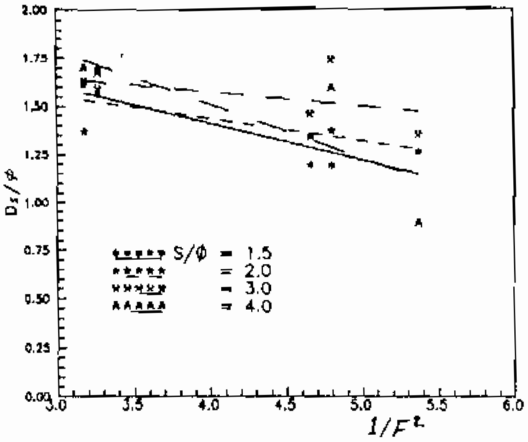


Fig.7- $1/F^2$ *versus* Ds/Φ ($1/F^2 = 3.$ *to* 6.)

Experimental results may be classified into five types of flow according to the behaviour of scour with Froude number. The first type is for Froude number, $1/F^2$, *less than three. This type of flow is accompanied with high velocities which lead to washout bed materials within a relatively small time. Results of this type of flow were excluded due to difficulties of recording scour progress and also as these cases are not practical.*

The second type of flow is limited with Froude number, $1/F^2$, *from 3.0 to 6.0. In this type of flow, progress of scour is clear. Scour extends to a long distance downstream of pipelines, i.e, there was no recorded scour in upstream side of pipelines. For this type of flow, to predict maximum scour depth, equation (1) is the estimated formula that is a function of pipeline diameter,* Φ, *Froude number,* $1/F^2$, *and spacing between lines, S. This equation is based on the technique of curve fitting as follows;*

$$Ds/\Phi = 2.32 - 1/F^2 \left[0.1((S/\Phi)-2.6)^{1.5} + 1.2 \right] \qquad (1)$$

The third type of flow is characterized by Froude number, $1/F^2$, *that ranged between 6.0 to 12.0. Results of this type of flow were illustrated in Fig.(8). From this figure, it is evident that, maximum* *scour depths at submarine pipelines are in medium range comparing with the results of second and fourth types of flow. For this type, Eqn.(2) was derived to estimate maximum scour depth as follows;*

$$Ds/\Phi = \left[\ 7.88/\ln[(2S/\Phi)+3]\right] - \left[\ 1.83 - .1(S/\Phi)^{1.5}\ \right]\ \ln\ (1/F^{2}) \qquad (2)$$

Figure (9) shows the illustration of results those obtained from the case of the fourth type of flow, ($12. < 1/F^2 \leq 32.$). In this type of flow, velocity of flow and the existed scour were small with respect to previous types and changing Froude number within the range had small influence on the recorded depths of scour. Equation (3) is the proposed one to estimate scour depths using the parameters of, pipeline diameter, spacing between them and Froude number as follows;

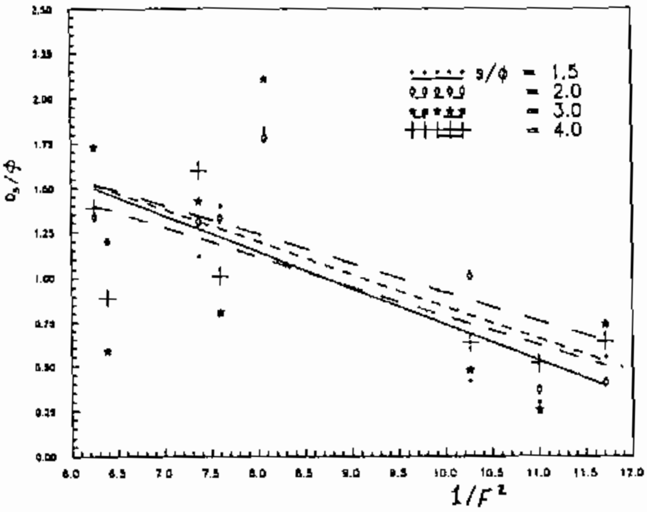


Fig.8- $1/F^2$ versus Ds/Φ ($1/F^2 = 6.$ to $12.$)

$$Ds/\Phi = 1.2\ln\ [(S/\Phi)+.12] - .013\ (1/F^{2})(S/\Phi) \qquad (3)$$

The fifth type of flow is for Froude number, $1/F^2$, greater than 32.0. In this type, velocity of flow was small and there were no scour hole recorded at pipeline positions.

The computed maximum scour depths according to Eqns. (1), (2) and (3) are compared with the recorded ones those obtained from experiments as shown in Fig. (10). From this figure, it is clear that most of computed data points lie within a scatter of ±20% for equation (1) while for Eqns. (2) and (3), there were over and under estimations due to the sensitivity of measurements which lead to a tangible error for small depths.

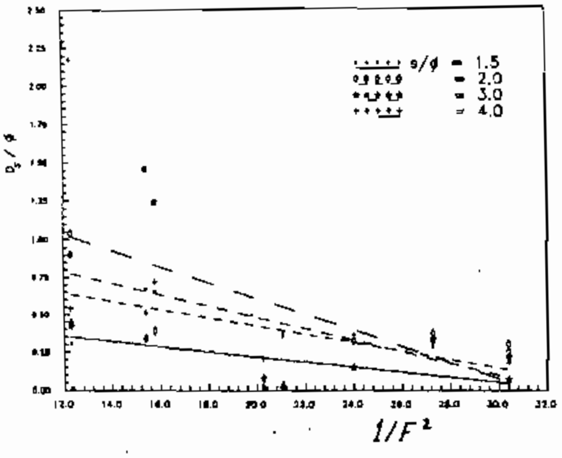


Fig.9- $1/F^2$, versus Ds/ϕ ($1/F^2 = 12.$ to $32.$)

The fifth type of flow is for Froude number, $1/F^2$, greater than 32.0. In this type, velocity of flow was small and there were no scour hole recorded at pipeline positions.

The computed maximum scour depths according to Eqns. (1), (2) and (3) are compared with the recorded ones those obtained from experiments as shown in Fig. (10). From this figure, it is clear that most of computed data points lie within a scatter of ±20% for equation (1) while for Eqns. (2) and (3), there were over and under estimations due to the sensitivity of measurements which lead to a tangible error for small depths.

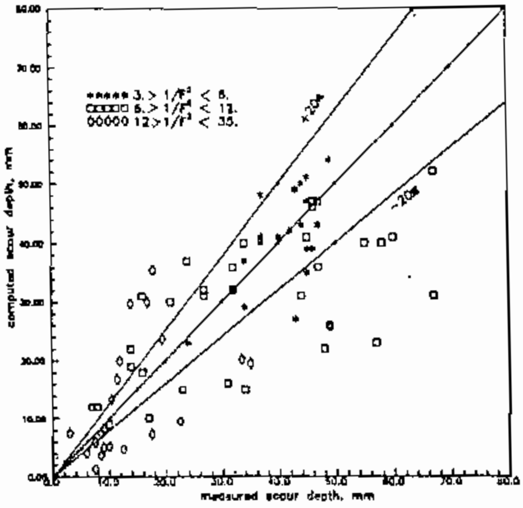


Fig. 10- Comparison between measured and computed scour depth.

NCLUSIONS

For double submarine pipelines just resting on a flat and rizontal erodible bed, experimental observations showed that, ximum scour depth occurs within a distance starting from the midway tween pipelines up to 13 thirteen times the pipeline diameter in wnstream direction. Three formulae were derived to predict maximum our depth at double submarine pipelines as a function of Froude iteria. Scour at double submarine pipelines may be eliminated for lues of Froude number less than 0.18.

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TATION

The following symbols are used in this paper:

Ds = *scour depth;*
$d50$ = *mean particle size;*
F = *Froude number,* $v/\sqrt{gy}$ *;*
g = *gravitational acceleration;*
L = *length of scour;*
q = *unit flow rate;*
S = *spacing between double submarine pipelines;*
V = *mean velocity;*
Y = *flow depth; and*
ϕ = *pipeline diameter.*