Numerical Modelling of Local Scour around Offshore Pipelines

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Abstract

Based on an intensive review on the development of numerical models of local scour below offshore pipelines over the last two decades, a numerical model is developed for predicting the time development of scour hole below a pipeline. The present numerical model solves the flow field using a Large Eddy Simulation (LES) model. The morphological change of the seabed is calculated via the continuity equation. The sediment deposition and entrainment rates are linked with the concentration of the sediment. The application of the present model to some laboratory tests demonstrates the robustness of the present model.

Résumé

Basé sur une revue intensive du développement des modèles numériques d'étude de l'érosion locale sous des conduits situés en pleine mer, un model numérique a été développé pour prédire le temps de development d'un trou due à l'érosion sous un conduit. Ce modèle numérique, résout le champ d'écoulement en utilisant un modèle "Large Eddy Simulation" (LES). Le changement morphologique du fond marin est calculé à partir de l'équation de continuité. La déposition sédimentaire et le taux d'entraînement sont liés à la concentration sédimentaire. L'application de ce modèle à quelques essais de laboratoire démontre la robustesse du modèle.

1. Introduction

Offshore pipelines laid on an erodible seabed are subject to local scour due to the disturbance to the local flow conditions. Local scour can leave the pipeline unsupported over sections that may extend significant distances. The pipeline may then subject to fatigue damage due to the oscillatory loads induced by waves or vortex shedding, or to mechanical damages such as by fishing trawls. An important aspect of pipeline design is the assessment of the likelihood for significant scour to occur and, if necessary, either how the design can be modified to reduce the risk of damage arising from scour or, alternatively, what preventive measures can be taken to reduce the occurrence of scour (Whitehouse, 1998).

Considerable research effort has been devoted to local scour adjacent to offshore pipelines and significant insights to the mechanisms of local scour have been achieved

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over the last two decades (see Whitehouse 1998; Sumer and Fredsøe 1999). Most of the investigations on local scour around pipelines are experimental and mainly on two-dimensional scour processes. There is no doubt that physical modeling is a fundamental and effective method to understand the mechanisms of scouring process. However, small-scale laboratory tests do suffer from scale effects because most of the scale-down models can not satisfy the similarity laws exactly. There are several scale effects such as the pipe Reynolds number, pipe roughness, in-coming flow turbulence, etc. (Sumer and Fredsøe, 1999). The scale effects need to be considered when the experimental results are interpreted to prototype situations. Unfortunately little is known about these scale effects and none of these effects have been studied in a systematic manner (Sumer and Fredsøe, 1999).

In contrast to the scaled-down laboratory tests, numerical models of local scour around pipelines do not suffer from scale effects. Once the numerical model is developed, it can be applied to different operational conditions including those can not be achieved under laboratory conditions. Many issues that could not be investigated thoroughly by model tests can be examined numerically. A typical example of this is the scale effects. Since it is very difficult to carry out experiments with large model pipes under laboratory conditions, the understanding to the scale effects is still limited. However the scale effects can be easily investigated using a proper numerical model. Numerical tests on the same scour process can be run under both model and prototype conditions. The individual factors that may affect the scour process can be isolated and controlled easily by numerical model. In that sense, a good numerical model can certainly be complementary to model tests and can assist design engineers to identify the most crucial cases for which model tests may be run. The ultimate goal of numerical models will be replacing (at least partially) the costly model tests and to be used directly in the design of pipelines.

Development of numerical models for local scour around pipelines has been slow, despite of their relative significance. There mainly two kinds of numerical models on local scour below a pipeline have been developed: simple mathematical models and integrated mathematical models (Sumer and Fredsøe, 1999). The simple model concerns the scour around a fixed pipe while the integrated model considers dynamic interactions between a flexible pipeline and the resulting scour process. Most of the models reported in literature so far are simple models. The idea of the integrated model however is to predict the entire scour process such as the occurrence and disappearance of scour along a pipeline, scouring and backfilling below the pipeline due to the sagging of pipeline. It is obvious that such a model is much more complex than the simple scour model and needs to be based on the development of the simple model. Due to the complexity of the problem and the limited computer resources that were available, current knowledge on the simple models prevents a comprehensive integrated model from being developed. Therefore the focus will be given to the simple mathematical model in this paper.

Over the last two decades, mainly two kinds of numerical model for scour prediction have been developed. One is based on the potential flow theory, such as Hansen et al. (1986) and Li and Cheng (1999a), and the other is based on the k-ε models, such as Leeuwenstein and Wind (1984), Brors (1999) and van Beek and Wind (1990). It has been demonstrated that the potential flow models are able to predict the maximum depth and the upstream part of scour hole correctly. However, none of the potential flow models can explain the gentle slope of the scour hole formed downstream the pipe (Li and Cheng, 1999a). This is mainly due to the fact that the potential flow model can not simulate the vortex shedding process associate with the flow around the pipeline. It has beenn understood (Sumer et al., 1988) that the gentle slope of the scour hole formed downstream the pipeline is mainly due to the vortex shedding around the pipeline.

Early numerical models based on k-ε turbulence models seemed to have difficulties to predict the shape of scour hole. Leeuwestein et al. (1985) developed a numerical model based upon k-ε turbulence model and a sediment transport equation. A numerical package named ODYSSEE was used to calculate the turbulent flow field. As for the computation of the sediment transport and the variation in seabed topography they reported a failure in obtaining a real scour hole shape by using an empirical bed-load formula. This was ascribed to the ignorance of the suspended-load contribution in the model. In the numerical part of the investigation by Sumer et al. (1988), the so-called Cloud in Cell (CIC) method was employed to simulate the flow. It was reported that the CIC method generally gives good prediction on the gross characteristics of the organized wake behind the pipeline. However, there was no evidence in the paper showing that a numerical model was employed to calculate the seabed deformation. Instead, by comparing the effective Shields parameter with its time average value, an important conclusion was drawn by Sumer et al. (1988) that the organised wake behind the pipeline has strong effects on the profile of scour hole downstream of the pipeline. The time-averaged bed shear stress is not a suitable parameter to use in predicting the lee-wake scouring behind a pipeline.

Some improvements on the k-ε based models have been achieved recently. Van Beek and Wind (1990) developed a numerical model based on k-ε turbulence model and a transport equation for suspended sediment. The application of the model to scour prediction below a pipeline with and without an attached spoiler showed fairly agreements with the measured equilibrium scour holes, although a certain degree of underestimation of downstream scour hole was quite evident in the report. The predicted rate of erosion was about three times as fast as in the physical model. BrØrs (1999) presented a model that includes the description of fluid flow by the standard k-ε turbulence and the suspended and bed-load sediment transports. Density effects were considered in the vertical momentum equation and in the turbulence equations. Flow around a surface mounted cylinder was predicted in good agreement with the experiments. However, in the scour calculation the model did not predict periodic vortex shedding, even during the later stages of scour development. The author suggested that a fine mesh (5000 nodes) is needed to predict the phenomena of vortex shedding. For the scour calculations, the prediction of a clear water scour hole (θ = 0.048, where θ is the Shields parameter) agreed well with Mao's (1986) experimental measurements. No attempts were made for cases of live bed scour.

Recently, Li and Cheng (1999b) developed a numerical model for local scour around pipelines employing a slightly different approach. The flow around the pipeline is solved using a Large Eddy Simulation (LES) model that results in more accurate prediction of seabed shear stress than traditional k-ε turbulence models. The equilibrium scour hole is determined by iterations, based on the assumption that the shear stress on the seabed is equal or less than the far field shear stress for live bed scour (or the critical shear stress for clear-water scour) every where when the equilibrium scour hole is established. The predicted equilibrium scour hole compared very well with the experimental results by Mao (1986) for both clear water and live-bed conditions (Li and Cheng, 1999b; 2000a). The advantage of the model is that it does not employ any empirical sediment transport formula. However, the disadvantage of the model is that it can not describe the time development of the scour hole due to use of the equilibrium assumption in the model.

In summary, it seems that none of the current models are able to simulate the time development of two-dimensional scour hole accurately even under steady current conditions. The key elements in developing a comprehensive model of time-dependent scour lie in two folds: 1) an accurate flow model that can result in accurate prediction of vortex shedding behind the pipeline and, 2) a proper sediment transport model.

The objective of the present paper is to develop a numerical model that is capable of predicting the time development of local scour below a pipeline. The model will employ the LES flow model developed by Li and Cheng (2000a). The morphological change of the seabed will be calculated in the same fashion as that used by Brørs (1999). The rate of bed-level change will be determined from the deposition rate D and the erosion rate E. The deposition rate D will be set equal to the difference of setting velocity and upward turbulent velocity times the near-bed concentration. The erosion rate E will be determined from the near-bed turbulence intensity and the concentration gradients. The concentration of the suspended-load will be calculated by solving the scalar transport equation of suspended-load concentration. The boundary condition for the near-bed concentration of suspended-load will be specified using an empirical formula derived from experimental measurements (Zyserman and Fredsøe, 1990). Details of the model implementation will be given in the following two sections.

2. Mathematical model

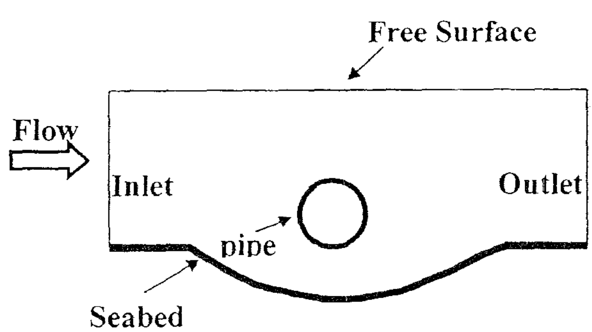

Fig. 1 Definition Sketch: calculation domain

2.1 Flow model

It has been demonstrated both experimentally (Sumer et al., 1988) and numerically (Li and Cheng, 1999b) that the local scour below a pipeline depends strongly on the vortex shedding flow around the pipeline. Li and Cheng (1999b) demonstrated that the fluctuating seabed shear stress plays an important role in the so-called lee-wake scour process. Therefore accurate prediction of the fluctuating seabed shear stress is very crucial to the prediction of local scour below a pipeline. Past experiences of authors' and some others (Li and Cheng, 1999b; Beaudan and Moin, 1994) indicated that the Large Eddy Simulation (LES) model is suitable for the vortex shedding flow around a circular cylinder.

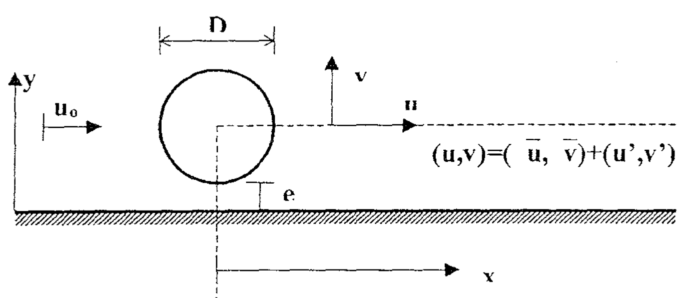

Fig. 2 Definition Sketch: a pipe near a wall

To simulate the flow around the pipeline, the Large Eddy Simulation model employed by Li and Cheng (2000a) is used in the present paper. The spatially-filtered Navier Stokes equations together with the governing equation for centration of suspended sediment can be written in the following dimensionless form:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \frac{\partial p}{\partial x} = \frac{1}{Re}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) + \frac{\partial \tau_{11}}{\partial x} + \frac{\partial \tau_{12}}{\partial y} \tag{2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \frac{\partial p}{\partial y} = \frac{1}{Re}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{\partial \tau_{12}}{\partial x} + \frac{\partial \tau_{22}}{\partial y} \tag{3}$$

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + (v - \omega_s)\frac{\partial c}{\partial y} = \frac{\partial\left(\overline{-c'u'}\right)}{\partial x} + \frac{\partial\left(\overline{-c'v'}\right)}{\partial y} \tag{4}$$

In the above equations, c is the concentration of suspended sediment, τ_{ij} is the subgrid scale shear stress, and Re is the Reynolds number based the incoming flow velocity u_0 and the diameter of the pipeline D . All quantities in the above equations are normalized by the density of the fluid ρ, incoming flow velocity u_0 and the diameter of the pipeline D. Smagorinsky's (1963) subgrid scale (SGS) turbulence model is adopted to close the equations, which relates the turbulence stress to the mean flow using an eddy-viscosity as,

$$\tau_{ij} = \nu_t\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) \tag{5}$$

$$\overline{-c'u'} = \frac{\nu_t}{\sigma_c}\frac{\partial c}{\partial x} \qquad \overline{-c'v'} = \frac{\nu_t}{\sigma_c}\frac{\partial c}{\partial y} \tag{6}$$

where ν_t is the eddy viscosity with $\nu_t = (C_s\Delta)^2\sqrt{2S_{ij}S_{ij}}$, S_{ij} is the strain-rate tensor ($S_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$), C_s is a coefficient and is taken as 0.1 in this study, σ_c is the turbulent Prandtl-Schmidt number (a value of σ_c =0.5 was suggested by Celik (1988)) and Δ is the filter width related to the grid size as $\Delta=(\Delta x\ \Delta y)^{1/2}$.

2.2 Boundary conditions

To solve the above equations, proper boundary conditions have to be specified. At the inlet boundary (see Fig. 1), the transverse velocity component is set to zero, and a uniform profile for the longitudinal velocity component is specified based. A vanishing-gradient of velocity componets is applied at the outlet boundary, and a symmetry boundary condition is prescribed on the top free surface boundary. At the non-slip wall boundary and the cylinder surface, zero velocity components are specified. On the inlet, outlet and wall boundaries, the pressure is obtained by applying the momentum equations in the direction normal to the boundaries.

In addition to the flow boundary conditions, boundary conditions on the concentration of suspended sediment have to be specified. At water and pipeline surfaces, the net sediment flux normal to the surfaces is zero. This results in

$$\overline{c'v_n'} - w_s c \cos\gamma = 0 \tag{7}$$

where $\omega_S c$ is the downward flux of sediment due to gravity, and $\overline{c'v_n'}$ is the flux of sediment due to turbulence motion (usually upward); γ is the angle between the surface and horizontal plane.

The free falling velocity normally decreases as the concentration of sediment increases. The reduction of ω_s due to high particle concentration is considered using an empirical formula (Richardson and Zaki, 1954):

$$\frac{\omega_s}{\omega_o} = (1-c)^m \tag{8}$$

where ω_0 is the settling velocity of single particle in quiescent water; m is a grain size related constant, m=2.65~5.0.

At the erodible seabed, either the net flux of sediment or sediment concentration need to be specified. Since the residual flux is not readily calculable, alternatively, the near bed suspended load concentration is specified using an empirical formula (Zyserman & Fredsøe,1990)

$$c_b = \alpha \frac{0.331(\theta' - 0.045)^{1.75}}{1 + 0.72(\theta' - 0.045)^{1.75}} \tag{9}$$

where c_b is sediment concentration at an elevation b=2d, d is grain size, α is a coefficient, θ' is Shields parameter related to skin friction; the 0.045 is considered as critical value of Shields parameter for initiation of motion.

Equation (9) is based on the extensive experimental tests for sediment diameter ranged from 0.19 mm to 0.95 mm.

The sloping bed effect on sediment entrainment is considered by the modification of critical Shields parameter.

$$\frac{\theta'}{\theta_o'} = \cos\delta \pm \frac{\sin\delta}{\tan(\phi_S)} \tag{10}$$

where θ_o' is the Shields parameter related to skin friction on flat bed; δ is the angle between the seabed and the horizontal plane; ϕ_S is the angle of repose. The positive sign on the right hand side in Eq. (10) is for an up slope flow and negative sign is for a down slope flow.

At inlet boundary, a power-law is used to specify the concentration profile (Rouse, 1939).

$$c(y) = c_b\left[\frac{y}{y_b}\frac{h-y_b}{h-y}\right]^{-B} \tag{11}$$

where h is water depth, b is Rouse number, for d_{50} = 0.36mm sediment B = 2.8, and c_b is reference concentration at the level of y_b above seabed given by Eq. (9).

2.3 Numerical method

The governing equations (1) to (4) together with the boundary conditions are solved using finite difference method in a curvilinear coordinate system. The convection terms in equations (2) to (4) are discretized using a third-order upwind scheme and the other terms are discretized using central difference. A second-order scheme is used for all the time dependent terms. For details of numerical implementation, readers are refered to Lei et al. (1999).

2.4 Morphological model

The presence of pipeline breaks the local sediment balance and causes the variations in flow field. The location at which deposition or erosion takes place depends on whether the amount of sediment settling, D, is larger or less than the amount of sediment entrainment, E. The net cross boundary flux of sediment is zero only under equilibrium conditions. In general, there is a residual flux, which is normally the cause of morphological change of seabed.

For two-dimensional suspended-load dominant applications, the general sediment continuity equation can be written as

$$(1-n)\frac{\partial y_s}{\partial t} = (\omega_s - v)c_b + \frac{v_t}{\sigma_c}\frac{\partial c}{\partial y} \tag{12}$$

where n is the porosity of bed; y_s is bed level.

The first term on the right hand of equation (12) is the rate of deposition of entrained material, expressed as volume of sediment grains settling from suspension onto unit area of bed per unit time. The second term is the actual rate of entrainment of sediment mass from the bed, expressed as volume of sediment grains eroded into suspension from unit area of bed per unit time. Equation (12) indicates that the bed morphological change y_s is not only a result of upward diffusive flux and downward settlement but also the contribution of convective transport vc_b. It should be noted that the bedload sediment transport is not included in the morphological model given in Eq. (12). This implies the use of the assumption that the gradient of bedload transport in the flow direction is negligible. This is mainly based on the experimental findings that the bedload sediment transport is only confined within a very thin layer of a thickness of a few sediment diameters (Zyserman and Fredsøe, 1990).

2.5 Solution process

The solution process of local scour below a pipeline will start by solving the flow field and suspended-load concentration field around the pipeline with a specified seabed profile. Once the flow and suspended-load concentration fields are obtained, the morphological change of the seabed can be calculated by solving the continuity equation of sediment transport (Eq. (12)). The flow and suspended-load concentration fields will be calculated again with the updated seabed profile and the seabed is adjusted again with the new flow and concentration fields. This process will be repeated until the desired time of solution is reached. Since the morphological change of the seabed normally has a much larger time scale than the flow field, the solution of the flow field and update of the seabed profile use different time-steps to reduce the computation time. In the present study, the dimensionless time-step used to calculate the flow field is 0.001 while the time step used for morphological calculation is about 2. Given that a typical vortex shedding period is about 0.2, the seabed is updated once in about 10 shedding periods. This can save considerable calculation time.

3. Results and discussion

3.1 Validation of the LES model

In order to evaluate the performance of the present LES flow model, calculations are carried out for a case where experimental measurements are available (Jensen, 1987). In Jensen's experiments, the pipe was placed at 0.37D above a plane bed with a water depth 265 mm, the pipe diameter D= 30 mm and a Reynolds number Re= 7000 (based on free-stream velocity and cylinder diameter). A comparable set up is simulated numerically in a domain of 3000×350 mm with a pipe of diameter of 100 mm being placed at the position of 37 mm above the flat bed and 1000 mm from the inlet of the domain. A 153×63 mesh with grid points being concentrated towards the pipe surface and the seabed is employed for all the cases after a careful mesh-dependence study.

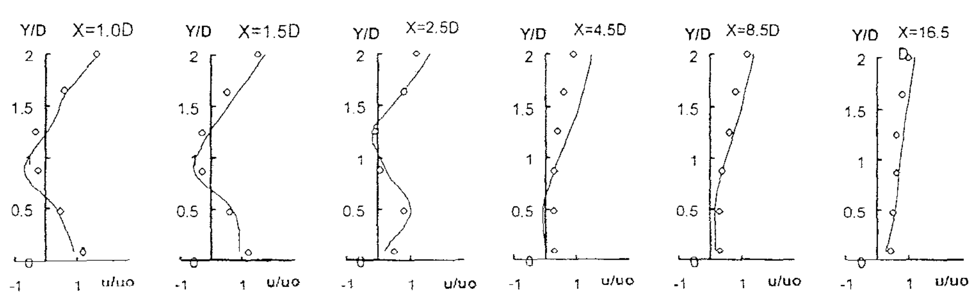

Fig. 3 Time-averaged horizontal velocity component $\overline{u}/u_0$ °Experiment by Jensen, --Model prediction

Fig. 3 and Fig. 4 give the horizontal and vertical velocity components at a number of sections downstream the pipeline together with the experimental results of Jensen (1987), respectively. It can be seen that the numerical model simulates the gross behaviour of the flow quite accurately. Fig. 5 and Fig. 6 show the comparison of the distributions of r.m.s horizontal and vertical components of velocity with the experimental results of Jesen (1987) at the same cross sections. It is seen again that the numerical results are in a fair agreement with the experimental results. This demonstrates that the present flow model (LES) is able to predict the gross behaviour of the vortex shedding flow investigated here.

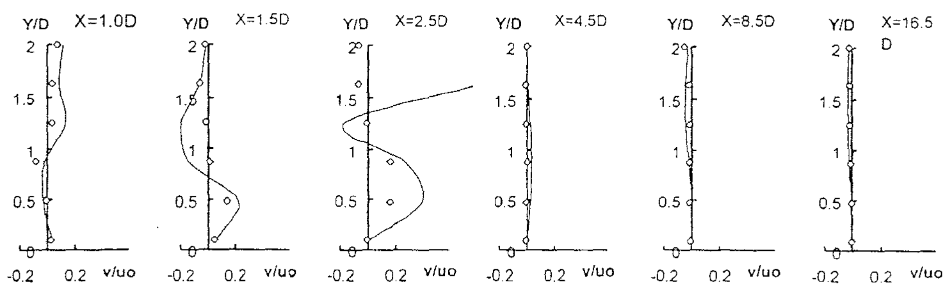

Fig. 4 Time-averaged vertical velocity component $\bar{v}/u_o$. ° Experiment by Jensen. --Model prediction

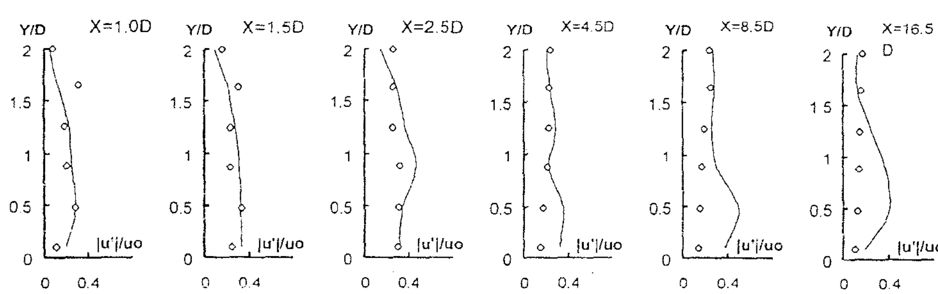

Fig. 5 r.m.s. values of horizontal fluctuations component u'/u_o. ° Experiment by Jensen, --Model prediction

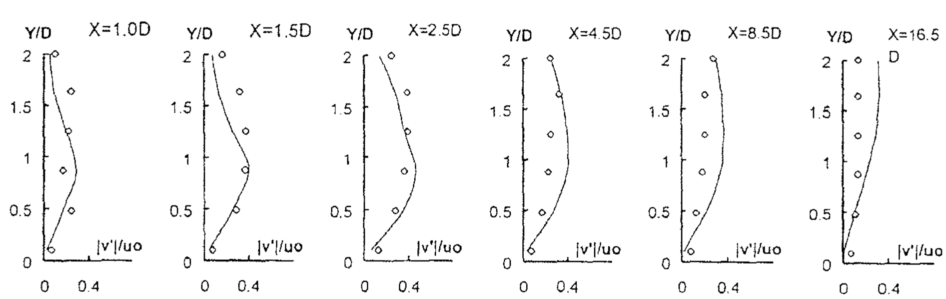

Fig. 6 r.m.s. values of vertical fluctuations component v'/u_o ° Experiment by Jensen, --Model prediction

3.2 Local scour below a pipe on the seabed

To validate the numerical model developed in the present paper, some of the model tests conducted by Mao (1986) are chosen here as the test cases of the numerical model. Table 1 gives a summary of the cases for which the numerical tests have been run. The flow conditions, pipe diameters and particle diameter in the experiments are kept the same in the numerical tests. For all the numerical tests, a rectangular domain of 3000×350 mm with a pipe of diameter of 100 mm being placed at 1000 mm from the inlet of the domain. A 153×63 mesh with grid points being concentrated towards the pipe surface and the seabed is employed for all the cases after a careful mesh-dependence study. The numerical results on the time development of the scour hole as well as the maximum scour depth are compared with the experimental results of Mao (1986).

Table 1: Flow and sediment conditions for the numerical tests

Case	Pipe diameter (mm)	Sand size d_{50} (mm)	Flow velocity U_0 (cm/s)	Initial gap ratio e/D	Shields parameter θ
1	100	0.36	35.0	0	0.048
2	100	0.36	50.0	0	0.098
3	100	0.36	50.0	0.5	0.098

Fig. 7 and Fig. 8 show the scour development below the pipeline in time for case 1 and case 2, respectively. In those two cases, the pipe was originally placed on the seabed. The case1 is a case of clear water scour and the case 2 is a case of live bed scour. Measurements of scour profiles are available even at very early stage of the scour development. This is extremely valuable to validate the present numerical model. It can be seen that the predicted time dependent scour profiles generally agree with the experiments very well. Descripancies however exist at relatively early stage of the scour development for both cases. Accumulations of the sediments were observed between 1D and 3D downstream of the pipe in the experiments of Mao (1986). This is not predicted by the numerical model. The main reason for the difference could be that non-uniform sands were used in the experiment while the numerical model can only deal with uniform sands. The accumulation part of the seabed observed in the experiments might be comprised of sands of larger diameters than the diameter used in simulation, d_{50}. The accumulations did disappear when the scour holes approached to equilibrium. The predicted equilibrium scour profiles agree very well with those measured in experiments in deed.

Fig. 9 and 10 gives the time development of maximum scour depth for case 1 and case 2 respectively. It can be seen that the agreement of the numerical results with experimental results are extremely well. The different scour rates at different stages of scour development are well captured. It can be seen that at the early stage of the scour development, the scour rate is very high. This is mainly due to the strong tunnel

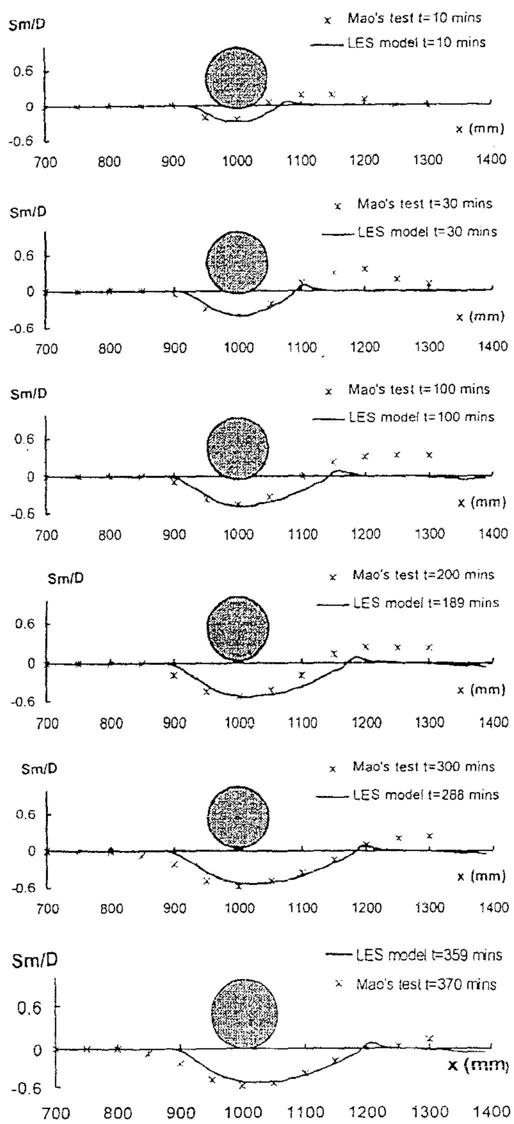

Fig. 7 Comparison of scour hole shapes, D=100 mm , e=0, θ=0.048

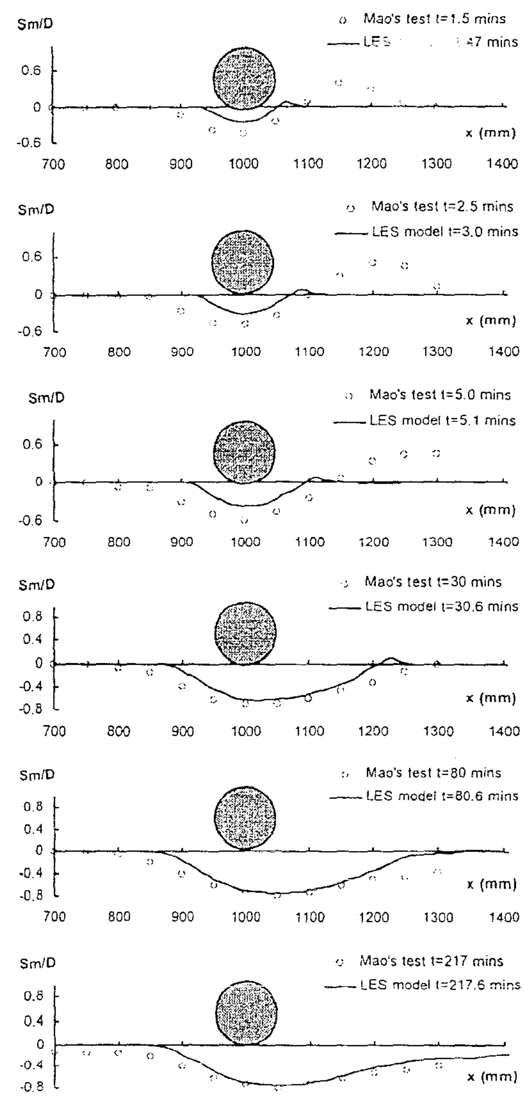

Fig. 8 Comparison of scour hole shapes, D=100 mm , e=0, θ=0.098

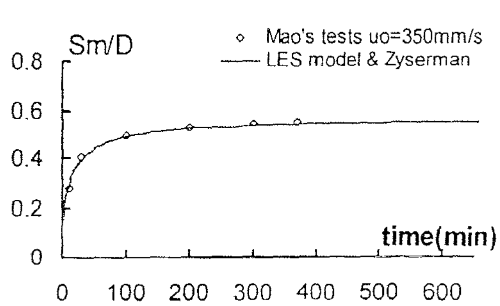

Fig. 9 Time development of scour depth (D=100 mm , θ=0.048)

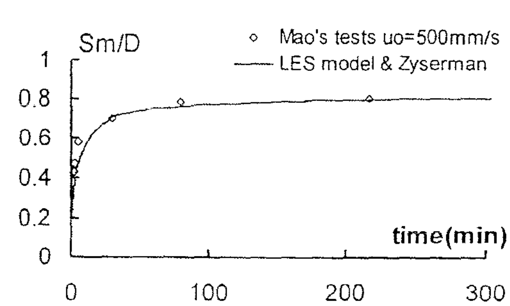

Fig. 10 Time development of scour depth (D=100 mm , θ=0.098)

scouring underneath the pipeline. As the scour develops, the scour rates decrease significantly. This suggests that the scour mechanism has changed from tunnel scour satge to lee wake stage. It is obvious that the lee wave scour has a larger time scale than the tunnel scour. This is consistent with the experimental findings.

Fig. 11 shows the comparison of the numerical results with the experimental results of Mao (1986) for case 3 where the pipe was initially placed half a diameter above the original seabed. The lee wake scour is normally the dominant scour mechanism under such a situation. Since the vortex shedding is the major cause of the lee wake scour, it is generally more difficult for the numerical model to predict the scour accurately for such a case. Nevertheless, the present numerical model handles such a situation very well, as shown in Fig. 11. This again demonstrates the rubustness of the present numerical model.

Fig. 12 shows the flow fields around the pipe at different stages of scour development. It can be seen that at early stage of the scour development (t = 5 min), a strong flow jet passes through the gap between the pipe and the seabed. It is believed that this strong flow jet is the major cause of the tunnel scouring. As the scour hole develops, this flow jet becomes weaker and the vortex shedding become more pronouced. The dark colour near the scoured seabed represents the high concentration of the sediment. Initially there is a large concentration area right behind the cylinder and this dark moves downstream gradually as the scour hole develops. When the scour hole almost reaches equilibrium (t = 500 min), the sediment concentration becomes very small even in the neigbourhood of the seabed. This suggests that the seabed shear stress is very close to the shear stress of incoming

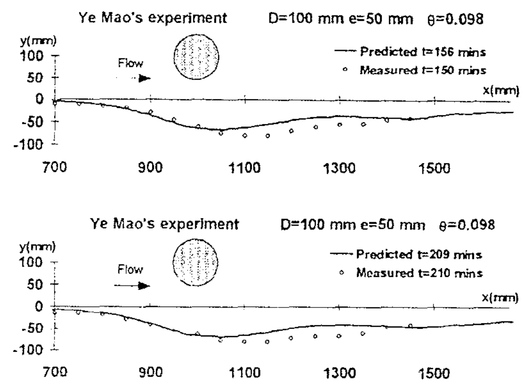

Fig. 11 Comparison of scour hole shapes, D=100 mm , e=0.5, θ=0.098

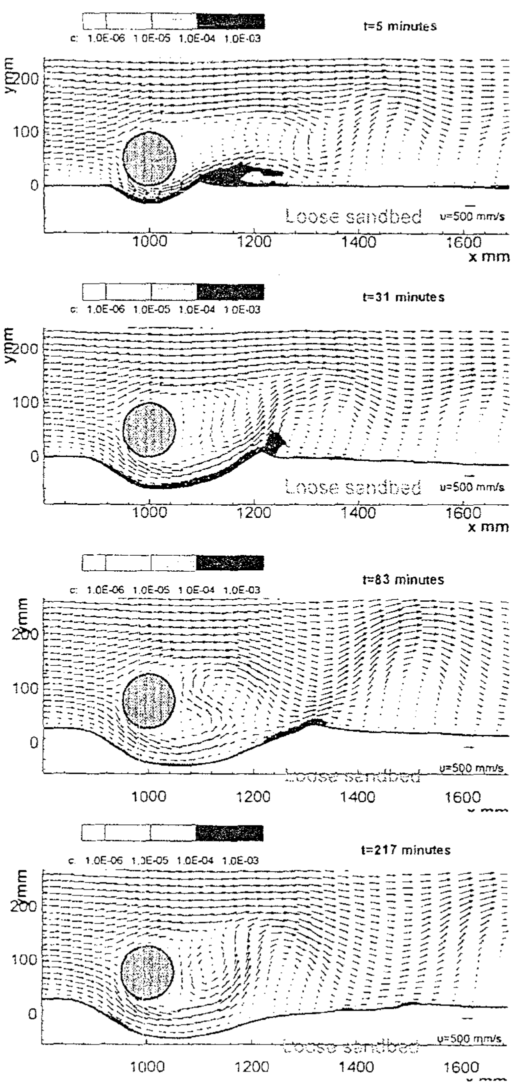

Fig. 12 Flow and sediment concentration fields at different time D=100 mm, e=0, θ=0.098

flow. It can also seen from Fig. 12 that the vortex shedding exists even in the early stage of the scour (t = 5 min). This is consistent with the experimental observation of Mao (1986).

4. Conclusion

A numerical model for local scour below a pipeline has been developed in this paper. The numerical model employs a LES model to simulate the flow field and a sediment concentration for sediment transport. The validation of the flow model and the application of the present model to some of the test cases of Mao (1986) allow the following conclusions being made:

1. The Large Eddy Model predicts the gross features of a flow around a pipeline near a plane boundary quite well;
2. The present numerical model predicts the time development of local scour very well for both clear water scour and live bed scour situations;
3. The model gives good prediction on the local scour below a pipeline that was initally above the seabed. This suggests the model predicts the lee wake scour quite well.
4. The model predicts the time development of the maximum scour depth very well. This suggests that model captures the scour mechanisms (tunnel scouring, lee wake scouring and even the transiotion between the two) very well.
5. The model can be further extended to local scour below pipelines under waves.

5. Reference

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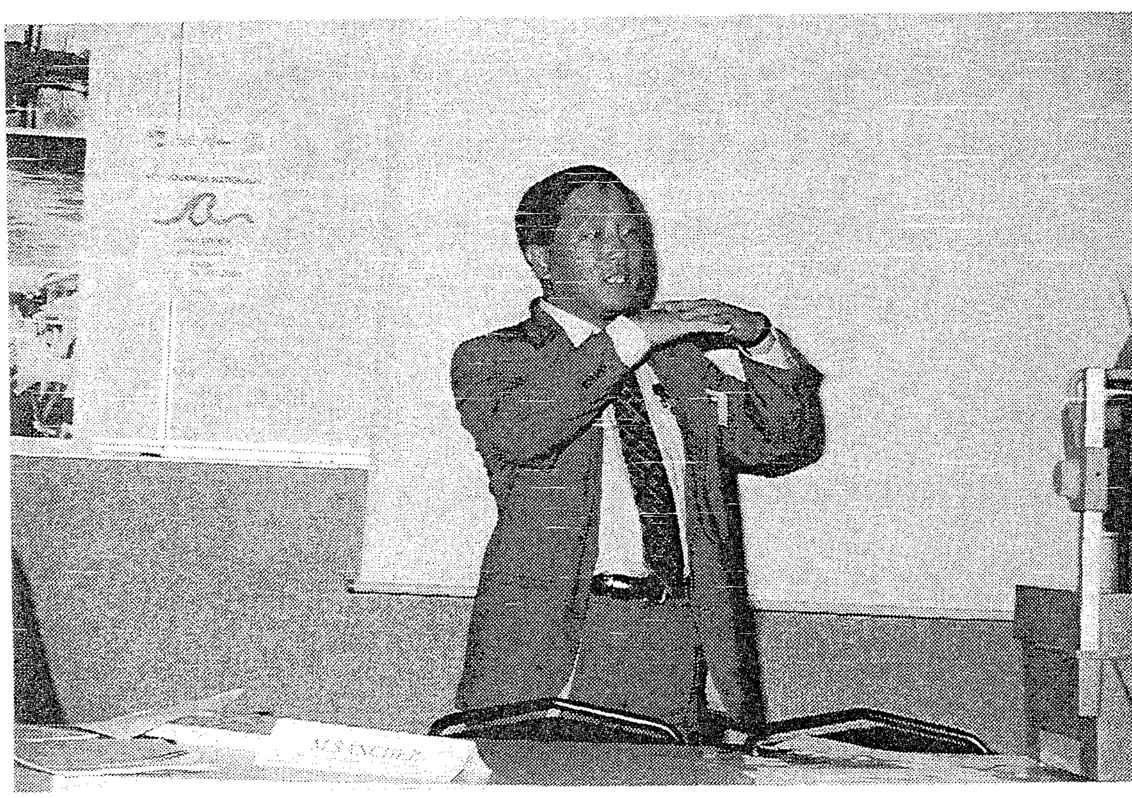

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