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Hosted by Spain Water and IWHR, China

2023 IAHR-SHCS

International Workshop on Scour around Hydraulic and Coastal Structures

September 4-6, 2023 Nanjing, China

ABSTRACT COLLECTION

河海大學 HOHAI UNIVERSITY

THE UNIVERSITY OF AUCKLAND Te Whare Wananga o Tamaki Makaurau NEW ZEALAND

四川大學 SICHUAN UNIVERSITY

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General Information

The IAHR-SHCS, hosted by Hohai University and The University of Auckland, aims to provide an international platform for researchers to present and discuss recent advances and future challenges on "Scour around Hydraulic and Coastal Structures".

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Chapter 1

Keynote Speech

Scour at various hydraulic structures

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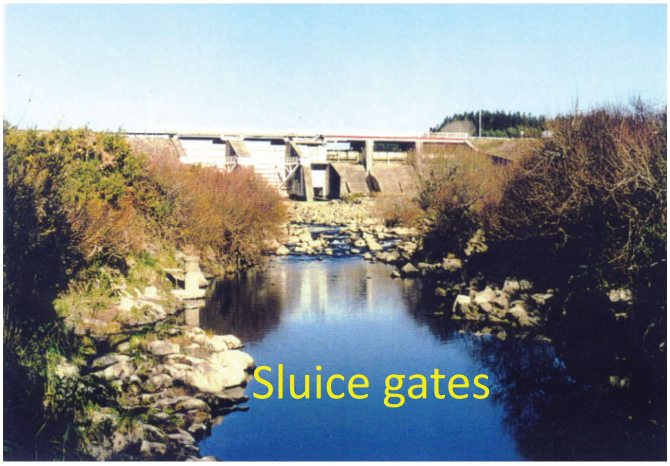
ABSTRACT

Three cases of scour at hydraulic structures are discussed as shown in the photographs. Experimental data analyses are used to derive simple design relationships, the data being derived from flume tests undertaken at The University of Auckland (UoA) as well as other data where appropriate. A common theme is testing under mobile bed flow conditions using the water and sediment recirculating flumes at UoA, these including 2400mm wide and 1500mm wide flumes, both capable of generating flows exceeding 1 m^3/s. For each type of scour, countermeasures are discussed.

Research of scour at off-shore monopile foundations is being undertaken currently (at the time of writing) as part of a major project headed by Hohai University. Laboratory studies at UOA are presented, namely the effects of monopile vibration on scour depth, with and without riprap protection. The experiments are being done in the 2400mm flume under clear-water and live-bed conditions, for a range of vibration amplitudes and frequencies. Results to date show that vibration amplitude leads to deeper scour. The riprap protection experiments show that larger riprap is more effective as a countermeasure, as expected.

An extensive, current (at the time of writing) UOA laboratory program of scour due to superstructure submergence ('pressure scour' at bridges) is presented. The results are used to show the effects of the independent parameters (flow intensity, superstructure geometry and superstructure submergence) on scour depth under clear-water and live-bed conditions.

Laboratory data for scour downstream from sluice gates are presented and analyzed to derive a simple design methodology. The dataset comprises previous UOA experiments and data from other studies, but are dated. In the authors opinion, new experimental studies of this important topic are warranted. Young researchers are encouraged to consider this topic.



Scour and scour protection at offshore substations

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ABSTRACT

An offshore substation (OSS) (Fig. 1) is a dedicated structure that transmits energy to the shore, the energy being delivered from wind turbines to OSS through array cables, and transmitted to the shore through an export AC or (usually) a DC cable. OSS is also feasible for floating wind farms as well with water depths of O(100 m) or shallower. (For floating offshore wind farms with water depths larger than O(100 m), floating OSSs are necessarily yet to be developed, Rouxel, 2021.)

When placed on the sea bed, the presence of OSS structure will change the flow pattern in its immediate neighborhood, resulting in one or more of the following processes such as the contraction of flow, the formation of near-bed and near-structure vortices, the generation of turbulence, etc. These changes usually increase the local sediment transport capacity and thus lead to scour. Scour is a threat to the stability and integrity of OSSs. Stone protection is used to protect the structure against the scour where essentially the bed area underneath and around the OSS structure is covered by a protection layer. (Sumer and Fredsoe, 2002, may be consulted for general knowledge of scour and scour protection.)

In this keynote address, the highlights of an extensive study on scour and scour protection at an OSS in the North Sea will be presented. The presentation is organized in two parts, namely (1) scour, and (2) scour protection.

Regarding the former, the work associated with this part of the presentation may be summarized as follows. In a desktop study, scour at the OSS structure has been assessed, starting with the simplest case, namely the isolated pile, followed by, with increasing complexity, assessing the influence of neighboring pile (the pile-group effect), that of other near-bed elements (J tubes, horizontal members and cables), and that of global scour at the corners of the footprint of the OSS platform, the most critical locations as far as the scour is concerned. This assessment exercise has been conducted in current only, as the latter metocean condition constitutes the most unfavorable condition. To test and verify the results, a series of laboratory experiments in a physical modelling study have been carried out in a test basin, located at the ITU Hydraulic Laboratory. We note that a special attention has been paid to the similarity conditions and scaling laws, and the aforementioned physical modelling experiments have been designed according to these conditions/laws.

Regarding the second part, namely, the scour protection, the work associated with this part of the presentation may, likewise, be summarized as follows. Similar to the first part of the study, scour protection for the present OSS has been designed in a desktop study whereby a two-layer protection system (comprising a top armor layer and a bottom filter layer) has been considered, taking into consideration the scour assessment made in the first part of the study. In the design of the protection layer, various criteria (related to several hydrodynamic processes such as hydrodynamic stability of armor stones, winnowing, filter criteria, bedform destabilization, edge scour, liquefaction, among others) have been checked. Similar to the first part associated with the scour study, to test and verify the results of the desktop study, an extensive series of laboratory experiments in a physical modelling exercise have been conducted in the same test basin. The metocean conditions tested in the experiments comprise various combinations of waves and current. Similarity conditions and scaling laws related to the scour-protection processes, likewise, have been worked out, and the experiments have been designed according to the latter.

The presentation will also discuss future prospects (use of CFD and also cutting-edge laboratory methods) in studies of scour and scour protection at OSS or similar structures in the offshore environment.

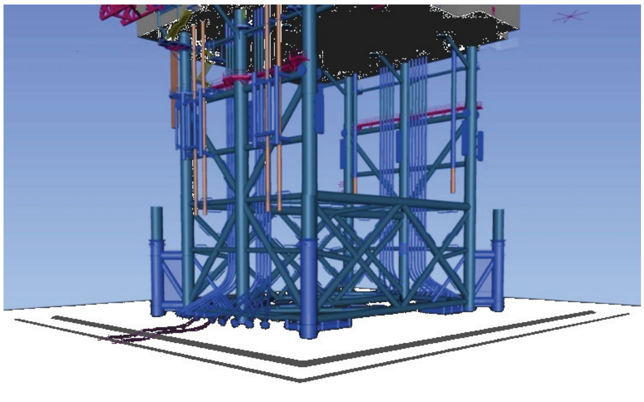

Figure 1. An offshore substation with near-bed structural elements visible, namely, main piles, pin piles, J-tubes, horizontal and diagonal structural elements, etc.

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On the use of the Phenomenological Theory of Turbulence (PTT) to provide a universal jet-scour formula

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ABSTRACT

Scour induced by jets constitutes a classic problem of fluid mechanics, for which no unique solution has been achieved for all combinations of sediment sizes and flow intensities. The safety of hydraulic structures might be compromised by the level of scour nearby. For almost one hundred years now, a number of widely-used, experimental formulas have been proposed around the world for the equilibrium scour depth (Schoklitsch, 1932; Mason and Arumugam, 1985; Bormann and Julien, 1991; and Hoffmans and Verheij, 1997). Most formulas have been developed on dimensional analysis and heuristic arguments; further, they possess experimentally-determined free exponents. Also, laboratory tests have been devoted to investigate the time evolution of the scour depth (Laursen, 1952; Blaisdell et al., 1981), and diverse expressions have been obtained. One key feature of those very useful formulas is that they are not easy to extrapolate to field situations where the flow and sediment conditions significantly differ from those at the laboratory.

As an alternative to the purely empirical formulas, some semi-theoretical expressions have been put forward, such as those of Bormann and Julien (1991), and Stein et al. (1993), with the ability to represent not only the equilibrium state but also the transient scour phenomenon.

Recently, a radically-different approach was pioneered by using the Phenomenological Theory of Turbulence (PTT) applied to the eddies of the scour process (Bombardelli and Gioia, 2005, 2006; Gioia and Bombardelli, 2005; Bombardelli et al., 2018; Palermo et al, 2021; Di Nardi et al., 2022 and 2023). In this presentation, we introduce the theory and walk through its different levels of prediction, which can be obtained to represent equilibrium as well as the time-dependent scour depths.

The PTT applies to fully-developed flow turbulence, and addresses the steady production of turbulent kinetic energy (TKE). It follows two principles: (i) the TKE per unit mass is determined by scales associated with the largest (energy-containing) flow scales or eddies, being independent of viscosity; (ii) such turbulent energy, which is introduced at a rate ε, is transferred (it “cascades”) from large to small scales at that rate ε, until its dissipation into internal energy at sufficiently-small scales.

In the case of jets, the large scales are dictated initially by the thickness of the water layer where the jet impacts. Such layer enlarges as the scour proceeds, and the energy-containing eddies increase their size, concomitantly. By assuming that eddies harbored in the coves in between the roughness elements are within the inertial sub-range, we can use the Taylor-Kolmogorov scaling to relate the velocity scales of the two sizes of eddies. Then, by adopting a physically-based expression for bed shear stress, an equation is derived as a function of the velocity scale of the largest eddies. Finally, by using Shields criterion for incipient sediment motion, a formula for the scour depth can be derived. This methodology has been checked to offer accurate predictions of the scour depth for laboratory tests, at the time of bringing more physical insight into the interpretation of the problem.

The theory was also validated at large scales in Palermo et al. (2021), and it was successfully applied to conditions of variable jet discharges (see, for instance, Di Nardi et al., 2022 and 2023).

In addition to discussing previous developments and validations, we present herein a description of current efforts to generalize the theory to all sizes and flow conditions, hoping to uncover a “universal” theory for scour.

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Design and installation of scour protections around monopile foundations– lessons learnt from field experiences

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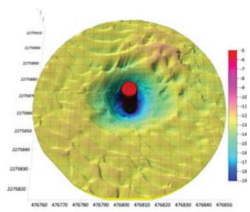
ABSTRACT

Scour protection measures are often installed around monopile foundations of offshore wind turbines installed on erodible seabeds in shallow waters to prevent the erosion of sediments around monopile foundations (e.g. Whitehouse et al. 2011; Sumer and Fredsoe 2002). Although scour protection measures are intended to protect wind turbines from the impact of environmental conditions, they may have negative impacts on the wind turbine systems if they are not adequately designed and installed. A number of incidents related to scour protection measures have occurred worldwide, leading to lengthy operational downtimes and significant maintenance costs. The talk will present lessons learnt from field survey data from Europe and China and potential solutions of the problems identified, based on existing knowledge and some preliminary results of physical model testing conducted purposely.

Ripraps are one of the most commonly used scour protection measures for monopile wind turbines installed offshore (Whitehouse et al. 2011). Riprap scour protection is normally formed by placing rock particles around the pile to prevent the erosion of sediments. Ripraps can be installed either prior to or after the installation of monopoles, which are referred to as pre-installations or post-installations respectively hereafter. Field experiences suggested that pre-installations of ripraps appeared to work well in preventing excessive local scour around the wind turbines surveyed in a number of European offshore wind turbines ((Whitehouse et al. 2011). On the other hands, significant secondary local scour was observed around wind turbines with post-installations of ripraps, based on the observations from wind turbines installed in European (Whitehouse et al. 2011) and Chinese waters. Subsequent remedial works through more rock dumping in some of the projects did not achieve the expected outcomes and even worsened the conditions. The excessive secondary scour around some of those wind turbines adopting post-installations has led to the exposure of buried cables and structural damages of power cables at locations near the wind turbines. An example of field survey results of excessive secondary scour after the post-installation of riprap scour protection in one of the offshore wind turbines is shown in Figure 1. The present talk provides interpretations of the occurrence of excessive secondary scour, based on the existing knowledge and the outcomes from purposely designed physical model tests. Finally methods for remedial rock dumping and cable protection are suggested.



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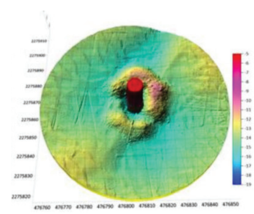

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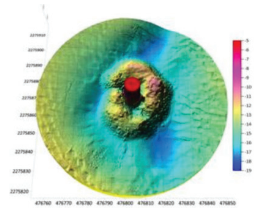

(c) October 6,2022

Figure 1 Field survey of local scour around an offshore wind turbine foundation.

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Predicting structure-induced sediment scour rates

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ABSTRACT

The vast majority of structure-induced (local) sediment scour research has been devoted to understanding the complex flow and sediment transport processes and to predicting equilibrium scour depths. Much has been learned over the last few decades through laboratory and field testing and ever improving numerical computation models. As a result, the accuracy of equilibrium scour depth prediction models has improved significantly. Less studied, but also important, is the rate at which local scour occurs. The ability to predict scour rates allows more accurate estimates of design scour depths for real world situations where the design flow is time dependent and/or the sediment properties are depth dependent. A methodology for predicting local scour rates at structures with complex geometries under clearwater flow conditions is discussed along with examples that illustrate where and how the methodology can be used. The time dependent local scour depth, y_s, is expressed as:

$$y_s = y_{se} \tanh\left[C \left(\frac{t}{t_{ne}} \right)^{n_1} \right] \quad (1.1)$$

where

$y_{se} \equiv$ equilibrium scour depth,

$t \equiv$ time,

$t_{ne} \equiv$ time required to reach near equilibrium depth, and

$C, n_1 \equiv$ parameters dependent on quantities that will be known to the user

The local scour rate is:

$$\frac{dy_s}{dt} = \frac{y_{se} n_1 C}{t_{ne}} \left(\frac{t}{t_{ne}} \right)^{n_1 - 1} \operatorname{sech}^2 \left[C \left(\frac{t}{t_{ne}} \right)^{n_1} \right] \quad 0.1 \le \frac{t}{t_{ne}} \le 1$$

(1.2)

The time required to reach a specified ratio of scour depth to equilibrium depth is:

$$t_{y_s} = t_{ne} \left[\frac{1}{2C} \ln \left(\frac{1 + (y_s / y_{se})}{1 - (y_s / y_{se})} \right) \right]^{1/n_1} \quad 0.1 \le \frac{y_s}{y_{sne}} \le 1$$

(1.3)

and by substituting t_{y_s} from Eq. (1-3) into Eq.(1.2) an expression for the scour rate as a function of scour depth can be obtained:

$$\frac{dy_s}{dt} = \frac{y_{se} n_1 C}{t_{ne}} \left(\frac{t_{y_s}}{t_{ne}} \right)^{n_1 - 1} \operatorname{sech}^2 \left[C \left(\frac{t_{y_s}}{t_{ne}} \right)^{n_1} \right] \quad 0.1 \le \frac{t_{y_s}}{t_{ne}} \le$$

(1.4)

The equilibrium scour depth (for both simple and complex structures) is to be computed using the methods presented in Sheppard et al., (2023). Laboratory time history local scour data was used to develop expressions for coefficients C and n1.

Information that will be needed to extend and improve the accuracy of this model is discussed followed by examples of how the model can be used for estimating design scour depths for situations where the model is applicable.

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Scour mechanism of vibrating submarine pipelines

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ABSTRACT

Submarine pipelines constructed in the riverine, coastal, and offshore environments are important engineering structures for a myriad of purposes. In the coastal and offshore environments where such pipelines often are used to convey hydrocarbon across a body of water, their failure not only has severe economic consequences, but also causes serious adverse environmental impact. One of the main causes of submarine pipeline failure is the formation of a scour hole in its vicinity, affecting the integrity of its foundation and sometimes causing failure. Moreover, the scour length sometimes can induce vortex-induced vibration of the pipeline, causing rupture. Scouring generally is attributed to the formation of local vortices which enhance the shear stresses and turbulence, thereby causing soil erosion and scour hole formation. Earlier research studies, e.g., Chiew, 1990, were conducted using a static pipeline to induce the formation of a 2-dimensional scour hole in both laboratory and numerical studies. Very few of these studies had included vibration effects on scour because a 2D rigid pipeline was investigated.

In more recent years, researchers, e.g., Wu and Chiew, 2012, began working on 3-dimensional pipeline scour where both the scour depth, width and length are formed and measured in the tests. When the scour hole reaches a certain length, self-induced vibration due to the exposure of the pipeline can occur. Besides the occurrence of self-induced vibrations, forced vibration that is attributed to the movement of the pipeline due to the local hydrodynamic forces also occurs. One of the earliest works on vibrations effects on scour hole formation was that by Li et al., 2013, who examined how a 3-dimensiaonl pipeline vibrating in all 3 dimensions affects pipeline-scour; which somewhat resembles a vibrating catenary riser. Their work reveals that the resulting scour hole profile (Figure) is significantly different from those formed with a rigid, 2-dimensional pipeline. This pioneering work shows, amongst other things, that the effect of vibration, which often is present in the field, should be included to have a better understanding on pipeline-scour and so that failure can be minimized.

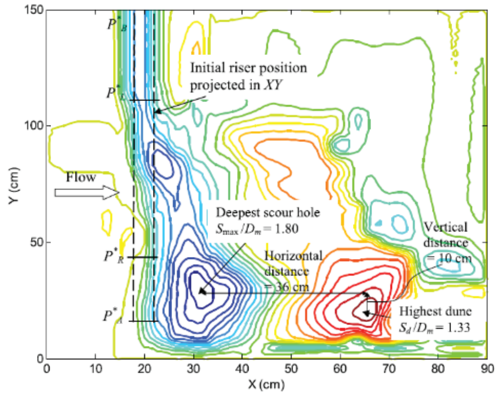

Figure 1. Pipeline-scour profile with vibration (Li et al., 2013)

This paper outlines some of the state-of-the-art laboratory works on vibration effects on submarine pipeline scour. It presents how both self-induced and force-induced vibrations affect scouring, showing that the scour mechanism is markedly different from that of a rigid, 2-dimensional scour with a rigid pipeline where vibrations are absent. The main finding shows that 1-dimensional vertical vibrations can cause the pipeline to move up and down from the seabed, creating a gap to be present which allows a gap-flow between the underside and the pipe and the seabed. This creates a nozzle effects. Moreover, depending on whether the pipeline pounds on the seabed during its descend towards the bed (pounding effect), the result on local vortex formation and seabed erosion can be very different. The extent of the vibration acceleration and frequency also can affect the formation of the scour hole.

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Re-visiting regression equations for equilibrium scour depths and time scales for monopiles

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ABSTRACT

Empirical formulations for the engineering prediction of live-bed equilibrium scour depths, as well as time scales (for both scour and backfilling), are re-visited for monopiles. Following prior work (Larsen et al. 2017), it is argued on physical grounds that dimensionless time scales ought to scale proportionally to the Shields parameter raised to the −3/2 power, based on scaling common to numerous sediment transport rate formulae. This is in contrast to stronger power dependence found in many existing formulations based on laboratory experiments, which may become unreliable when extrapolated to field-scale storm conditions. In light of this, existing data sets for scour and backfilling time scales are re-analyzed. Novel parameterizations are developed for their prediction which are in line with the argument above, while maintaining similar coherency with existing data as in previous parameterizations. Re-analysis of existing data sets for equilibrium scour depths is likewise performed. An existing framework (Sumer & Fredsøe 2002) valid for slender monopiles is extended to incorporate the so-called large monopile regime (non-negligible diffraction), especially important e.g. for modern wind turbine installations. An example of the latter is demonstrated in Figure 1, depicting the dimensionless equilibrium scour depth-to pile diameter ratio (S_{eq}/D) versus wave-current parameter (m=0: pure waves, m=1: pure current) for a wide range of Keulegan-Carpentar numbers KC.

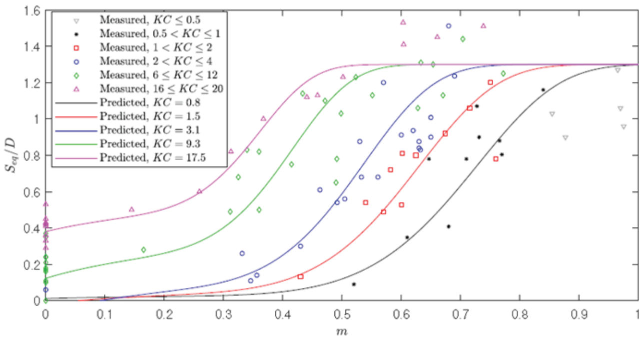

Figure 1. Comparison of measured (Sumer & Fredsøe, 2001; Qi & Gao, 2014; Sumer et al., 2013; de Lemos et al., 2023) and predicted equilibrium scour depths around a monopile in waves-plus-current conditions, as a function of wave-current parameter m and Keulegan-Carpentar number KC. Predicted lines utilize the average KC of the corresponding group of measurements having the same color.

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Extended applications of the concept of hydraulic radius

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ABSTRACT

The hydraulic radius has been widely used to evaluate resistance and average velocity for pipe and open channel flows in hydraulic engineering. It is defined as the ratio of the area to wetted perimeter for a cross section in an open or closed channel. It has a dimension of length, being equivalent to the flow depth for wide channels and half the width for narrow channels.

In spite of the fact that the hydraulic radius is a geometric parameter for a cross section, it also serves as a measure of the size of dominant eddies in turbulent flow. With this understanding, Gioia & Bombardelli (2001) showed that the hydraulic radius is helpful in theoretically explaining the Manning equation in terms of turbulent energy cascade.

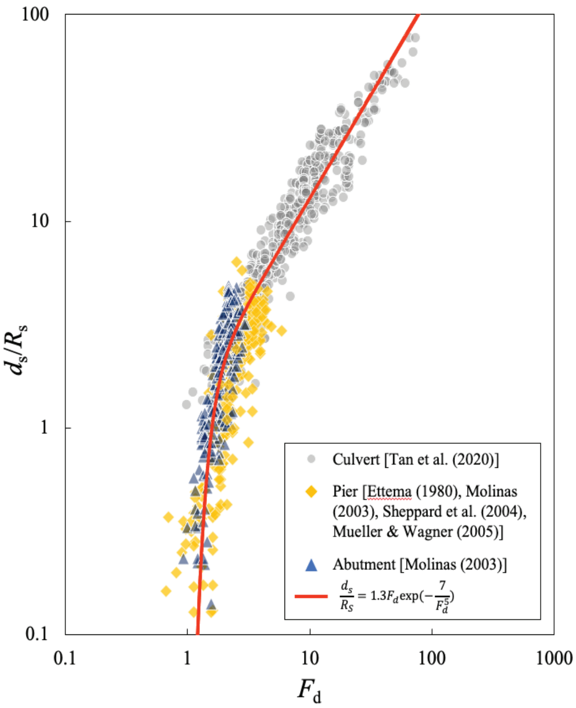

Figure 1. Dependence of scour depth normalized with redefined hydraulic radius on densimetric Froude number

By applying the concept of hydraulic radius to a three-dimensional domain, the resistance induced by vegetation in open channel flows can be conveniently estimated in terms of drag coefficient and Reynolds number, of which both are defined based on vegetation-related hydraulic radius (Cheng & Nguyen, 2011).

Furthermore, the concept of hydraulic radius can be used to compare equilibrium scour depths at bridge piers, abutments and culverts. In these scour cases, the hydraulic radius measures the eddy size that dominates the incoming turbulent flow, and potentially the scour hole (Cheng & Wei, 2019; Cheng et al., 2011). By analyzing experimental data collected under the clear-water scour conditions, we show that the scour depth, when normalized with the redefined hydraulic radius, depends solely on the densimetric Froude number. The functional relation holds for all scour cases involving piers, abutments, culvert and wall jets.

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Simulation of scour around jacket foundations of offshore wind turbines in sandy seabed

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ABSTRACT

Exploration of offshore wind energy has been a vital alternative to mitigate environmental pollution due to continuous consumption of fossil fuels. Among all types of foundation supporting the offshore wind turbines, the jacket foundation is well known for its application in mild and deep sea areas.

Physical model tests were firstly conducted to investigate scour process around the jacket foundation under complex hydrodynamic loadings. In the cases of steady currents without foundation angle, local scour around the jacket foundation could be classified into three types, i.e., independent development type, weak interference type and strong interference type, based on the influence of flow intensity. With the increasing flow intensity and decreasing water depth, local scour intensifies although the maximum scour depth always occurs at the upstream side of front pile. However, the foundation angle would alter shelter effects from the front pile and make the maximum scour depth occur at the back pile or the middle piles. Compared to the steady current, the bi-direction currents would lead to a reduction about 20% in the maximum scour depth. The location of the maximum scour depth also alternately changed between the front and back piles.

The effects from wave on local scour around the jacket foundation were also studied. For example, the maximum scour depth was found linearly related to wave height, water depth and wave period. For the combined wave-current conditions, scour process was divided into the clear-water scour and live-bed scour. In the case of clear-water scour, the maximum scour depth increased with an increasing KC number, which differs from that of live-bed scour.

In addition to physical investigation, numerical techniques were also employed to study scour process around the jacket foundation. a scour numerical model for the jacket foundation was developed using the three-dimensional Reynolds-Averaged Navier-Stokes (RANS) equations and the turbulence model. The sand bed sediment surface was handled using the immersed boundary method, and the wall shear stress was incorporated into the local scour simulation around the jacket foundation. This model has been validated based on the physical experiment in this work. The model properly reproduces the local scour around the jacket foundation.

Figure 1. Jacket foundation application in offshore wind energy industry

Figure 2. The jacket foundation model

Chapter 2

Session A: Scour Around Hydraulic Structures

PIV measurements of flow in the scour hole induced by different types of plane jets

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ABSTRACT

We have conducted a series of studies to investigate the flow in the scour hole induced by different types of plane jet using particle image velocimetry (PIV), including that by a plunging jet downstream of a weir without an apron (Si et al., 2018) or with an apron (Si et al., 2019), a submerged wall jet (Si et al., 2020), as well as an oblique jet at varying impinging angles (Mao et al., 2023). The scour hole generated by a plunging jet downstream of a weir without an apron is depicted in Fig. 1(a). It is clearly depicted that four types of roller (or recirculating vortex) are involved in scour development and the scour is mainly caused by the major roller, as shown in Fig. 1(b). The average kinetic energy (AKE) distributions reveal that the rollers are maintained by jet impingements on both the concave scoured bed and the water surface. The gap gradually enlarges between jet regions with high transport capability, which adversely affects scour development. The turbulence kinetic energy (TKE) dissipates along the main jet direction. As the scour hole develops, the regions of significant TKE move successively away from the bed with a reduction in scour rate. The plunging jet zone has negative Reynolds shear stress (RSS), and absolute values there are larger than in other zones in the scour hole. Meanwhile, the regions of significant positive RSS change in size and location with scour development.

In addition, the cyclical jet-flipping in the scour hole induced by a wall jet is investigated in Si et al. (2021). The transitional vortical structures during jet flipping (both upward and downward) are clearly captured and analyzed. We also successfully reconstructed the global-domain distributions of pressure in the local scour hole by solving the pressure Poison equations based on the PIV data (Si et al., 2022).

More recently, we conducted experiments to analyze the development of the scour hole induced by an oblique jet on erodible sand bed (Mao et al., 2023). Attention is paid to the effects of varying impinging angle from 20° to 80° on the scour hole profiles and flow structure in the scour hole.

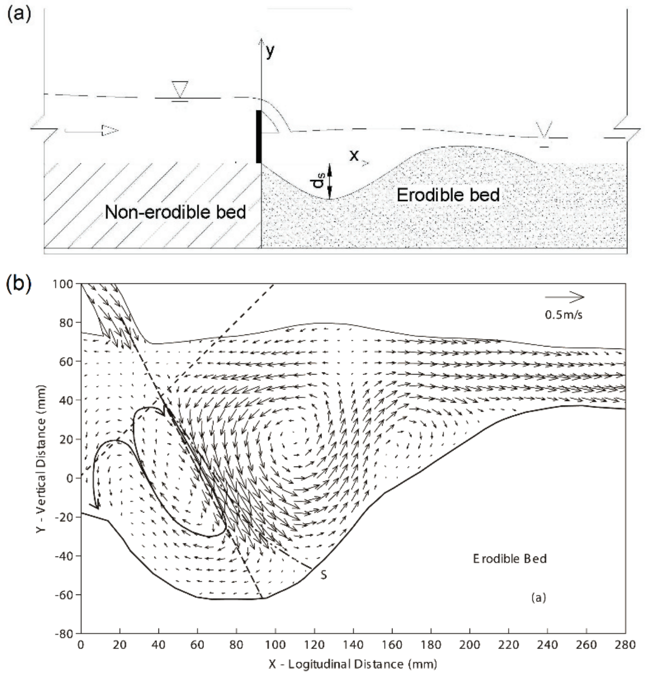

Figure 1. (a) Schematic diagrams of experimental setup (Side view); (b) PIV measurement results.

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Flow-sediment interaction and formation mechanism of sediment longitudinal streaky structures in smooth channel flows

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ABSTRACT

Bed load streaky structure is a typical bed morphological feature, but its formation mechanism remains unclear. The flume experiments were conducted to quantitatively identify the characteristics of turbulent coherent structure, sediment particle movement and bed structure. A workflow combining the particle tracing velocimetry (PTV) method and Kalman Filters algorithm was established to identify the trajectories of sediment particles on the bed surface. Feature matching velocity (FMV) was applied to acquire the flow surface field and structure-from-motion (SFM) was used to reconstruct 3D bed topography. All the flow velocity, sediment movement, and bedforms show streaky feature in the streamwise direction at $0.068<\Theta<0.113$, and the streaky structures gradually fade away at $0.113<\Theta$. Their original instantaneous turbulence properties in the spanwise direction disappear, and three fixed time-averaged streaky structures are formed. The streaky structures have larger spatial scales in the middle of the channel than those near the sidewalls. The spanwise distance between adjacent streaky structures remains about twice the whole flow depth. Finally, a formation mechanism based on the interactions of fluid and sediment is proposed. Our results highlight the important role of the interactions among turbulent coherent structure, sediment motion, and bed topography in the formation of streaky structures in a straight open channel.

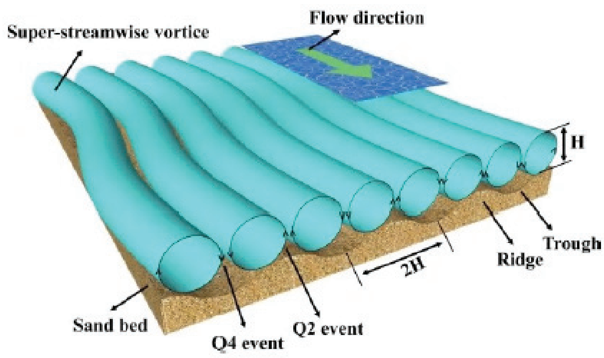

Figure 1. A formation mechanism for the Bed load streaky structure based on the interactions of fluid and sediment.

Dual breach erosion in dams by overtopping

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ABSTRACT

Due to the increased flood events during the past two decades, the frequency of dam failures caused by overtopping has increased around the world. The significant fatalities and economic losses of these failures highlight the need for understanding the dam breaching process induced by overtopping. Most previous research projects focus on the single breach development on overtopping dam failures, whereas the damage to a failed earthen dam is potentially impacted by the location, size, and number of breaches along the dam crest. The study of multiple breaches has received less attention even though the earth fissures, uneven dam crest level and weak sections (e.g., sluice gate and pipes) could lead to this phenomenon. Compared to single breach evolution, the development of multiple breaches is more complicated and may cause higher damage as large volumes of water simultaneously flow into the downstream area.

A series of dual breach dam tests with four different breach separation distances was conducted to systematically study the effects of dual breaches and breach separation distance on the breach erosion. Based on quantitative analysis of the non-cohesive dual breach erosion, three types of breach evolution are observed, namely no breach merging process, spatial breach process with merging and plane breach process with merging. Compared to the single breach model of non-cohesive dams, the inflow discharge threshold of the plane breach erosion increases significantly in the dual breaches model. This result indicates that the model with two breaches has a larger capability to discharge flow than that of the model with a single breach. In the non-cohesive dual breach model, the threshold of the inflow discharge for the plane breach mode increases with an increase of the breach separation distance. However, the threshold stabilises around a constant value (i.e., 20.0 l/s for the presented test setup) once the breach separation distance is longer than four times the dam height. This study improves our understanding of the fundamental mechanisms of dual breach erosion caused by overtopping.

Experimental and numerical study on the local scour of caisson during construction

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ABSTRACT

Caisson and caisson-pile foundations are widely used to support long-span bridges, whose local scour has been extensively studied. However, most of the research has focused on the local scour of the foundations fully settled into the sediment, and research on the local scour of foundations during settlement construction is lacking.

During construction, the caisson will undergo the process of suspended positioning and sinking, and the caisson section of the caisson-pile foundation will suspend due to the process of pile sinking. When the caisson suspends When a caisson is suspended in water, the flow under the caisson will accelerate, which impacts the scour of the riverbed and increases the settlement difficulty and risk of the caisson. Therefore, it is very necessary to study the local scour of the suspended caisson.

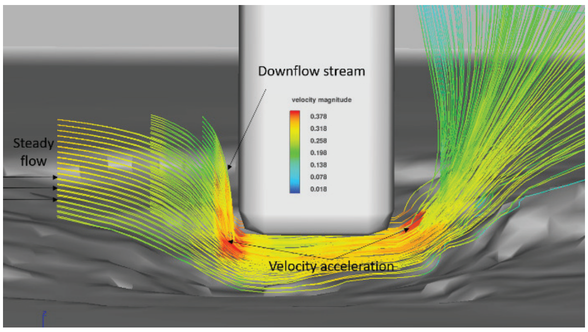

Figure 1. Streamline of water flow particles around caisson

This study conducted a series of experimental and numerical investigations into the local scour of the caisson and the caisson-pile foundation during construction. For the caisson, the effect of suspended clearance (the distance between the caisson and the riverbed) on the local scour was studied experimentally and numerically. The development law and mechanism of caisson scour under different suspended clearances were obtained. Besides, the effect of sinking speed on the local scour was studied numerically, and the development of scour depth as a function of sinking speed was acquired. Additionally, for the caisson section of caisson-pile foundation, the local scour development of caisson section during the process of suspension- implantation was investigated by experiments, and the scour development of caisson section during the process of suspension-implantation was achieved.

The following conclusions can be drawn: 1) The maximum scour depth under and around the caisson increases with the decrease of the suspended clearance. 2) The sinking speed has no influence on the equilibrium scour depth of caisson. 3) The equilibrium scour depth of caisson in the process of suspension-implantation is larger than that in the state of implantation.

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Rapid bed degradation in mountain rivers: challenges and countermeasures

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ABSTRACT

In the past decades, the sediment flux of many rivers around the world has decreased significantly due to human activities such as river damming, sediment bed mining and river training, leading to general bed degradation in many rivers. A series of recent river disasters show that strong human disturbances may cause serious bed degradation in a short period (termed as rapid bed degradation) in mountain rivers, significantly endangering the stability and safety of river embankments, instream or river-crossing infrastructures (e.g., sills, weirs, pipelines, culverts, bridge piers) and waterway. The present study summarizes cases of rapid bed degradation in mountain rivers based on field survey and literature, illustrating the challenges in understanding the underlying physics and countermeasures.

Figure 1. Damages and failures of instream structures caused by rapid bed degradation in mountain rivers.

Figure 2. Failure of grade controls due to improper design

Based on field survey, flume experiments, numerical modelling and theoretical analyses, the present study has revealed the mechanism of rapid bed degradation due to sediment supply reduction and base level fall in mountain rivers, proposed design method and recommendations for sequential grade control structures in rapidly degrading mountain rivers, and illuminated the eco-hydraulic characteristics of grade control structures for fish habitat restoration. The findings of the present study have improved the understanding of rapid river bed degradation process and provided theoretical and methodological support for grade control in rapid degrading mountain rivers.

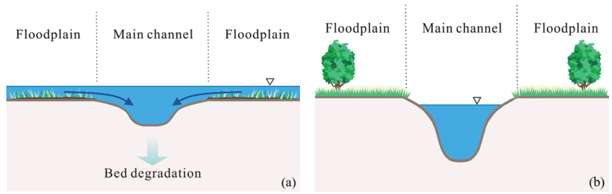

Figure 3. Sketch of rapid bed degradation process caused by base level fall in compound channels

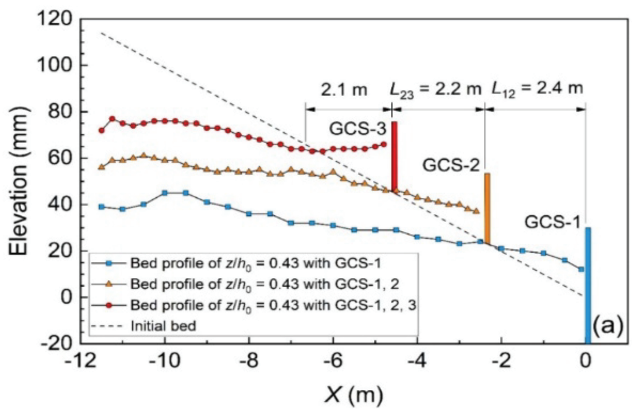

Figure 4. Impacts of sequential grade control structures on bed profiles in a degrading channel

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Grain sorting in sediment dynamics: new insights from particle-level investigation of granular segregation

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ABSTRACT

Grain sorting in sediment dynamics has significant implications for scour, erosion, geomorphology and biological processes in fluvial and coastal environments. Coarsening of the river bed and seabed, for example, adds additional difficulties for accurate prediction of sediment transport rate under certain flow and current conditions, which is expected to compromise scour and erosion control measures designed based on classic approaches. Grain sorting involves a wide range of mechanisms due to the complex actions of gravity, fluid flows, and particle interactions. As such, seemingly contradictory phenomena occur under different conditions and forcing, and a unified understanding of grain sorting in sediment dynamics is still missing.

Here, we present recent advances in a multiscale framework of grain sorting (Jing et al. 2017, 2021, 2022), in which the driving and resistive forces of sorting (or, particle-size segregation in the context of granular flows) at the grain level are formulated, leading to a general description of gravity-, shear-, and fluid flow-induced segregation flux in dense granular flows. This description is compatible with state-of-the-art sediment-fluid two-phase flow continuum models from which the relevant granular flow fields can be obtained. Figure 1 presents test results of the model in a rather idealized granular systems where creeping and inertial flows are simulated using the discrete element method (DEM). Results indicate that predictions of the "tracer" particle migration velocity agree well with the DEM data, demonstrating the potential applicability of the model in a wide range of sediment transport conditions.

The presented framework of grain sorting modeling rests on a foundation of physical principles at the grain level. Therefore, it should be sufficiently versatile to be applied to more realistic situations, such as those involving size-polydispersity, non-spherical particle shapes, cohesion, and interstitial fluid effects. The potential applicability of the proposed framework in the simulation of grain sorting, as well as its impact on sediment transport modeling during wave- and current-induced scour around river and marine structures, will be discussed.

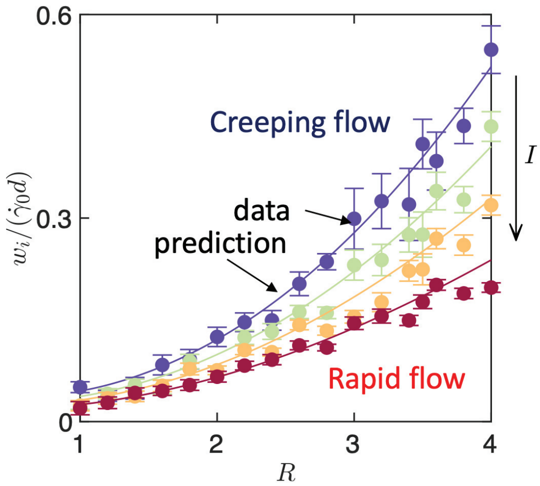

Figure 1. Tracer particle migration velocity w_i vs. the tracer-to-bed particle size ratio R for various idealized sediment transport conditions from creeping to rapid flows.

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Some aspects of the local scour and erosion processes in rivers and seas

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ABSTRACT

Local scour is an important issue in the stability and protection design of hydraulic and coastal structures. Inappropriate scour design and evaluation may lead to failure of the structure, environmental pollution, and significant economic losses.
An important element consists in the evaluation of the maximum value of local scour and erosion and their development over time. Some case studies in laboratory channels will be described, even in the presence of oscillating hydraulic jumps, and in wave tanks. Comparisons between numerical and experimental results will also be presented.

By way of explanation and as an example of the case studies that will be presented, in one of the studies we numerically focus on the vorticity generation mechanism in a scour hole developed downstream of a grade control structure in sand-bed channels, providing a full hydrodynamic picture of the scouring process. The liquid-granular flow has been simulated through a Weakly Compressible SPH (WCSPH) scheme with a two-equation turbulence model, where the two phases are treated as continua with different physical and rheological properties. The validity of the numerical scheme adopted here was checked against the experimentally observations of the local scour holes downstream of hydraulic jumps. As experimentally observed, our results indicate that there are three regions: the first is dominated by a jet-like flow characterized by a high velocity, which plays an important role in the scour process; the second is dominated by a clockwise local vortex at the position of the maximum scour depth; the third is dominated by velocity vectors mainly directed in the longitudinal direction of the channel. The equilibrium configuration of the flow field and bed topography is reached after a transient period in which the system oscillates between two flow patterns: (i) the scour hole shows a relatively steep hump downstream of it, increasing the free surface elevation and generating a B-jump type with a counterclockwise rotating macro-vortex structure which pushes the main flow towards the bed, where strong erosive action is observed; (ii) the scour shows a relatively modest inclination of the scour cavity, leading to the formation of a wave jump dominated by a clockwise rotating macro-vortex structure.

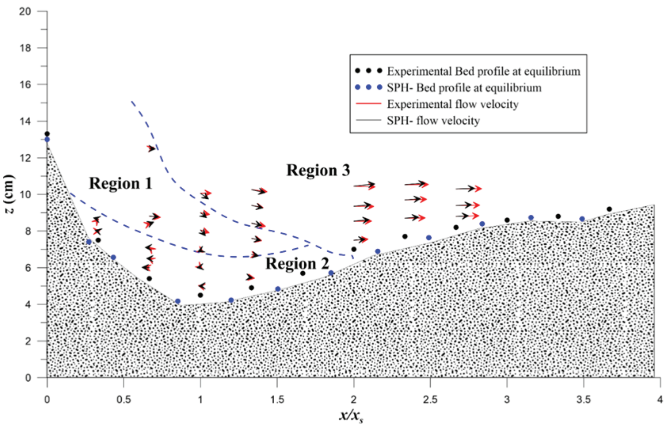

Figure 1. Vector map of the flow velocity, V_{xz}, in the scour hole at the plane of flow-symmetry (y=0) (x_s is the x-position from the sill at which the scour attains its maximum depth).

Other case studies will be presented, briefly describing some physical models developed by our research group also for coastal erosion processes (Mossa, 1999; Mossa et al., 2003; Ben Meftah and Mossa, 2006; De Padova et al., 2022).

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Fluvial scour in short- and long-term dynamic and changing environments

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ABSTRACT

The interplay of local and general scour in fluvial environments is profoundly influenced by the dynamic coupling of flow and sediment during extreme flooding events. Concurrently, the growing impacts of climate change amplify the challenges in sustainable river management, as they introduce more pronounced long-term variabilities in scour and erosion. Addressing these combined challenges necessitates a refined research methodology that encompasses both the immediate and prolonged scour processes. In this presentation, the speaker will highlight recent research insights that embody a dynamic perspective, focusing on: 1) the mechanisms of local and general riverbed scour in bridge-contracted compound channels during extreme floods, accounting for significant bed mobility (Yang et al. 2021) (see Fig.1); 2) the intricacies of live-bed scour at instream structures as they respond to fluvial bedform migration (Yang et al., 2023); 3) the distinctive and acute riverbed aggradation alongside severe bank erosion observed in New Zealand's proglacial rivers, exemplified by the Waiho River (Beagley et al., 2020) (see Fig. 2). Particularly, the presentation will showcase our experimental works in large-scale flumes and field survey data using airborne lidar on manned vehicles. We expect that findings provide more insights into the pivotal fluvial scour and sediment transport processes that can not only benefit the academic community but also assist with natural hazards mitigation in the future.

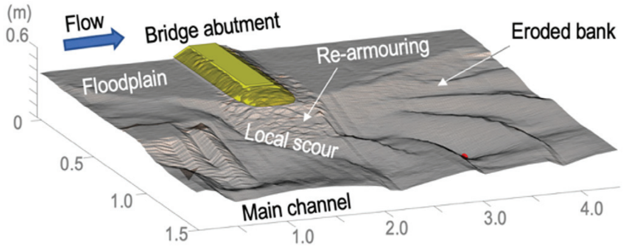

Figure 1. Post-flood scanning in laboratory showing local scour, bank erosion, re-armoring and bedform intrusion in a compound river channel interfered by a bridge.

Figure 2. Waiho River bridge failure during the 2019 flood. The bridge suffered the combined influence of severe bed aggradation and local scour.

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Seepage effects on flow and sediment transport rate

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ABSTRACT

Laboratory experiments were conducted to investigate the influence of both suction and injection on sediment transport in closed-conduit flows in this study.

The results of experiment tests on suction show that the bed load transport rate essentially remains unchanged for small values of suction rates before abruptly increasing beyond a certain threshold. Theoretical analyses of the forces acting on a spherical particle also are conducted and a conceptual model set up to analyze suction effects on particle mobility by considering the near-bed velocities (see Fig. 1). The model hypothesizes that (1) the bed particle experiences an additional downward vertical drag force induced by suction; and (2) increasing suction will lead to larger horizontal and vertical near-bed velocities, which enhances both the driving force and effective weight of the particle. To qualitatively examine how suction affects the near-bed flow behavior, physical modeling capability software was used to simulate the physical system and the results confirm that the near-bed velocities increase with suction.

The results of experiment tests on injection show that the sediment transport rate essentially remains unchanged when the ratio of the injection velocity and that at boiling, $V_i/V_{cr} < 10$. However, significant sediment transport rate is observed when V_i/V_{cr} increases beyond this limit. In the literature, three semi-empirical models have been developed to relate seepage effects on the sediment transport rate. The experimentally measured data in the pre- and post-boiling condition (Liu and Chiew 2014, and the present study, respectively) are compared with these models. The results show that the models of Francalanci et al. (2008) and Nielsen et al. (2001) perform poorly in predicting injection effects on the sediment transport. Although Yang's (2013) model could reasonably predict the influence of injection on the sediment transport rate in the post-boiling condition, it similarly fails when applied to the pre-boiling condition.

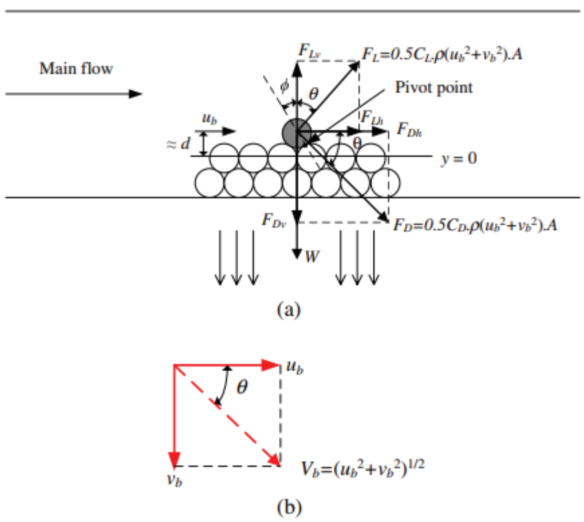

Figure 1. (a) Forces and notations for a single grain in closed-conduit flow with suction; (b) velocity of flow approaching a bed particle in closed-conduit flow with suction

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Time scale and equilibrium depth of local scour around a vibrating pipeline

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ABSTRACT

Submarine pipelines are widely used to transport gas and oil from production wells to processing facilities in offshore engineering. Pipelines that oscillate above the seabed intensify local fluid motions and augment the sediment transport, thereby exacerbating the formation of scour holes beneath the pipelines, which can impact the design of near-seabed infrastructures in the offshore industry.

The equilibrium scour depth and time scale of the scour process are the two main factors required to describe the scour development, which is essential in the design of offshore pipelines. The equilibrium scour depth around a fixed pipeline has been studied extensively in two- and three-dimensional model experiments and numerical models in steady currents (Chiew 1991; Liang et al., 2005; Fuhrman et al., 2014), in waves (Sumer and Fredsøe, 1990), and combined waves and currents (Zhang et al., 2016).

To describe the temporal development of the local scour depth under clear-water conditions, an exponential function was proposed by Cheng et al. (2016) as follows

$$\frac{d_s(t)}{d_{se}} = 1 - exp\left[-C_e\left(\frac{t}{T_e}\right)^{n_e}\right] \quad (1)$$

where $d_s(t)$ = maximum scour depth at time t, d_{se} = equilibrium scour depth, T_e = time scale for the equilibrium state, C_e = coefficient, and n_e = exponent.

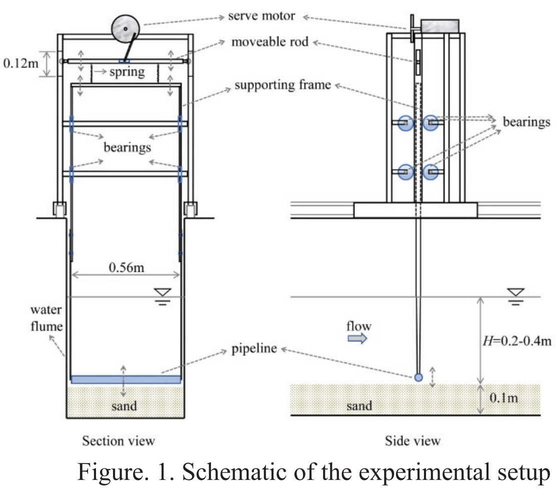

Figure. 1. Schematic of the experimental setup

The time scale and equilibrium depth of local scour around a forced vibrating pipeline were experimentally investigated using results obtained from systematically design tests. Large variations of vibration amplitude (A_0), frequency, and Shields parameter ratio were used. Both the equilibrium depth and developing rate of the scour hole are found to increase with vibration amplitudes, frequencies, and Shields parameter ratios. The influence of vibration amplitudes on accelerating the scour rate is more significant in the high A_0 conditions, due mainly to the direct impact of the pipe on the sand bed than that at the low A conditions, where direct impact is absent.

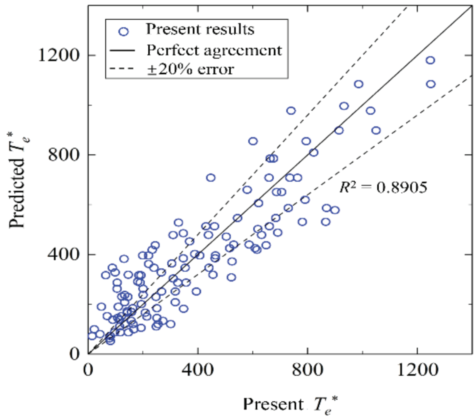

Figure 2. Predicted time scale of and integrated results

No explicit and monotonical relationship is established between time scale and vibration amplitudes or frequencies independently. However, time scale increases with the increase of the maximum pipe oscillation velocity.

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Critical shear stress for erosion of mud and sand-mud mixtures

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ABSTRACT

In many natural environments, e.g., estuaries, delta, mangrove forests, muddy and silty coasts, non-cohesive sediment and cohesive sediment are not completely separated and often occur as sand-mud mixtures. Existing experiments have shown that sand-mud mixtures behave like cohesive sediments if they contain a sufficient amount of cohesive particles, otherwise like non-cohesive sediments. The surface erosion process of non-cohesive sand-mud mixtures is primarily controlled by the sand component, with individual sand grains being eroded, while in cohesive mixtures, the process is controlled by the mud fraction, typically eroded in agglomerate form. This study investigates the erodibility of sand-mud mixtures, including pure mud.

First, the fractal theory and the van der Waals force between particles are employed and the momentum balance analysis is performed to examine the incipient motion of the mud aggregates. A formula of two coefficients for the surface erosion threshold of pure mud is developed. Among the two coefficients, one represents the fractal dimension and the other denotes the cohesion of the sediment. The comparison between the formula and experimental data shows that the fractal dimension of mud is a function of the compactness degree of sediment and the diameter of primary particles. The effect of the particle size on the fraction dimension is rarely mentioned in the research of cohesive soil. For sediments with relatively large particle diameters and low solid volume fractions, the contribution rate of aggregate weight may be significant and cannot be neglected. However, for the most common types of cohesive sediment found in river and marine beds, which typically have relatively high solid volume fractions, the contribution rate of aggregate weight is sufficiently low and can be disregarded. For these sediments, the developed formulas can be further simplified to a simple formula with only one coefficient for practical use.

On the basis of the above understanding of erosion threshold of mud, the threshold of surface erosion of sand-mud mixtures is further investigated using the same approach. A formula for the critical shear stress of sand-mud mixtures is derived, which is a function of the primary particle diameter of the sand and mud components, mud content, and dry bulk density. This formula effectively represents the erosion threshold of sand-mud mixtures and simplifies to the classical formula for non-cohesive sediment when the mud content is zero, and to the earlier developed formula for mud when the mud content is 100%. The developed formula suggests that the variation of the critical shear stress of sand-mud mixtures over mud content is mainly caused by the varying dry bulk density of the mud component in the mixture, which is controlled by the network structure of the sand and mud mixture.

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Experimental study on the influence of plane layout on the scour of straight-closed guide bank

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ABSTRACT

Many transportation routes in the northwest region of China, which traverse wide and shallow river reach in front of mountains, often use a multi-bridge approach to cross the river. These routes need straight-closed guide banks to guide the upstream flood flow smoothly through the bridge openings. However, this practice can lead to damage of the road embankments approaching bridges due to excessive scour at the foundation of guide banks. However, existing scour formulas are primarily designed for curved guide banks with low blockage ratio and small attack angle. They are not applicable to the straight-closed guide banks with high blockage ratios and large flow attack angles. This study employs generalized physical model experiments to investigate the impact of attack angle and blockage ratio on the scour of guide bank. The results revealed that the attack angle of the guide bank affects both the maximum scour location and scour depth. As the attack angle increases from 10° to 90°, the maximum scour location gradually moves upstream from the outlet of the bridge opening to the head of the bank. Regarding the impact on scour depth, the overall trend indicates that the maximum scour depth of guide bank increases with the enlarging of the attack angle. The maximum scour depth increases quickly when the attack angle of guide bank is less than 60°, while the influence diminishes notably when it surpasses 60°. Similarly, an increase in blockage ratio also leads to an increase in the scour depth.

Furthermore, it is found that when the attack angle exceeds 30°, the blockage ratio affects both the contraction scour depth and the local scour depth. Therefore, it is recommended that for guide banks with large attack angles, the total scour depth should be calculated directly. The findings can provide references for the design of straight-closed guide banks and similar structures.

Keywords: Guide bank, Scour, Plane layout, Attack angle, Blockage ratio

Effect of approaching bedforms on the local scour depth at rock weirs

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ABSTRACT

Rock weirs typically placed by loose rocks and span the full width of channel, are eco-friendly grade-control structures (GCSs) commonly built in small and medium-sized rivers (USBR, 2016). A rock weir in rivers can preventing bed degradation, whereas the over-weir flow can cause local scour that can threaten the structure stability. Current studies mainly focus on the clear-water scour at rock weirs (Scurlock et al., 2012), remaining the live-bed scour (e.g. the effect of approach bedforms on the scour depth) at rock weirs are unknow. As such, predictors for accurately estimating the scour depth at rock weirs are far from complete.

Experimental tests using sand-water recirculating flume and uniform coarse sand (d_{50} = 1.17 mm) were conducted to study the live-bed scour at rock weirs. The rock weir was placed by loose rocks (artificial pebbles that have the same shape and density as river pebbles, Zhang et al., 2023) spanning the full width of the flume in a I-shape. A brick foundation was set below the weir. Various combinations of flow intensity, submergence and void ratio were tested in this study. The scour depth at rock weirs was manually read using cameras focused through transparent grid sheet attached to both sides of the flume (Guan et al., 2015).

For live-bed scour conditions, scour occurs both upstream and downstream of rock weirs. In response to the periodic motion of the approaching bedforms, the equilibrium scour depth fluctuates around a mean depth (Fig. 1). The equilibrium upstream scour depth increases first and then decreases with increasing flow intensity, decreases with increasing weir height, but is less affected by increasing void ratio. The equilibrium downstream scour depth decreases first and then increases with increasing flow intensity, increases with increasing weir height, and decreases with increasing void ratio. New predictors for both upstream and downstream equilibrium scour depths at rock weirs are proposed for design.

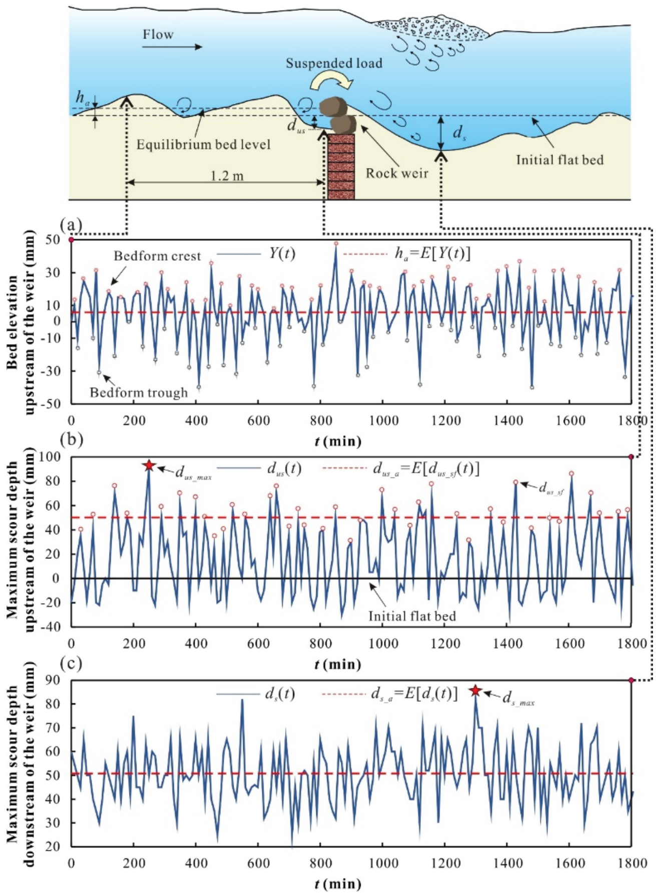

Figure 1. Fluctuations of (a) the bed elevation upstream of rock weir, (b) the upstream scour depth, and (c) the downstream scour depth at rock weirs

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Numerical study on the erosion protection effect of a spoiler structure

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ABSTRACT

As a Marine structure, monopile foundations can significantly alter the hydrodynamic conditions surrounding the piles. The main causes of local scour around monopile foundations are the horseshoe vortex, downward flow and wake vortex. This study focuses on a large-diameter monopile foundation used in offshore wind power and proposes a spoiler structure. A three dimensional numerical model is established to investigate the influence mechanism of the spoiler structure on local scour around the monopile. The influence of length L and height H of the spoiler on the location and strength of local horseshoe vortex is discussed, and the distribution characteristics of the bed shear stress are obtained. Comparing the distribution of local horseshoe vortex and bed shear stress with and without the spoiler, it is found that the spoiler ribs can significantly reduce the strength of the horseshoe vortex and the regional shear stress between ribs. The local horseshoe vortex exhibits three flow mechanisms under different geometric spoiler structures, namely independent horseshoe vortex, disturbed horseshoe vortex, and separated horseshoe vortex. In these three states, the protected bed area shows a linear relationship with the spoiler geometric length or height. In addition, the spoiler has a good scour protection characteristics with an H/L ratio of 1.

By analyzing the flow field characteristics around the spoiler, the influence mechanism of ribs on the horseshoe vortex and shear stress distribution around the monopile foundation is revealed. Overall, the spoiler structure effectively protects against local erosion, providing valuable insights for the design of monopile foundations.

Process-based design method for pier local scour depth under clear-water condition

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ABSTRACT

Accurate estimation of local scour depth has long been considered to be an important step for the design of bridge piers. Methods currently serving in different countries are generally based on equilibrium equations, which can be classified as "equilibrium methods", and have been found to either overestimate or underestimate the local scour depth. The inaccuracy and uncertainty of equilibrium methods were discussed in detail, and can be mainly attributed to the impact of the concept of the equilibrium scour depth d_{se}: (1) there is no objective and universal d_{se} criterion for laboratory experiments; (2) it is difficult to judge the equilibrium of local scour in field; (3) the utilization of existing experimental data is limited; and (4) it is difficult to unify the d_{se} criterion of database for equation establishment.

In this study, we proposed a new design method for clear-water local scour depth based on temporal evolution characteristics. We collected data from 67 experiments from the referenced literature and conducted 4 in-house experiments. Using factor analysis and trial calculation, we derived a new temporal equation for local scour depth evolution, i.e., Eq. (1). Comparison in Fig. 1 showed that the maximum predicting error of the total 71 experiments was reduced from 162–534% using four existing temporal equations to 34% using Eq. (1).

$$\frac{d_s}{d} = \frac{1}{2} K_s K_\theta \sigma^{-1} \frac{h^{0.15} D_{50}^{0.25}}{d^{0.4}} \left(\frac{U_0}{U_{sc}} \text{-}1 \right)^{0.5} \ln\left(1 + 0.006\Delta \frac{U_0 t}{d}\right) \quad (1)$$

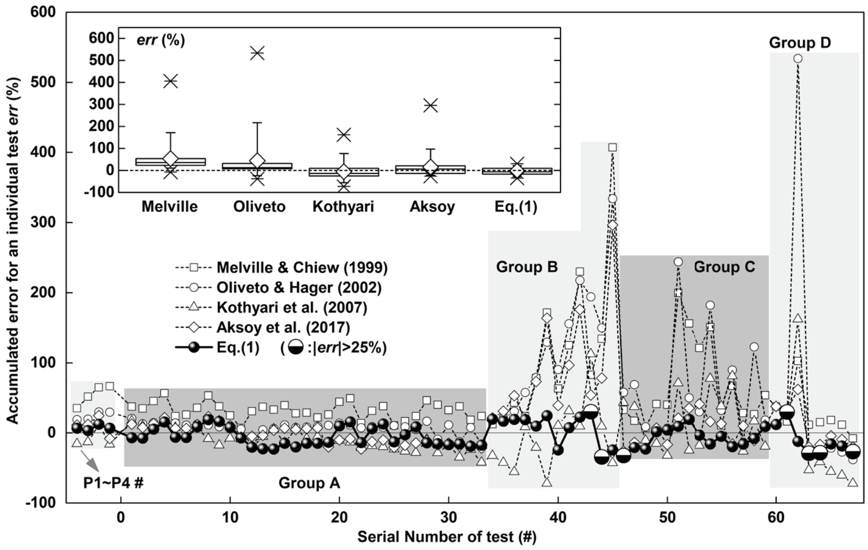

Figure 1. Accumulated predicting error for the dataset of the new temporal equation compared with four existing equations. The meaning of the symbols in the box chart are as follows: (-) is the maximum and minimum error value, (◇) is the average error, (×) is the error with cumulative frequency of 99% and 1%, (┬) and (┴) correspond to the error with cumulative frequency of 90% and 10%.

Using Eq. (1) as the crux, a process-based design method for d_s was proposed, and illustrated by an idealized scenario step-by-step with four assistant curves as shown in Fig. (2): The $U_0 \sim h$ and $U_c \sim h$ curves were used to determine the unknown parameters h, U_0 and U_c, following the basic principles of hydrology, hydraulics and sediment transport dynamics. The $d_s \sim t$ and $F(t)$ curves were used to determine the design standard and calculate the design d_s. In addition to its understandability and usability, the new method had better flexibility and fault tolerance, as it did not involve the concept of equilibrium scour depth, which lacked an objective and universal criterion.

Characterization of sand motions around vibrating monopile foundations

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ABSTRACT

Monopile foundations of offshore wind turbines undergo continuous vibrations due to the cyclic lateral loads induced by waves and winds. To focus on the dynamics of sand behavior around vibrating foundations, researchers conduct two-dimensional experiments enabling convenient observation of sand motions and bed deformation around the structure, facilitating a better understanding of how the sand responds to the cyclic vibrations. Previous studies have investigated sand motions around vibrating monopile foundations under dry conditions and found sand convective and subsidence motions around them. However, two questions remain unclear: (1) what's the influence of backfilled sand on the sand motions around vibrating monopile foundations? (2) whether the same convective and subsidence motions occur under saturated conditions and whether there are any differences in sand motions between dry and saturated conditions.

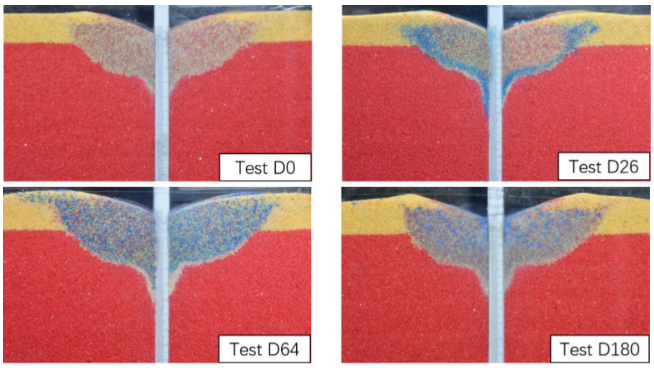

Figure 1. The final shape of the sand deformation around the vibrating monopile in 4 tests

Thus, this study with two experiments is presented. The first experiment was designed in two-dimensional conditions and different particle sizes of backfilling sand were used. As shown in Fig.1, the backfilling sand (blue color) is mixed evenly within the convective zone if the backfilling sand and original bed sand (red color) are of similar size. The relatively larger backfilling particles are prone to be concentrated in the upper part of the convective zone, while the relatively smaller backfilling particles usually migrate away from the vibrating monopile to the boundary of the convective zone. The experimental results indicate that backfilling sand with a larger particle size can effectively reduce the depth of the subsidence hole and mitigate the sand convective velocity around the vibrating monopile, compared with backfilling material of smaller or the same size as the original sand bed.

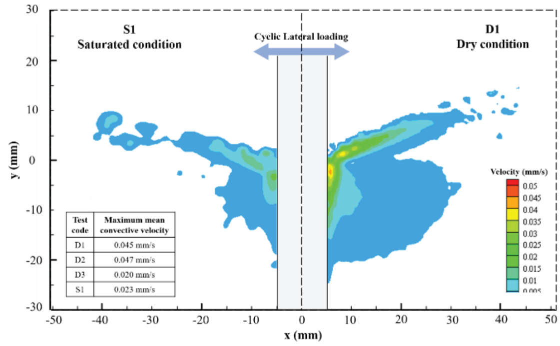

Figure 2. Mean velocity field around the vibrating monopile foundations under dry and saturated conditions

The second experiment investigates sand motions around vibrating monopile foundations under dry and saturated conditions. The experimental results indicate that the compacted sand surrounding the structure reduces the vibration amplitude of the monopile. But the vibration amplitudes are more significantly attenuated under saturated conditions compared to dry conditions. Moreover, as shown in Fig.2, the convective motions of sand under the saturated condition are weaker than those under the dry condition, which suggests that the viscous dissipation effect may weaken the convective motions around the vibrating monopile foundations.

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Scour mitigation and erodibility improvement using soybean urease-induced carbonate precipitation

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ABSTRACT

Enzyme-induced carbonate precipitation (EICP) is a new developing method in the engineering of soil reinforcement. In this paper, the erosional behaviour of EICP-treated sand was investigated to explore its potential applications in scour mitigation and erodibility improvement. The urease enzymes were extracted from soybeans by low-energy coarse filtration. Granular sand columns treated with 10 U/mL of urease and 1 M of cementation solution, together with non-treated specimens, were tested in a closed flume system. The flume can generate surface-parallel flow with different shear stress for examining scour behaviour. The evolution of scouring resistance of specimens over curing time was obtained through erosion rate tests. The carbonate content and microstructure of the treated sand columns were examined. The results indicated that the carbonate content of specimens increased as a function of curing time until the cementation solution was totally converted. Enhancing the scouring resistance of specimens through EICP was confirmed, for which higher carbonate content promotes sediment incipient velocity and critical shear stress. Low erosion rates of strongly cemented sand were observed for those cured for more than 12 hours. With the increase of the specimen cementation strength, the erosion mode of the specimen changed from the surface particle eroding to the agglomerate detachment. Additionally, the microstructure analysis showed that the effectiveness of EICP for scour control was also dominated by calcium carbonate crystal features besides carbonate content.

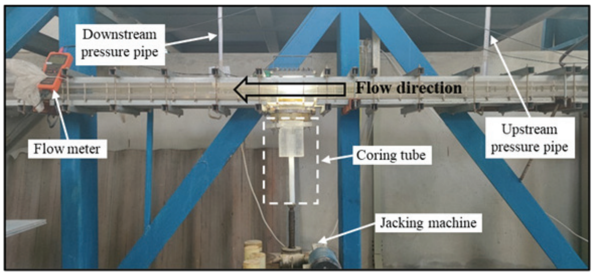

Figure 1. Test section of experimental flume system.

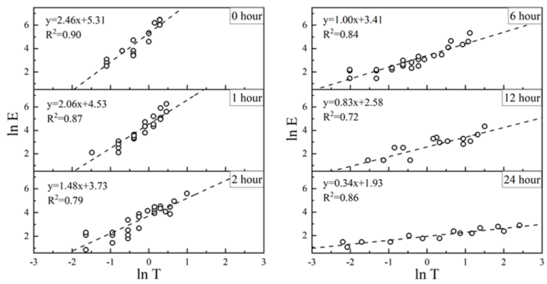

Figure 2. Log-transformed relationship between dimensionless erosion rate and dimensionless shear stress.

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Chapter 3

Session B: Scour Around Costal Structures

Research and application on scouring at the seawalls foot for the seawall safety engineering in Zhejiang province

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ABSTRACT

Under the influence of extreme hydrodynamic forces，the severe scouring of the riverbed at the seawall foot will lead to the overall instability of the seawall structure，which is one of the main factors causing the damage of the seawall.For the Seawall Safety Engineering in Zhejiang Province, this paper systematically analyzes the scouring characteristics of the seawall foot and research difficulties , studies the method of determining the scouring elevation, puts forward the research ideas and calculation technology system of the design scouring elevation of the seawall foot. And takes the Yuecheng Seawall Safety Engineering in Shaoxing city as an example to carry out demonstration application.

The main conclusions are: the strong hydrodynamic force causes severe scouring of the riverbed, the law of erosion /deposition is complex, and the standard of scouring elevation at seawall foot is different, which are the main difficulty in the research of scouring at the seawall foot. The the design scouring elevation should be the elevation under the corresponding hydrodynamic conditions of the seawall defense standard.The analysis of measured data, mathematical model calculations, and physical model experiments are effective methods for studying scouring problems. For the curved concave bank section, and complex bank sections affected by wading structures in the estuarine area, the combination of the above three methods should be used to determine the design scouring elevation。The remaining bank sections should be studied using at least two methods: analysis of measured data and mathematical modeling methods.

For the Yuecheng seawall, the front water area has strong tidal currents and deep troughs that are close to the bank. The seawall foot is severely eroded and shows an increasing trend, with a measured minimum scouring elevation of -3.24 m. By using research methods such as measured data analysis, mathematical model calculations, and physical model experiments, the flow velocity in the water area in front of the seawall can reach 4.82~6.61 m/s under 300 year dynamic conditions, and the design scouring elevation is -4.0~-6.0 m, providing key parameters for the design and erosion prevention of the Yuecheng Seawall Safety Engineering.

Scour around windfarm monopile foundations subjected to lateral cyclic loadings

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ABSTRACT

Monopile foundations are regarded as the most favorable foundation type for offshore wind turbines constructed in relatively shallow waters with water depth less than 35m (Gavin et al., 2011). It is reported that monopile foundations of offshore wind turbines (OWTs) experience continuous cyclic lateral loads induced by winds and waves during their operation period, which may result in vibration of monopile foundations and changes in the scour process. Previous experimental studies show that the current-induced equilibrium scour depths at vibrating monopiles may be less than those at static monopile foundations (Al-Hammadi and Simons, 2020; Guan et al., 2019). However, scour processes around vibrating monopile foundations under current-only conditions with different flow intensities and under combined wave-current conditions remain unclear. New experimental studies are presented to further investigate the scour characteristics around monopile foundations of OWT subjected to lateral cyclic loadings under current-only conditions and combined current-wave conditions.

The experimental results of current-only cases in different flow intensities indicate that the scour process around monopile foundations subjected to lateral cyclic loading is mainly influenced by three factors: vibration-induced sediment subsidence, vibration-induced sediment refill, and current-induced erosion. Based on the experimental data, a “regime transition flow intensity” is obtained, at which the equilibrium scour depth remains constant regardless of any changes in the vibration amplitudes. Furthermore, two distinct scour trends under low and high flow intensities are identified. The increase of vibration amplitude in the low flow intensity regime leads to an increase of equilibrium scour depth. Conversely, the increase of vibration amplitude in the high flow intensity regime leads to a decline of equilibrium scour depth. This reduction is attributed to a more substantial sediment refill induced by the vibrations. Furthermore, the experimental results indicate that equilibrium scour depths at monopile foundations subjected to cyclic lateral loads perpendicular to the flow direction are generally larger than those under cyclic lateral loads parallel to the flow direction.

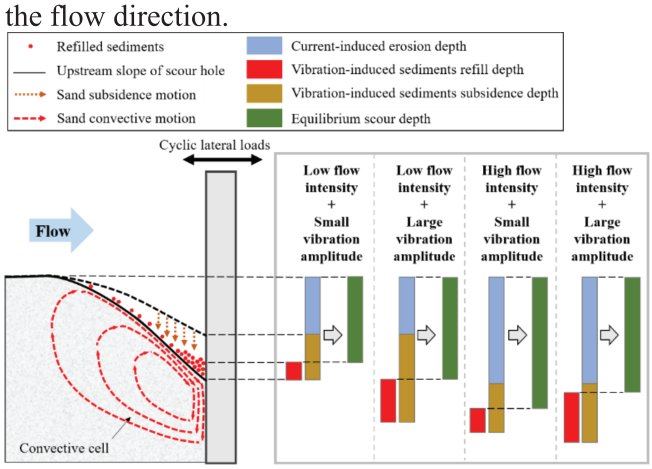

Fig1. Schematic drawings of equilibrium scour holes development patterns under different combinations of flow intensities and vibration amplitudes

The preliminary experiment in combined wave-current conditions shows that equilibrium scour depth at monopile foundations subjected to cyclic lateral loadings is proportional to the loading intensity in relatively weak hydraulic dynamic conditions while it is inversely proportional to the loading intensity in strong hydraulic dynamic conditions.

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Introducing metagenomics as a tool to study microbially induced calcium carbonate precipitation in natural systems

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ABSTRACT

Microbially Induced Calcium Carbonate Precipitation (MICP) is a widely recognized natural process involving the interaction of metabolic byproducts, such as bicarbonate ions (HCO_3^-) and calcium ions (Ca^{2+}), leading to the formation of calcium carbonate ($CaCO_3$) minerals. MICP has gained significant attention due to its applications in various biotechnological fields, including soil and water remediation, soil bioconsolidation, CO_2 bio-sequestration, and self-healing bio-concrete (Castro-Alonso MJ,, *et al.* 2019). The precipitation of $CaCO_3$ is a common phenomenon observed in marine sediments, freshwater, soils, caves, and hypersaline habitats. While laboratory-scale investigations have focused on promising pure species like *Sporosarcina pasteurii* for MICP applications, the microbiological and molecular concepts of MICP and the mechanisms by which different microbial groups contribute to MICP in natural environments remain largely unexplored.
MICP formation can be broadly classified into two categories: Ureolytic and Non-ureolytic pathways (Figure 1). However, so far, mostly ureolytic activities have been extensively studied at the laboratory scale. The potential of non-ureolytic pathways for MICP demands further investigation, as stimulating mixed microbial populations holds promise for *in-situ* applications and offers advantages over single-species-driven approaches.

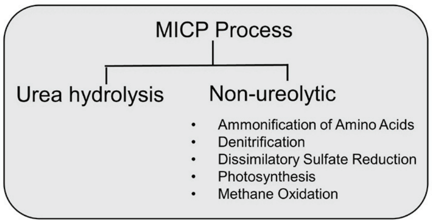

Figure 1. Two major routes for MICP.

This study investigates MICP capacity in the natural environment by focusing on the six sample (S1-S6) microbiome of Challenger Deep bottom-axis sediments (Zhou YL, *et al.* 2022). Through metagenomic analysis using the Squeezemeta pipeline (Tamames J, Puente-Sánchez F, 2019) and in-house R-scripts, we uncover microbial taxonomic and functional insights behind MICP processes. Our analysis reveals the presence of both urease (EC 3.5.1.5) and carbonic anhydrase (EC 4.2.1.1) genes, suggesting the potential involvement of the ureolytic pathway. Additionally, we observe a significant functional capacity of the microbial population associated with non-ureolytic routes, such as energy metabolism pathways (*e.g.*, nitrogen, sulfur, methane metabolism) and amino acid metabolism (Figure 2).

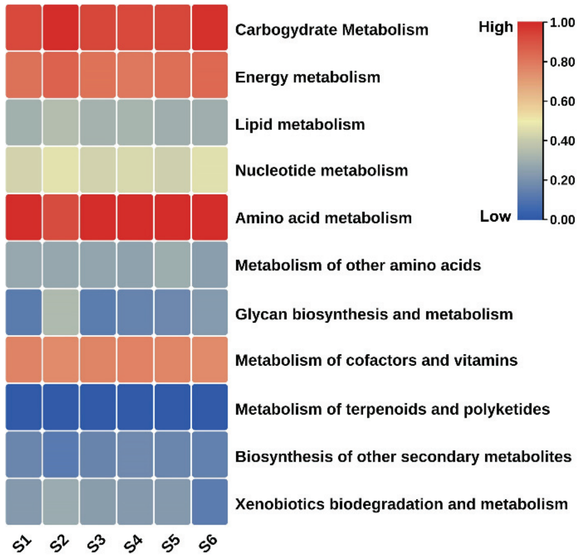

Figure 2. Functional capacity of the microbial community.

This study highlights the applicability of metagenomics as a powerful tool for studying native mixed microbial populations and their possible contribution to MICP in marine sediments. By leveraging this knowledge, we propose the potential for enhancing MICP production by stimulating the mixed microbial population. Our findings contribute to a deeper understanding of MICP processes in natural microbial communities and open avenues for exploring their practical applications.

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Experiment investigation of local scour around subsea porous caissons

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ABSTRACT

For subsea structures in the coastal and offshore engineering, complex configurations are always equipped with horizontal and vertical beams inside, for example the subsea production system. It is believed that the structure porosity would be one of the key factors that largely affects the flow structures and the sediment transport. However, the previous studies always applied solid structures as a simplification. Little is known for the effect of structure porosity on the local scour. Hence the local scour around the finite high permeable structures, simplified as cubic porous caissons as shown in Fig. 1, was studied experimentally in this study.

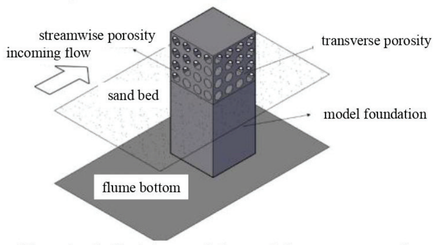

Figure 1. Sketch definition of the cubic porous caisson model

The corresponding experiments were conducted in the non-linear wave flume at Dalian University of Technology. The cubic porous caissons were made of acrylic material with its side length being 20 cm. To ensure the stability during the test, a foundation with dimensions of 0.4m (depth) × 0.2m (width) ×0.2m (length) is installed deeply in the sand bed as shown in Fig. 1. The structure porosity is realized by opening circular holes in the front and rear surfaces of the model caisson in the stream-wise direction. The change of the porosity is obtained by altering the diameter of the circular hole. In the present study, the diameter of the circular hole ranges from 0cm to 4cm, resulting in the structure porosity ratio P changing from 0% to 50.3%. In the present the porosity ratio P is defined as,

$$P = A_{\text{hole}}/A_{\text{cross}} \quad (1)$$

where A_{hole} is the total area of permeable parts for the upstream or downstream surface of the caisson and A_{cross} is total area for the upstream or downstream surface of the caisson. In addition to the above experiment setup, the effect of the transverse structure porosity ratio P_t, ranging from 0% to 38.5%, on the local scour was also investigated, and the test cases were summarized in Table 1.

Table 1. Experimental tests performed on tests of local scour around the cubic porous caissons.

Test No.	Streamwise P_s (%)	Transverse P_t (%)
A1	0	0
A2	3.1	0
A3	12.6	0
A4	28.3	0
A5	38.5	0
A6	50.3	0
B1	12.6	12.6
B2	12.6	38.5
B3	38.5	12.6
B4	38.5	38.5

In the experiment, the water depth is 50 cm. The median particle size of sand d_{50} is 0.378 mm, corresponding to the critical shields parameter θ_{cr} = 0.0336. The depth averaged velocity U is 0.353m/s, resulting in the shields parameter θ = 0.0429. Hence all the tests are live-bed conditions.

From the experimental results, it is found that local scour initiates from the two upstream corners of the caisson, and the velocity amplification at the upstream corners plays a more significant role than the horseshoe vortex. The equilibrium scour depth, scour rate as well as the downstream dune size decrease as the increase of the streamwise porosity P_s. One interesting phenomenon found is that the transverse porosity P_t has a very weak influence on the above mentioned variables. Based on the new finding, an empirical formula, considering the effect of the structure porosity on the local scour depth, was established as following,

$$S_0/D = \beta(1-P_s)^{0.75} \quad (2)$$

where, β is a constant. For Test No. A1-A6, $\beta \approx 0.849$; for Test No. B1- B4, $\beta \approx 0.823$.

Theoretical methods of prediction-monitoring-assessment and new technology of prevention and control of offshore wind power pile scour process

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ABSTRACT

Offshore wind power pile scour problem throughout the whole process of offshore wind power, and marine engineering foundation scour disaster prevention and control research involves marine engineering, geotechnical engineering, sediment dynamics and other disciplines, the use of a single field of theory and research methods can not fundamentally solve the problem of scouring disaster, so we need to be from a multidisciplinary cross-disciplinary point of view, the use of a comprehensive multidisciplinary background of the means of research on the scour problem to carry out an in-depth investigation.

This study intends to take the scouring problem in the whole process of offshore wind power pile foundation design-construction-operation and maintenance as the research object, and based on the in-depth examination of different states of the soil body during the scouring process of the seabed, the following research is carried out.

(1) Scour prediction: the key soil skeleton parameter affecting sediment erosion is identified as pore scale through modeling test, and the relative densities of fine sands are selected as test variables to obtain the prediction formulas of critical initiation current velocity of sediment and scour depth of pile foundation under different soil skeleton pore structures.

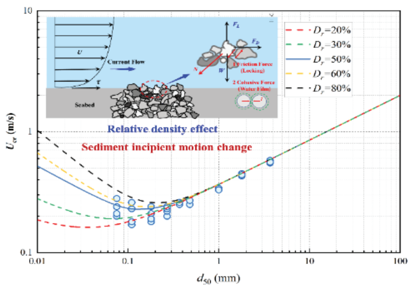

Figure 1.Critical initiation velocity of fine sand with different relative densities

(2) Scour monitoring: scouring seabed foundation is introduced into the wind power pile foundation coupled dynamic structural system, the finite element numerical analysis model of wind turbine-pile foundation-seabed foundation coupled dynamic action is constructed, the modal characteristics of the coupled dynamic system are analyzed, and the scouring depth of the pile foundation of the physical model is calculated, so as to form a real-time monitoring method of dynamic scouring depth of the pile foundation based on the identification of the modal pattern.

(3) Scour assessment: analyze the effects of scour pits, pile foundations, soil and loading parameters on the bearing characteristics of pile foundations, clarify the main controlling factors of the bearing capacity and deformation of pile foundations, and further reveal the time evolution mechanism of the cyclic cumulative deformation, so as to realize the whole process, long cycle and accurate assessment of the loss of bearing capacity and the increase of cumulative deformation of pile foundations due to scouring.

(4) Scour protection: it proposes a new technology for scour prevention and control of the foundation of submarine structures, introduces the concept of land grouting into the management of scour pits, realizes the prevention and control of seabed curing and essentially improves the anti-scouring performance of the seabed.And a new concept of scour control taking into account benthic ecological aquaculture is proposed

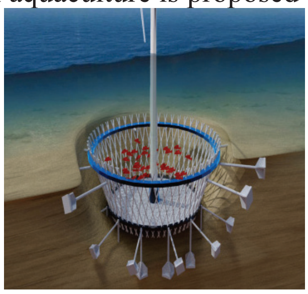

Figure 2.Scour hole supports with ecological functions for aquaculture nets

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Effects of the gap on the local scour around two tandem piles in shallow flows

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ABSTRACT

With the fast development and construction of Offshore Wind Turbines (OWT), the local scour around OWT piles in coastal areas provokes wide interests in academic and industrial communities. Different from the traditional pile foundation sufficiently submerged in water, the near-shore OWT steel pipe monopile often has a diameter ranging from 5 to 8 m, being larger than the water depth (Jensen et al., 2006). Therefore, the prediction of the local scour at the OWT steel pipe monopile is difficult because of the relatively low aspect ratio (flow depth-to-pile diameter ratio) and the low Froude number when an OWT situates in a shallow-water coastal area – a condition for which current scour equations do not account.

In addition, the array arrangement of the large-diameter monopiles further increases the complexity of the problem, and a comprehensive understanding of the interaction mechanism among the tandem piles (the simplest array arrangement) in shallow water is still lacking. In this paper, a series of numerical simulations of the local scour around two tandem circular piles with a wide range of aspect ratios are carried out, and the effect of the aspect ratio (h/D) and pile spacing (G/D) on the scour process and scour morphology is investigated.

The characteristics of the scour process, depth, and flow fields are shown to be significantly influenced by the pile gap ratio (G/D = 1.0–5.0) and water depth ratio (h/D = 0.5–3.0). Under the same G/D, the dimension of the scour hole and the maximum scour depth around two piles become larger with the increase of h/D. Under the shallowest water depth condition (h/D = 0.5), the scour dimension and maximum scour depth of the rear pile are larger than that of the front pile, due to the weak upflow and strong downflow upstream of the rear pile. However, under the deepest water depth condition (h/D = 3.0), the scour hole becomes smaller than that of the front pile, due to the significant upflow downstream the front pile by less confinement from the high water surface. The vortex shedding patterns and their interaction with the sediment transport in different G/D and h/D cases are also discussed.

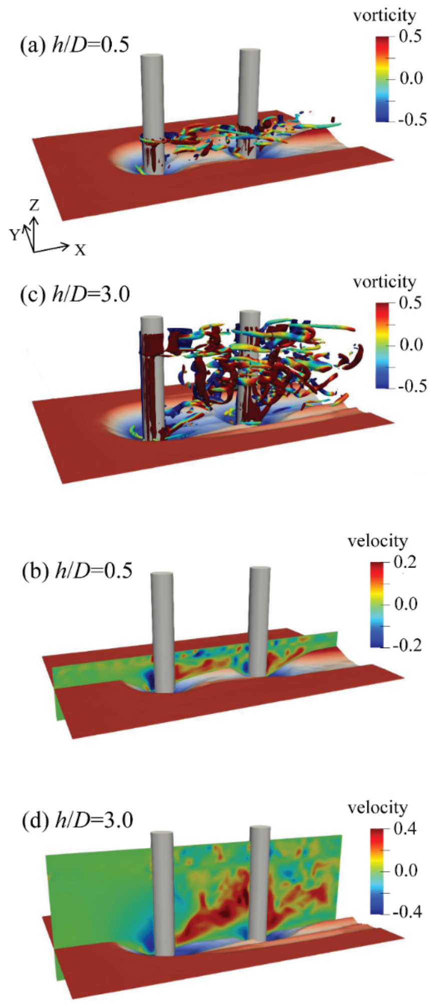

Figure 1. Vortex structures and velocity contours in the equilibrium state for G/D = 5.0 at (a,b) h/D = 0.5 and (c,d) h/D = 3.0 cases

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Applications of anti-scour solidified soil on marine structures and hydraulic engineering

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ABSTRACT

An effective method using KunZe fluidized solidified soil for anti-scour repair and protection has been widely applied on marine structure and hydraulic engineering in recent years. KunZe solidified soil is a clean, non-toxic material with high performances in multiple physical properties and anti-scour abilities in both fluid and solid (after hardening) state. Different from granular materials such as rocks and sandbags, free-flowing fluidized solidified soil is injected to seafloor area around offshore foundations by pumping operation, filling the scour holes to form low-slope-ratio capping structures with smooth surface for anti-scour protection. Since 2018, anti-scour solidified soil has been successfully applied on more than 700 monopile foundations in various scenarios such as shallow scour holes, deep scour holes with small areas and deep scour holes with large areas around foundations.

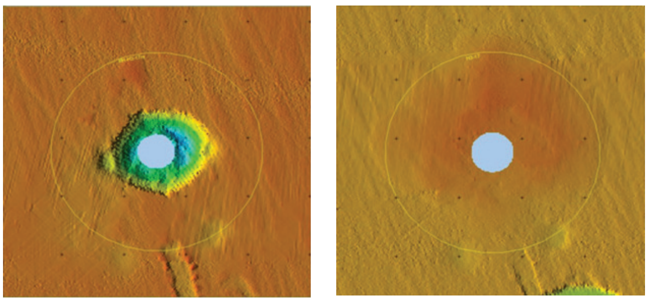

Figure 1. Comparison of effectiveness before/after using anti-scour solidified soil on monopile fundation (Scanned by multi-beam sounding system. Left: before; right: after.)

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Span shoulder migration in three dimensional scour around pipelines with wave plus current conditions

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ABSTRACT

When the pipeline is placed in the marine environment, the surrounding flow pattern will be changed relative to the undisturbed bed in the far field, which may in turn lead to scour as the result of increased local sediment transport capacity. Such scour propagation may potentially cause the sagging, the vortex induced vibrations and the fatigue failure of the pipeline. It is therefore of great interest to gain overall knowledge concerning the scour processes below the pipelines.

Many previous researchers focus on the 2D scour which in this case the scour only propagates in the vertical direction. Investigations that involved 3D scour around pipeline is mostly with the pure current or wave conditions. In this study, new analysis involving the span shoulder migration in the three-dimensional scour beneath submerged horizontal pipelines are presented. Specific emphasis is on gaining a better understanding of, and ability to predict, the span migration velocity with the current, and the wave plus current conditions. For the pure current cases, consistent with previous experimental observations, both a primary (faster) and secondary (slower) span migration are observed. Process visualization of suspended sediment patterns are in line with prior speculation that this transition coincides with reduced local bed shear stress amplifications as the scour hole both deepens and widens. Dimensional analysis and physical insight are combined, leading to a new rational model for predicting the span migration velocity in both live-bed and clear-water regimes, with predictions naturally coinciding at the limit of far field incipient motion conditions. In both regimes the data cluster as predicted, and fitted closed-form expressions are provided for predicting the span migration velocity. The rational approach likewise includes a new and simple criterion for the transition from primary to secondary migration in the live-bed regime. In the clear-water regime the model incorporates primary dependence on the ratio of the Shields parameter to its critical value. The developed rational model can be used to quantitatively predict all known major features of the span migration velocity in the early stages of the three-dimensional (live-bed and clear-water) scour beneath submerged horizontal cylinders induced by perpendicular flow, and can hence be regarded as the first complete model for this evolution. For the wave plus current cases, it is found that the migration velocity is decreased if the wave components were considered. By adopting the coefficient of relative strength in current, one model was proposed which predicts the span shoulder migration velocity with wave plus current conditions. The dependence of non-dimensional velocity on the Shields parameters was found to 3/2 power, which is the same to that in the pure current conditions.

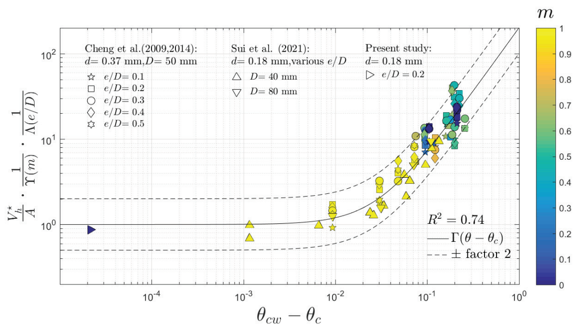

Figure 1. Span shoulder migration with wave plus current conditions.

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ISPH simulation of local scour around coast structures and turbulent flows under breaking waves

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ABSTRACT

Generation and transport of turbulence associated by wave breaking are dynamic, complex and multi-scale processes and extreme waves/currents may destroy the coast structures through continuous scour around them. A 3D incompressible Smoothed Particle Hydrodynamics (ISPH) erosion model is proposed to simulate the scouring process around coastal structures. The erosion model is based on the turbidity water particle concept and the sediment motion is initiated when the fluid bottom shear stress exceeds the critical value. To validate the developed model, a laboratory flume experiment was carried out to study the clear water scouring around a vertical cylinder under unidirectional current, in which high-speed video cameras were used for the real-time monitoring of sediment movement. Recently, the Incompressible Smoothed Particle Hydrodynamics (ISPH) method solving the 2D RANS (Reynolds Averaged Navier-Stokes) equations with the k–ε turbulence closure is constructed. The concept of “massless ISPH” utilizing the definition of "particle density" (number of computational particles within unit volume) is stressed. In the case of periodic wave breaking, the over-production of turbulence beneath surface waves is stressed and the modification for standard k–ε model proposed by Larsen and Fuhrman (2018) is adopted. The effects of initial seeding of turbulent kinetic energy and stress limiter coefficient λ_2 are studied. An adaptive wall boundary condition for k–ε turbulence model is employed to avoid the unrealistic production of turbulence near the wall boundary. The GC_DS (Gradient Correction_ Dynamically Stabilized) scheme proposed by Tsuruta et al. (2013) is adopted to reduce the numerical dissipation. The numerical results, in terms of free surface profile, mean velocity field, vorticity field, turbulent kinetic energy and turbulent shear stress, are compared with experimental data. Very reasonable agreement is observed. This research presents the first comprehensively validated ISPH model with the modified k–ε turbulence closure, which can be applied to transient free surface wave problems.

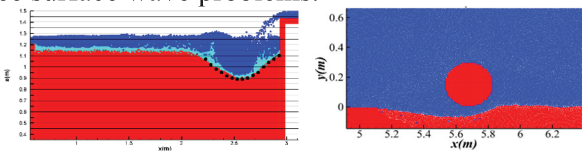

Figure 1. Comparisons between 3D numerical results (left) and experimental data (right) for scouring process

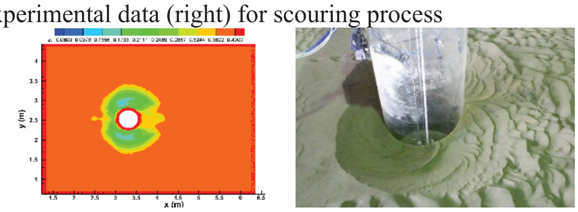

Figure 2. Comparisons between 3D numerical results (left) and experimental data (right) for scouring process

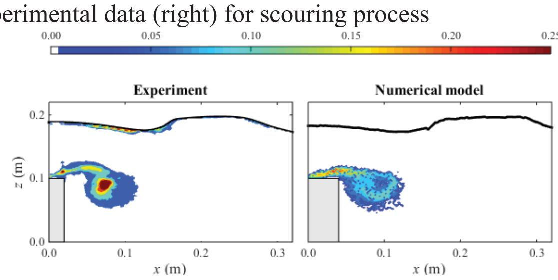

Figure 3. Comparisons between experimental data (left) and numerical results (right) for turbulence intensity (m/s)

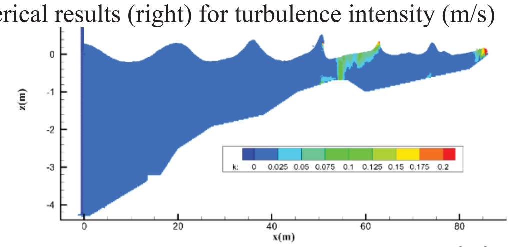

Figure 4. Evolution of turbulent kinetic energy (m^2/s^2) under a periodic breaking wave.

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Scour around a pile in silt under codirectional combined waves and current

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ABSTRACT

When a pile is placed in a marine environment, the presence of the pile will cause the flow pattern in its neighborhood to change, resulting in the contraction of flow at sides of the pile and the formation of vortices in its upstreaming and downstreaming. The change of flow will generally lead to an increase in the bed stress and then influence the local sediment transport capacity. It is well known that local scour around the foundations of a hydraulic structure can lead to damage or even to overall failure.

In most of previous studies on local scour around pile, scour in steady currents has been investigated quite extensively, and a great many works have been devoted to the flow pattern (horseshoe vortex combined with downflow and contraction of streamlines) and scour equations (e.g., Chiew, 1984; Melville, 1988; Ettema, 1980; Sheppard, 2000; Dey, 1995) . For scour around pile under the action of wave alone, the scour depth is found to depend mainly on Keulegan-Carpenter number (KC) and diffraction parameter (D/L). KC number governs the size and life span of horseshoe vortex and lee-wake vortex flow (Sumer et al., 1992; Kobayashi and Oda, 1994); the ratio D/L reflects the wave diffraction process as a incident wave impinging on the pile. For the local scour around a pile under combined waves and current, Sumer (2001) indicated that the scour depth increases with increasing dimensionless parameter U_{cw} and KC, and attains its steady-current value for $U_{cw} > 0.7$.

The sediment used in the above-mentioned studies is fine to medium sand, few study investigating the scour by waves and current in very fine sand and silt is yet available. The purpose of the present work is to make a systematic study of wave and current scour around a circular pile in silt.

The experiments were carried out in a flume (50m long, 0.5m wide and 0.7m high), which is capable of synchronously generating waves and current. Silt with $d_{50} = 0.075mm$, relative density Dr=0.36 and geometric standard deviation was $\sigma_g = 2.7$ were used in the experiments. And circular model pile with diameter D=5cm was implemented in the tests.

The results of experimental investigation on waves and current scour around a circular pile in silt are presented. The range of Keulegan-Carpenter number (KC), tested in the experiments is from practically 2 to approximately 12. The pore-water pressure were measured for all tests to see if there was a liquefaction process occurring in bed material. The U_{cw} ranges from 0 to 1, and the Shields parameter in this study is such that the bed is live. Experimental results indicate that, for wave only tests, scour of silt begins to occur when KC exceeds 3-4, and the scour depth is increased by a factor of 2 when the bed soil changed from sand to silt. For waves and current tests, the scour depth in silt no liquefaction occurring (low KC number) compares well with the corresponding scour data in sand. However, for larger KC number cases, the pore water pressure continues to accumulate and the bed soil is liquefied, a significantly larger scour depth is found in silt. The ratio of silt bed scour depth to sand bed scour depth is 1.3-1.7 where liquefaction occurs.

Figure 1. scour hole around the cylinder

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Numerical simulation of seawall breach erosion and inundation due to influx of floodwater — using Typhoon Maria (1808) as a case study

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ABSTRACT

Super Typhoon Maria (1808) struck Fujian Province, China, coinciding with a high astronomical tide. This event led to the breach of the seawall in Yacheng Town, Xiapu County, Ningde City (Fig. 1), and subsequent flooding of the town due to the seawater backflow. To comprehensively examine the patterns of seawall breaches and the breach process under the combined influence of typhoon waves and astronomical tides, this research adopted a methodology involving the superimposition of tidal levels and typhoon waves. This approach simulated the progressive development and flooding scenario of the breached seawall under various conditions. The study's objective is to establish a theoretical foundation and offer technical insights for disaster prevention and mitigation in coastal engineering.

This study conducted simulations to assess the combined impact of astronomical tides and typhoon waves on seawall failures, specifically overtopping and piping failures. The obtained results were compared with scenarios where piping failure was solely due to astronomical tides. It was observed that the outcomes of the first two cases exhibited similarities, with a peak discharge flow of around 230 m^3/s (Fig. 2) and a breach width of 26 m (Fig. 3). In contrast, the discharge flow resulting from astronomical tides alone was significantly lower at 22 m^3/s, accompanied by a narrower breach width of 8 m. Additionally, the article independently modeled the progression of flooding in the aforementioned scenarios following a seawall breach. Taking the flooding due to overtopping as an illustration (Fig. 4), the maximum inundation area was reached at approximately 120 minutes, with a maximum depth of 3.10 meters and an average depth of 1.23 meters. Subsequently, as the astronomical tide receded, floodwater gradually drained through the breach.

Figure 1. On-site photo of the breached seawall in Yacheng Town.

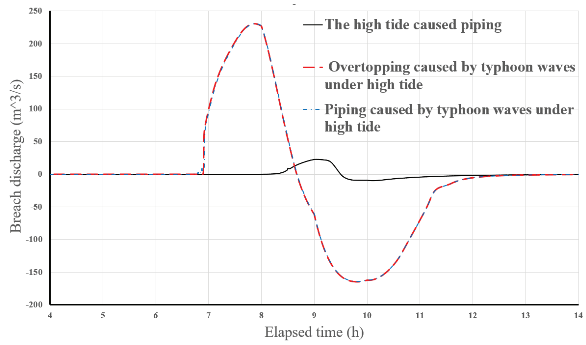

Figure 2. Computed discharge rates for various conditions of breach flow

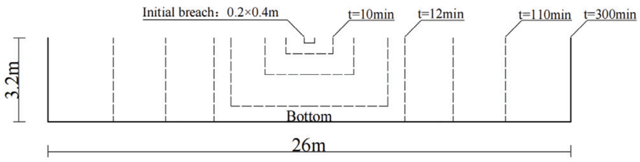

Figure 3. Expansion of seawall breach erosion under combined high tide and typhoon wave overtopping

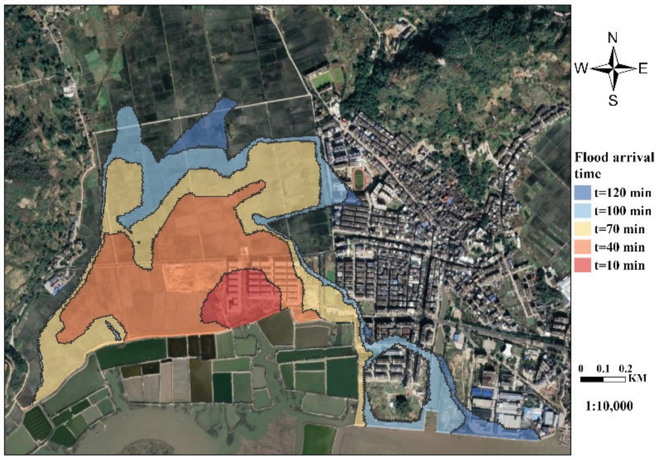

Figure 4. Evolution of inundation by seawall breach and influx of floodwater under combined high tide and typhoon wave overtopping

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Time development of clear-water scour around a pile foundation: a first principle-based approach

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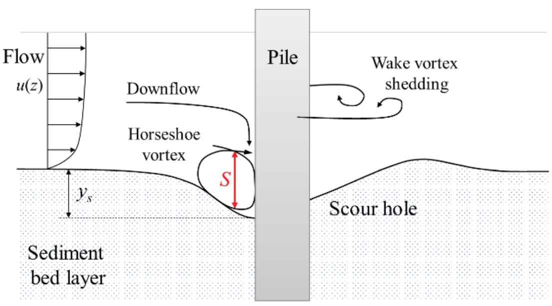
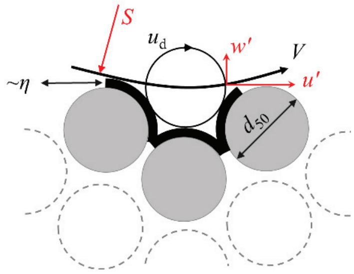
ABSTRACT

Existing prediction formulas for clear-water scour development are typically empirical fittings of lab-scale results. However, it is unreasonable to evaluate the in-situ clear-water scour process around a pile based on small-scale flume tests due to inherent scale effect. This study proposes a time-dependent model of clear-water scour development around a pile foundation under steady currents. A scaling expression of shear stress acting on sediment particles in the front of a circular pile is established based on the phenomenological theory of turbulence. By applying the sediment transport model of flat-bed to local scour around a circular pile, a physics-based ordinary differential equation for predicting the scour depth development is derived. The analytical solution of scour depth development is generally more consistent with the experimental data compared with previous models. The probability density function distribution of the proposed model's error mainly concentrates within the range of ±10%, which is significantly superior to previous models. The proposed model integrates all pertinent parameters that govern the scour process using fundamental principles, rendering it free from scale issues and applicable to prototype conditions. The present model is applied to evaluating clear-water scour development around typical prototype piles with diameters ranging from 2.0 m to 10.0 m. The predicted variations of equilibrium scour time with pile diameter, flow velocity and sediment particle size aligns closely with previous experimental observations.



(a)



(b)

Figure 1. Schematic diagram of fluid, sediment and cylinder coupling: (a) typical flow field structure around a cylinder; (b) the interaction of large-scale eddies (with length scale S), small-scale eddies (with length scale corresponding to diameter d_{50}) and sediment particles (adapted from Manes & Brocchini, 2015).

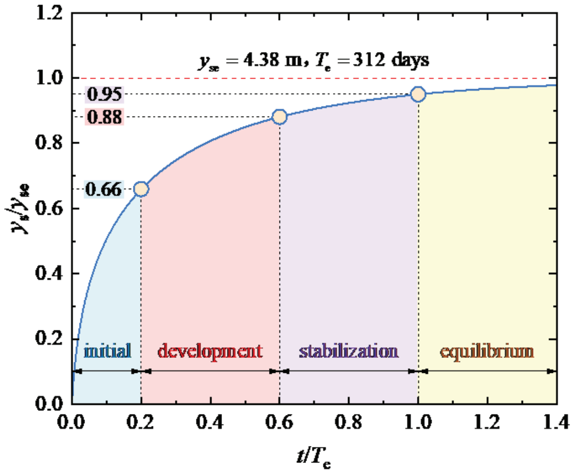


Figure 2. Prediction results of scour development under typical conditions.

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Tidal currents-induced scour development around pile foundations: effects of flow velocity hydrograph

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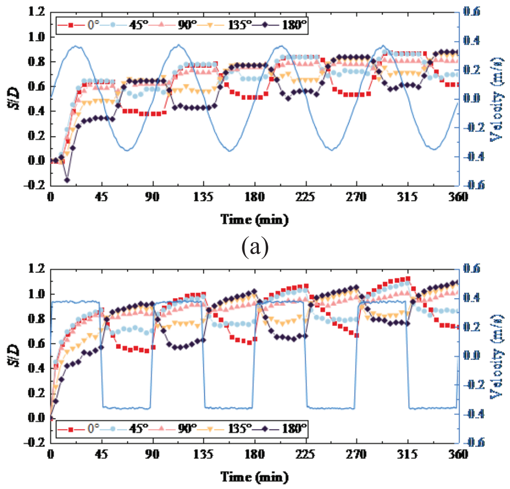
ABSTRACT

There is a lack of research in the existing literature regarding the scour of offshore wind turbine foundations under tidal currents, which primarily relies on laboratory experiments with simplified flow velocity hydrographs and mainly focuses on square tidal currents. To enhance the prediction accuracy of tidal scour for single pile foundations, systematic physical model experiments at a scale of 1:60 have been conducted on local scour of single pile foundations under typical tidal velocity hydrographs (including sinusoidal and square tidal currents) in a specially designed fluid-structure-soil coupling flume. The results demonstrate that the periodic change in flow direction associated with tidal conditions leads to a continuously evolving process of sediment erosion and backfilling around a single pile. The scour depth initially exhibits a high development rate under square tidal current, while it remains zero until the flow velocity surpasses the threshold value for scour under sinusoidal tidal currents. Although the shape of scour hole is similar for both sinusoidal and square tidal currents, there are significant differences in the development process of the maximum scour depth, presenting a shape of "short platform" and "serrated", respectively. The analysis employed the dimensionless effective flow work (DFW) method, revealing a consistent relationship between the dimensionless scour depth and the dimensionless effective work under both tidal and unidirectional current conditions. An equivalent velocity expression for sinusoidal and square tidal currents is proposed and verified using existing experimental data. Furthermore, an empirical expression for the reduction coefficient between square tidal currents and unidirectional currents under semi-diurnal conditions is also proposed. These research results establish a theoretical foundation for simplified tidal current methods in laboratory experiments and offer practical guidance for predicting the scour depth of tidal currents around single pile foundation for in-site offshore wind turbines.

Keywords: Local scour; Tidal current; Pile foundation; Flume experiment; Equivalent velocity; Reduction coefficient.



(a)

(b)

Figure 1. The evolution process of scour depth around single pile over time, the type of tidal current: (a) sinusoidal tidal current; (b) square tidal current.

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Scour characteristics around the tripod foundation of a tidal stream turbine

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ABSTRACT

Tidal stream turbines may experience severe scour in marine environments, posing a threat to the safety of these structures. However, only limited research has been conducted on the scour process around tidal stream turbines. To gain a deeper understanding of the nature of scour around these energy converters, a series of tests were conducted in a closed-circuit flume. The tests focused on the temporal development of scour depth around a turbine model supported by a tripod foundation. The flow conditions considered included steady currents and simulated tidal currents. The effects of the alignment angle of the tripod foundation and the flow velocity were analyzed.

The experimental results revealed that the scour pattern around the turbine model was greatly influenced by the alignment angle. This is because of the interactions between the approach flow and the tripod foundation under different alignment angles. In addition to local scour around each leg of the foundation, global scour occurred as a result of flow acceleration and streamline contraction beneath the structural elements of the tripod foundation. Remarkable scour holes also formed on the lateral sides downstream of the turbine model under steady current conditions, indicating high turbulence in this region. Under simulated tidal current conditions, fluctuations in the temporal development of scour were observed due to the reversing flow direction and migrating ripples.

By approximating the root mean square velocity of the simulated tidal current to the mean velocity of the steady current, the scour depths were found to be comparable under both flow conditions. Additionally, it was observed that the flow velocity maintained a linear relationship with the scour depth. Taking into account the influence of the tripod foundation and the turbine rotor, a prediction equation based on the effective flow work was proposed for determining the final scour depth of the turbine model. This equation was found to be suitable for both steady current and simulated tidal current conditions in the laboratory experiment.

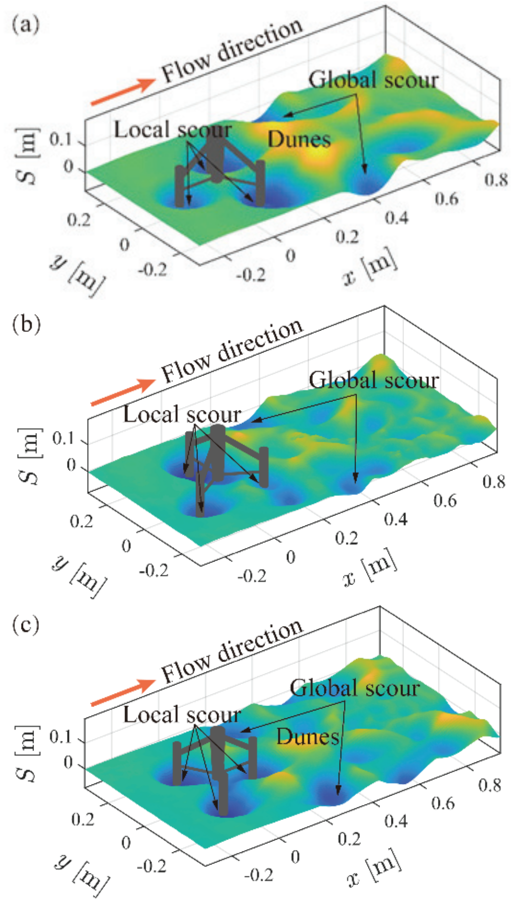

Figure 1. Scour morphology around the tripod foundation under various alignment angles. (a) 0°; (b) 30°; (c) 60°.

Experimental and numerical study of local scour around submerged circular-crossing and square-crossing piles under waves and current

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ABSTRACT

Experimental tests of local scour around a circular-crossing pile (CCP) and a square-crossing pile (SCP) were carried out to study the effects of superimposed waves upon current in the local scour process and the differences in characteristics in the two shaped piles. Non-uniform sediment with a gradation of 1.6 was used in the tests. Stokes waves of 0.11 m in height and 1.6 s in period were generated in a 50 cm water depth flume. The detailed flow turbulence characteristics of two submerged piles are determined by solving the Reynolds-averaged Navier–Stokes equations with the SST k–ω turbulence model. The model is verified by comparing experimental and numerical results for hydrodynamic parameters with the previous literature, both for square-crossing piles (SCP) and circular-crossing piles (CCP). The original topographies of a flat bed and a scoured bed (i.e., the initial and equilibrium scouring stages) are based on experimental results obtained by the authors in the present paper. Both SCP and CCP flow features in the scouring process are discussed. The temporal bed elevation profiles and scour depth development were very similar between the SCP and CCP, although the scour hole and sand dunes in the former were individually deeper and larger than the latter. The maximum scour depth in the SCP was nearly equal to that of the CCP in the waves-current condition, but it was much larger in the current-only condition. Both the time-averaged drag and the rms of the lift coefficient increase linearly during the scouring process in the SCP case, while in the CCP case, the rms of the lift coefficient increases first and then decreases to nearly the same value as during in the initial scouring stage. The minimum pressure coefficient is always located in the upstream corners in the SCP case. In the CCP case, it moves from 73.5° to 79° when the scour hole is fully developed. Downward flow behind the pile, which is generated by separated boundary layers above the top face of the pile, can reach the sand bed and turn the separated shear layers into patches of small vortices in the near-wake regions. The high shear stress zones are mainly at the scour edges under scoured bed conditions.

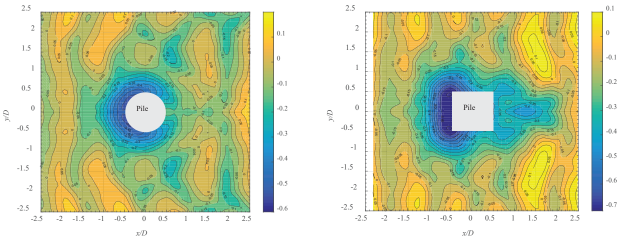

Figure 1. Contours of sand bed level around the SCP and CCP

A detailed riparian field study to assess the importance of bedrock groundwater in streamflow processes was established in the headwaters of the Afon Hafren, mid-Wales, UK. Results from this study identified distinct groundwater horizons close to the stream channel.

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Experimental study of scour countermeasures for offshore wind turbine monopile foundations

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ABSTRACT

The offshore wind energy industry is now thriving due to the increasing demand for renewable and green energy. The latest report from the Wind Europe Association stated that 70% of Europe's newly constructed offshore wind turbines use monopile foundations [1]. Local scour around monopile foundations is one of the most crucial factors for the substructure's stability. Previous studies show that about 33% of the cost of windfarms relates to the design and construction of foundations [2]. Thus, research into improving the performance of local scour countermeasures is essential for structural safety and cost control, contributing to the future development and prosperity of the offshore windfarm industry.

Scour protection is a common approach to mitigate local scouring of soil around monopile foundations at offshore windfarms. The present study is focused on the use of collars as a local scour countermeasure at monopile foundations. According to the collar installation height, a new definition of collar threshold elevation for no scour is given. Using this concept, scour patterns with collar protection are categorised into three types, each with unique scour topography. They are collars placed below the threshold elevation, collars placed above the bed level, and collars placed between these two elevations. The threshold elevation varies with different test conditions, and is mainly influenced by collar width and flow intensity. It is emphasised that the threshold elevation can be set at the bed level.

Results for the local scour and scour topography are presented, as well as a comprehensive equation for prediction of the equilibrium scour depth with collar protection. An equation for determining the threshold elevation is also proposed.

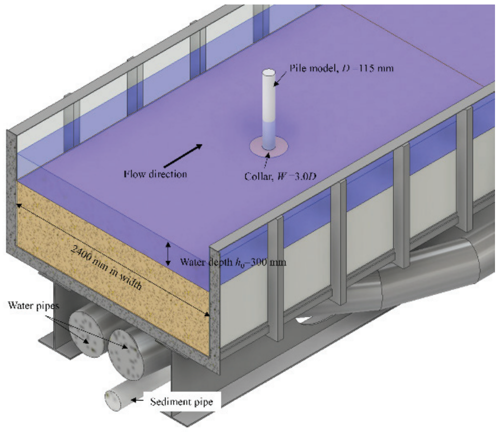

Fig.1 Experiment set-up

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Smart sediment particle for studying practicle entrainment mechanism

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ABSTRACT

The entrainment process of sediment particles plays a vital role in hydraulic engineering and can be employed for the design of channel stability, scour protection, etc. Due to the dynamic nature of turbulent flows, and the complexity of particle-fluids interaction, it is always challenging to conduct particle-entrainment studies of high accuracy, even in laboratories.

This study presents a new experimental technique for measuring sediment particle entrainment using a "Smart Sediment Particle (SSP)", which is an artificial sphere with instrumented Inertial Measurement Units (IMU). The embedded electronic devices inside the SSP enables the measurement of linear accelerations, and thus the hydrodynamic forces acting on the sediment particle can be obtained (Figure). We designed and performed a series of flume experiments in the Fluid Mechanics Laboratory at the University of Auckland. The SSP was placed on top of a bed comprising spherical particles in a hexagonally packed arrangement. The 3D particle accelerations were recorded for slowly increasing flow rate until the instant of particle entrainment. At the same time, the velocity field was measured using Particle Tracking Velocimetry (PTV).

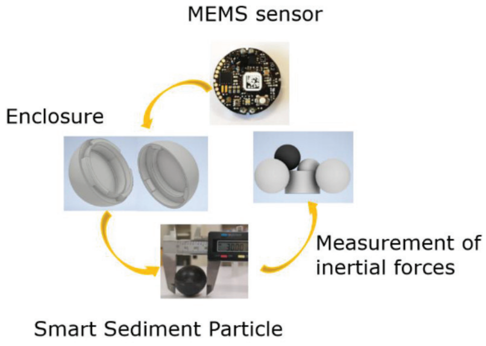

Figure1. Demonstration of the Smart Sediment Particle (SSP)

It is well known that the particle entrainment process involves complex parameter-dependence relations, such as particle shape and size, particle protrusion, and bed roughness, etc. In this study, the proposed technique was applied to investigate the effect of the particle protrusion above the spherical-particle bed and the bed arrangement type, on the particle entrainment. The synchronized acceleration data and the measure velocity field provided novel insight into the particles' behavior during the entrainment process, and strengthened the understanding of the threshold condition inducing the incipient particle motion. This technique shows satisfactory accuracy of data collection and is of prospect for future application in both laboratory and field environment.