Conference Paper, Published Version

Ohtani, Hideo; Tooe, Takao; Katsui, Hidehiro; Ishino, Kazuo; Ito, Kazunori

Characteristics of Local Scour Around Closure Works and the Application to the Bottom Change Simulation

CHARACTERISTCS OF LOCAL SCOUR AROUND CLOSURE WORKS AND THE APPLICATION TO THE BOTTOM CHANGE SIMULATION

Hideo OHTANI[1], Takao TOOE[2], Hidehiro KATSUI[3], Kazuo ISHINO[4] and Kazunori ITO[5]

[1] Member of JSCE, Construction Manager, Nagoya Branch., TAISEI Corporation
(1-1-4, Meieki, Nakamura-ku, Nagoya 450-6047, Japan)
E-mail: h_ohtani@ce.taisei.co.jp
[2] Member of JSCE, Acting General Manager, Technology Research Center., TAISEI Corporation
(344-1,Nase-cho,Totsuka-ku,Yokohama 245-0051,Japan)
E-mail: takao.tooe@sakura.taisei.co.jp
[3] Fellow of JSCE, Technical Counselor, Technology Research Center., TAISEI Corporation
(344-1,Nase-cho,Totsuka-ku,Yokohama 245-0051,Japan)
E-mail: ktihdh00@pub.taisei.co.jp
[4] Member of JSCE, Chief Research Engineer, Technology Research Center., TAISEI Corporation
(344-1,Nase-cho,Totsuka-ku,Yokohama 245-0051,Japan)
E-mail: kazuo.ishino@sakura.taisei.co.jp
[5] Member of JSCE, Senior Research Engineer,Technology Research Center., TAISEI Corporation
(344-1,Nase-cho,Totsuka-ku,Yokohama 245-0051,Japan)
E-mail: kazunori.ito@sakura.taisei.co.jp

River works are ordinary executed during dry seasons. Recently, however, not a few number of temporary closure works are set in the river throughout the year. In this case, the closure works must be stable against the flow in the rainy season, and the protection works have to be designed considering not only the local sour depth but also the area of the degradation.

In this study, the sour characteristic around the closure works is investigated by hydraulic experiments. The sour depth is affected by the dimensionless sheer stress and the ratio of the closure width and water depth. As for the closure's shape of the angle to the flow direction, the scour depth is deeper in case of the 90 degrees, while the area of the degradation along the wall is larger in case of 45 degrees. It also develops that the vortex at the corner causes the local scour. So we suggest the new simulation method for the local scour, to which the vortex tractive force model is introduced. As a result, the good results are obtained, which represent the local scour as well as the change of the river bed-form.

Key Words : *local scour, River closure works, vortex, bottom change simulation, Hydraulic model test*

1. SCOPE

Generally construction of the structure in a river is planned to be executed in low-water season. However recently, it is sometimes executed through a year including the flood period with a protection work like a temporary closure. In the latter case, the temporary closure work should be designed to give enough stability against hydrostatic and dynamic pressures as well as for the scouring, in which the scour prevention work must be well designed. The closure works must be accompanied by local scouring caused by the spatial velocity gradient along the structure and its characteristics are considered to resemble those of abutments and spur dikes, in which the maximum scour depth occurs at the upstream corner of the structure. The scouring around the abutment had been long studied and Brusesers and Raudkivi [1)] reported the general overview. Muramoto et al.[2)] also proposed the simplified equations to give maximum scour depths at the head of a spur dike on the basis of their experimental data. In designing scour prevention works, however, we need to know the information about the planar expansion of the local scour hole as well as the developing characteristics of the bed-form change. In such case we need a help of numerical simulation. Nagata et al. [3] was successful in simulation of the hose-shoe vortex and the local scour around a pier by 3D numerical computation. In planning temporal closure works, however, we should predict over all bed-form change for a wide area downstream excited by the change of approach velocity, sediment discharge distribution under many sets of disposition and configuration of the temporal closure works. Since it was difficult to predict the local scour and the bed-form change in a wide area simultaneously by one run of numerical computation, the temporal closure work was used to be designed with the use of model experiment or the experimental equations. This is why we developed a simulation program to cover the local scour and the bed-form change in a wide area simultaneously. To realize it we merged the expertise of scouring points and depths based on the experimental data and the state-of-the-art bed-form numerical analysis technique.

Here we propose the practical methodology to combine the experiment data for local scour and the numerical simulation method for bed-form change.

In the first place, we executed the local scour experiment around the temporary closure works. Secondly, we analyzed the data and extracted the scouring position as well as the tractive force to cause the scour hole, which was translated to mathematical model. Finally, we executed the numerical computation with the local scour subprogram and verified its applicability.

2. PHYSICAL MODEL TEST FOR LOCAL SCOUR AROUND THE CLOSURE WORKS

(1) Set up of physical model test

Movable bed experiments were conducted in order to investigate hydrodynamic feature of local scour around the closure works in a long flume shown in **Fig.1**. Phenomena of the local scour were observed through a glass sidewall of the flume. Bed-form change was measured by a laser distance meter. Velocity was measured by a magnetic type velocity meter. Dimension and the shape of the model of the closure works were set variously. Conditions of the tests are listed in **Table 1**. θ is an an angle of corner. Cutoff angle, θ, is defined in **Fig.1**. Dominant hydraulic values such as water depth h_0, velocity v_0

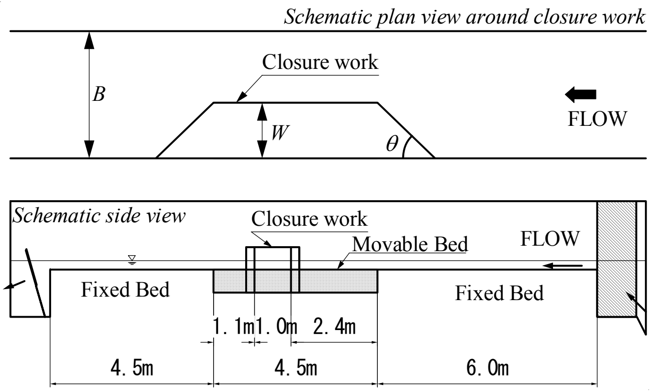


Fig.1 Set up of physical model test

Table 1 Conditions of physical model tests

case	Slope	Discharge	Width of Closure work	Width of flume	Particle diameter	Water depth	Velocity	Friction velocity	Tractive force	Fruid number	Attack angle	W/B	W/h_0
No.	1/i	Q(m^3/s)	W(m)	B(m)	d(m)	h_0(m)	V_0(m/s)	u_{*0}(m/s)	τ_{*0}	Fr	θ(°)		
1	2896	0.026	0.24	0.8	8.1E-05	0.101	0.321	0.018	0.258	0.32	90	0.3	2.4
2			0.16								90	0.2	1.6
3			0.08								90	0.1	0.8
4			0.24								45	0.3	2.4
5			0.16								45	0.2	1.6
6			0.08								45	0.1	0.8
7	4645	0.004	0.16	0.8	8.1E-05	0.036	0.142	0.008	0.055	0.24	90	0.2	4.4
8			0.08								90	0.1	2.2
9			0.16								45	0.2	4.4
10			0.08								45	0.1	2.2
11	2896	0.010	0.16	0.8	8.1E-05	0.055	0.230	0.014	0.143	0.31	90	0.2	2.9
12			0.08								90	0.1	1.5
13			0.16								45	0.2	2.9
14			0.08								45	0.1	1.5

and friction velocity $u*_0$ in the table are the results of the tests that were performed under the condition of the uniform flow without the closure works on the fixed bed in advance.

As particle diameter of sand, d=0.081mm, was selected. It is normally considered that fine sand less than d=0.1- 0.2mm behaves as wash load. Since comprehension with regard to the characteristics of soil varies among researchers, we rinsed the material thoroughly to expel the very fine contents, which led to eliminate the influence of viscosity as well as possible, here.

(2) Experimental result about scouring phenomena and discussion

Photo 1 is a snapshot of the flow and stirred up sand around the corner taken from inside of the closure work. In the experiment, when the water started to flow the separated vortex stirred up sand to make the local scour hole at the upstream corner of the closure work. At the upstream side of the scour hole, scouring region expanded gradually as the sand particles being washed away to keep the sand slope sustained the repose angle, being associated with the occasional collapse of the scour slope. On the other hand at the downstream side of the scour hole, it was observed that the sand particles were rolling up and down on the scour hole slope, some of which were picked up and suspended by the vortices. Occasionally the lump of sand was witnessed to be transported down the stream at the collapse of the scour slope. As the scour hole developed large enough the rate of development became reduced to make the scour hole equilibrium state. This is due to the back filling caused by the collapse of the sand slope plus reduced discharge rate of sand particles from the scour hole caused by the reduction of the tractive force ascribed by the increase of the scouring depth and the size. The slope angle of the scour hole showed constantly 32 °.

Fig.2 shows the final feature of the bed around the closure work. The maximum scour depth was at the corner of the closure. The lowered bed expanded from the scour hole toward the center of the river (i.e. channel). The area of the local scour in the case of θ =45° is wider than that in the case of θ=90°.

Fig.3 shows the maximum scour depth z_s vs width of the closure W. Though z_s could be dependent on the blockage ratio W/B as a rule by the occurrence of contraction, both parameters had no significant relation in the range of the experimental condition e.g. $W/B \leqq 0.3$. Whereas, dimensionless tractive force $\tau*_0$ for the uniform flow and the ratio of width of the closure work and the depth W/h_0 had more correlation, which could be expressed by the following equations through the multiple linear regression analysis,

$$\frac{z_s}{h_0} = 3\tau_{*0}^{\ 0.8}\left(W/h_0\right)^{0.9} \quad : \theta=90° \qquad (1)$$

$$\frac{z_s}{h_0} = 4\tau_{*0}^{\ 1.2}\left(W/h_0\right)^{1.2} \quad : \theta=45° \qquad (2)$$

The application range of W/h_0 should be taken within the experimental condition, since W is considered intuitively less influential on z_s as it becomes very large.

Fig.3 depicts as well the line drawn by the equation proposed by Muramoto et al[2], in which the approach velocity is nearly the critical velocity. In comparison with the result of this experiment, the equation by Muramot et al. gives rather larger values. The reason is on the difference of the shape of the structure where our experiment was for the longer

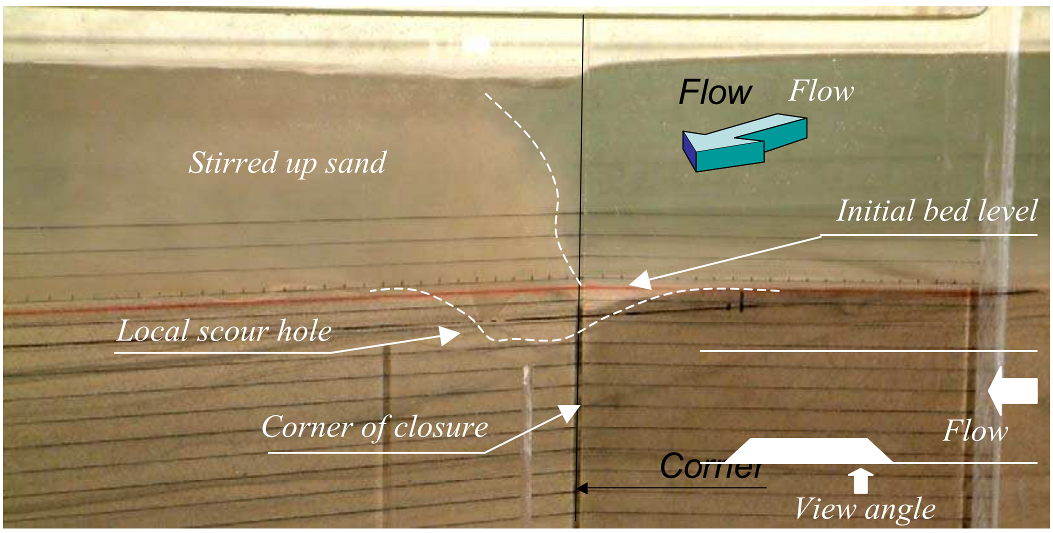
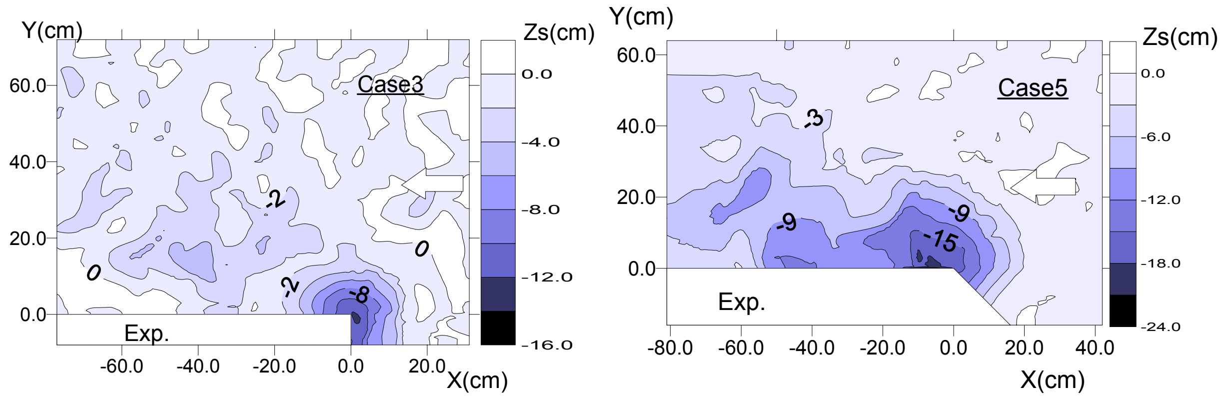


Photo 1 Snapshot of experimental situation of stirred up sand around the corner (θ=45°)



(a) θ=90° (b) θ=45°

Fig.2 Experimental result of Bed-form change

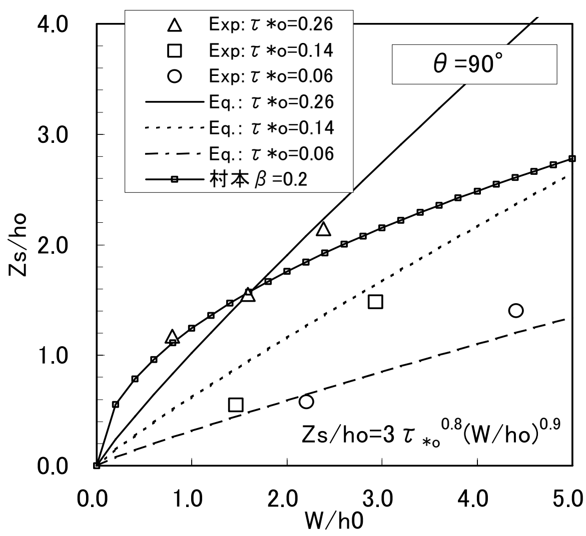


Fig.3 Relationship between scouring depth and W/h_0

structure along the downstream while theirs were for spur dike, in which downstream length was very short thus the gradient of the depth and the velocity was large. In the case for θ=90° the width of the scour hole can be estimated with the repose angle of the sand in water and the scour depth.

3. SIMULATION OF LOCAL SCOUR AROUND THE CLOSURE WORKS

(1) Theoretical consideration

In order to take practical local scour model into conventional calculation scheme for bed-form change which is based on the horizontally two dimensional flow simulation, we took tractive force into theoretical consideration. Set local velocity u as is expressed in Eq. (3), where $\overline{\mathbf{u}}$ is time average velocity $\mathbf{u}'$ and is the component of turbulent flow.

Here, total tractive force τ_t is a driving force of bed load and it consists of tractive force τ_f induced by mean flow and τ_v, by turbulent flow as like Eq.(4).

$$\mathbf{u} = \overline{\mathbf{u}} + \mathbf{u}' \tag{3}$$

$$\begin{aligned} \tau_t &= \rho c_f \left| u^2 \right| = \rho c_f \left| \overline{u}^2 + u'^2 + 2\overline{u}u' \cos\varphi \right| \\ &= \rho c_f \left| \overline{u}^2 + \overline{u}'^2 \right| = \left| \tau_f \right| + \left| \tau_v \right| \end{aligned} \tag{4}$$

Here, ρ is the water density and c_f is the friction coefficient. φ is the cross angle between and . In the case of local scour, since the vortex at the corner of the obstacle dominantly makes turbulent flow to cause local scouring, it is reasonable to think that τ_v should be correlated to the local vortex. This τ_v corresponds to the sub grid Reynolds stress of LES model. Thus, we propose the local scour sub-model for τ_v, which should be incorporated into a conventional calculation scheme of bed-form change.

(2) Local scour submodel and conventional bed-form change calculation scheme

Local scour submodel (LSM) in this paper is a kind of sub grid model as LES. LSM is applied to only where local vortex occurs. Calculation procedure of LSM is as follows; i) calculation of velocity field around the closure works by using conventional calculation scheme for bed-form change, ii) estimation of τ_v at local scour point, iii) calculation of bed load transport rate for local scour, iv) calculation of depth and width of scour hole with consideration of repose angle of bed material.

i) Software, Delft3D[4)5)], was used to simulate 2D velocity field bed-form change that can estimate bed load transport rate and suspended load simultaneously.

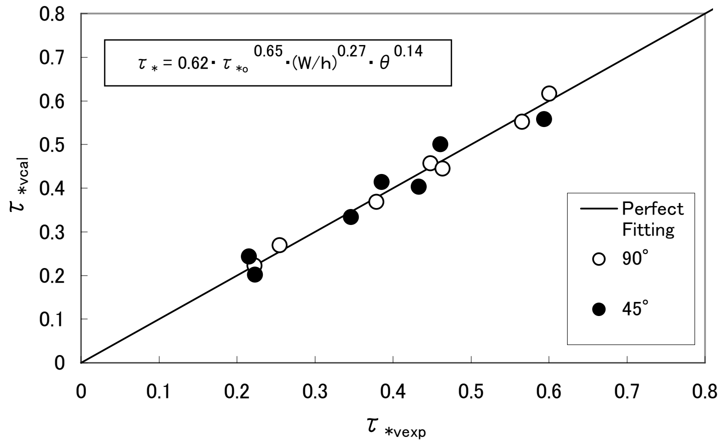


Fig.4 Comparison of τ_{*V} between experimental results and eq.(4)

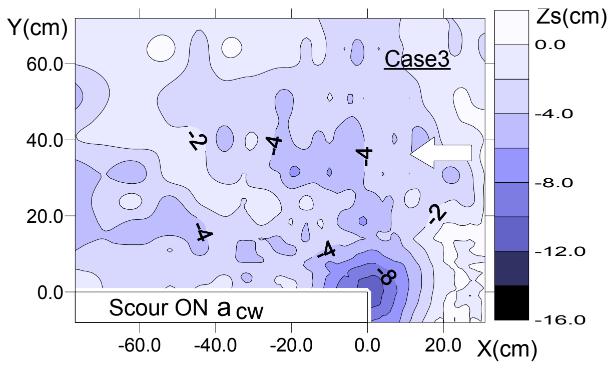


Fig. 5 Simulation results of proposed method (Case 3)

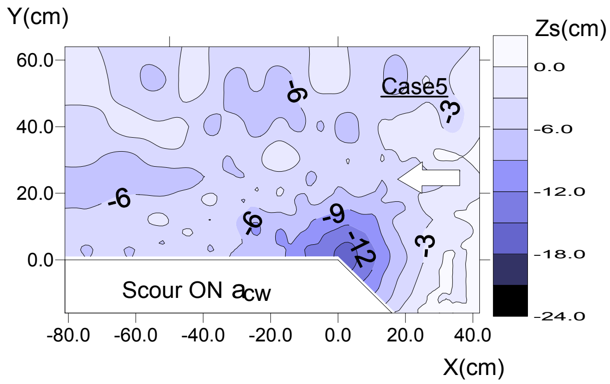


Fig. 6 Simulation results of proposed method (Case 5)

ii) $\tau*_v$ at local scour point is given by eq.(5). This equation was determined by the experimental results. $\tau*_0$ is tractive force at far upstream side of the closure works, where the flow is not disturbed by the existence of the closure works. The place is named reference point. **Fig.4** shows well fitting between calculation results by eq. (5) and experimental ones. The concept of Eq.(5) is similar to that of Tsujimoto et al [6], where they studied the relationship between vortex induced tractive force and tractive force at undisturbed region to estimate scouring of a bridge pier. As scour depth increases, tractive force due to vortex decreases. This attenuation effect is considered by Eq. (6), where h is the total water depth including scour depth, h_0 is the initial water depth. a_c is the ratio of tractive forces $\tau*_v / \tau*_0$. a_{cw} is the ratio of attenuation of tractive force due to increasing of scouring depth.

iii) Ashida-Michiue formula[7] was used to estimate bed load transport rate.

iv) Slope collapse model based on the repose angle of bed material was applied to evaluate the shape of the scour hole. When the slope angle in the hole surpasses the repose angle, redundant amount of bed material crumbles until the slope angle reaches the repose angle. Some portion becomes to suspended load and the other deposits into the scour hole. Simulation grid around the corner of the closure works is 2.5cm×2.5cm. LSM is applied to two points around the corner, named Extra-points, in this study. At the upstream boundary, discharge rate is input, and water elevation is fixed at the downstream boundary.

The selection of Extra point needs a technical expertise. When the shape of the closure works is simple like a rectangular or trapezoidal one, it is not so hard to decide Extra point from practical point of view, because the closure works has a sharp corner clearly. But how to decide extra point for more complex structure is a future challenge.

$$\tau_{*v} = 3.71\tau_{*0}^{0.85}\left(W/h_0\right)^{0.26}\theta^{0.45} \tag{5}$$

$$a_{cw} = \left(\frac{h_0}{h}\right)a_c = \left(\frac{h_0}{h}\right)\left|\tau_{*v}\right| / \left|\tau_{*0}\right| \tag{6}$$

(3) Results of Calculation and Discussion

The results of the calculation are shown in **Fig.5** and **Fig.6**. They are the result calculated by the proposed method that includes the additional tractive force. The proposed method can represent the depth of the scouring in the physical model tests.

Fig.7 shows time series of scouring depth change. In the figure, Scour OFF means the results of the conventional simulation method, Delft3D, which does not take into account $\tau*_v$, or the local scouring. The proposed model, a_{cw}, can simulate the scouring process quite well. The model, a_c, can also represent the equilibrium states without considering the dissipation of the vortex because of the effects of the slope collapsing model. But since the model, a_c, overestimates the depth of the scouring, the model, a_{cw}, that include the vortex dissipation effects is necessary.

Fig.8 shows the comparison of the final scour depth between the calculation and the physical model test for all case. Generally speaking the proposed methods can represent the scour depth of the physical model test.

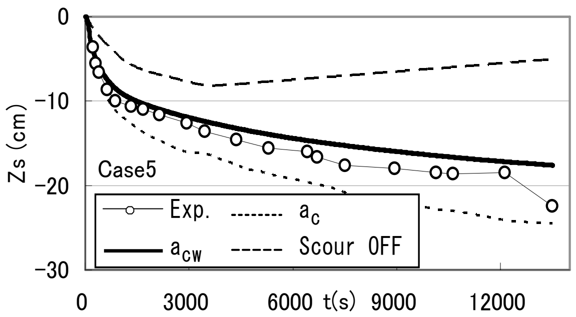


Fig.7 Time series of scouring depth in Case5 (θ=45°)

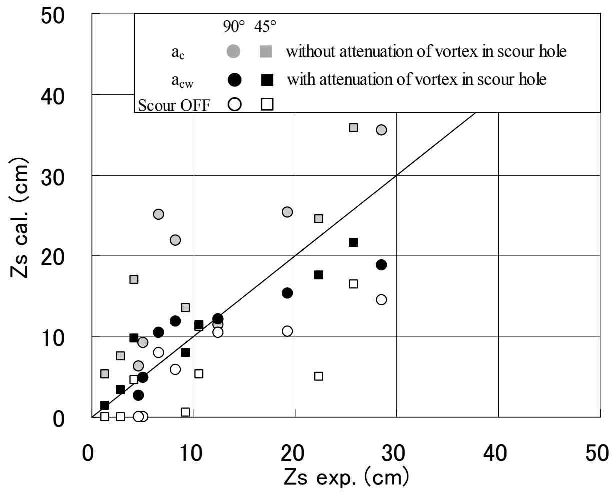


Fig.8 Comparison of maximum scour depth Zs

4. CONCLUSION

We proposed the simulation model for the final scouring depth and the scouring process around temporary closure by analyzing the hydraulic model test. The final scour depth can be explained by the non-dimensional tractive force and W/h_0. The final depth in θ=90° is larger than that in θ=45° except in the case that $\tau*_0$=0.26, the area of the scouring in θ =90°, however, smaller than that in θ =45°. The horizontal two dimensional model for the morphological change includes the tractive force on the corner can simulate not only the scour hole but also the morphological change. The proposed method can be applied to other structure if the scour process are available.

ACKNOWLEDGMENT: The author would like to present the sincere thanks to Dr Goto, Associate Professor of Kyoto University and Dr J,A Rolevink in Delft hydraulic Lab for their advise in developing the modeling.

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