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Development of Computer Program for Bridge Pier Scour Considering Accumulative Effect

축적 효과를 고려한 교각세굴 해석 프로그램 개발

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요 지

세립토에서의 세굴깊이의 발달은 일반적으로 조립토에서보다는 아주 천천히 진행된다. 조립토를 위해 개발된 방법을 시간효과와 무관하게 세립토에 적용한다면 세굴깊이가 과대하게 평가된다. SRICOS 방법은 점성토 또는 연암에 설치된 교각의 국부세굴깊이의 변화를 예측하기 위해 개발되었으며, 교량현장에서 채취한 흙에 대한 실험과 SRICOS 프로그램의 수행을 병행함으로써 적용된다. 본 논문에서는 SRICOS 방법을 간단히 설명한 후 프로그램의 세부적인 내용을 기술한다. 또한 이 프로그램을 이용하여 세굴에 미치는 각 매개변수의 영향을 평가하기 위해 실시한 매개변수 해석의 결과가 포함된다.

Abstract

The development of the scour depth in fine-grained soils is generally much slower than in coarse-grained soils. Applying the equations for coarse-grained soils to fine-grained soils regardless of time appears to be overly conservative. The SRICOS method was developed to predict the evolution of the local scour depth at a bridge pier founded in cohesive soils or soft rock. It is based on the combination of the computer program and the testing apparatus. In this article, the SRICOS method is briefly described, the details of the computer program are presented, and a parametric analysis is performed to evaluate the influence of each parameter.

Keywords : Pier scour, Shear stress, Erosion rate, Clay, Multi-layer

1. Background

The development of the scour depth in fine-grained soils is generally much slower than in coarse-grained soils. Applying the equations for coarse grained soils to fine-grained soils regardless of time appears to be overly conservative. Therefore, a scour analysis method for fine-grained soils needs to consider the time effect as well as soil properties and hydraulic parameters.

Annandale (1998) proposed a method called the Erodibility Index Method (EIM) to predict pier scour at bridges founded on erodible rock and other resistant materials. The method is based on comparison of the available stream power and the required stream power.

Therefore, the maximum scour depth can be determined at the point which the available stream power curve and the required stream power curve intersect each other. The Erodibility Index is determined by the following equation:

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$$K = M_s . K_b . K_d . J_s \qquad (1)$$

where, K is the Erodibility Index, M_s is the intact material strength number, K_b is the particle/block size number, K_d is the shear strength number, and J_s is the relative ground structure number. The relationship between the required stream power and erodibility index is given by:

$$\begin{aligned} P_{required} &= K^{0.75}, & K > 0.1 \\ &= 0.96K^{0.44}, & K < 0.1 \end{aligned} \qquad (2)$$

The method for the stream power shows relationships between the stream power amplification at the base bridge piers P_c/P_a and dimensionless scour depth $z/z_{\max}$. The available stream power (P_c) for round, square, and rectangular piers can be obtained by multi-plying the approach stream power (P_a) with the stream power amplification. $P_{required}$ and P_c are compared to calculate the scour depth.

Molinas et al. (1999) investigated bridge pier scour in unsaturated and saturated cohesive soils. They conducted experiments for 0.152 and 0.102 m diameter piers in three large flumes and observed the effect of clay content, compaction, and initial water content (IWC) on pier scour. Based upon dimensional analysis, experimental data, and regression analysis, the scour depth equation using parameters such as compaction, initial water content, and Froude number was developed as follows:

For unsaturated cohesive soil

$$\frac{z}{B^{0.66}y^{1.13}} = \begin{cases} 0 & \text{for } Fr \leq 0.2, Comp \geq 0.85 \\ 45.95(IWC)^{-0.36}\ Fr^{1.92}Comp^{1.62} & \text{for } Fr \leq 0.2, Comp < 0.85;\ \text{for } Fr > 0.2 \end{cases} \qquad (3)$$

For saturated cohesive soil

$$\frac{z}{y} = \begin{cases} 0 & \text{for } F > Fi \\ 9.61\left(\frac{B}{y}\right)^{0.66} (IWC)^{2.62}(Fr - Fi)^{0.32} & \text{for } F > Fi \end{cases} \qquad (4)$$

where z is the scour depth, y is the depth of approach flow, B is the pier width, $Comp$ is the degree of compaction, IWC is initial water content, $Fr = V/(gy)^{0.5}$ is the Froude number, $Fi = V_i/(gy)^{0.5}$, V is the approach average velocity, $V_i = 0.065/(IWC)^{2.92}$ is the scour initiating velocity, and g is the gravitational acceleration.

The SRICOS method, which stands for scour rate in cohesive soils, was developed to predict the scour depth z versus time t curve around a cylindrical bridge pier (Briaud et al, 1999a and b). This method has already been described in details in the two references cited and is briefly summarized here as background. The SRICOS method recognizes that the scour process is highly dependent on the shear stress (τ) imposed by the flowing water at the soil-water interface. Through tests performed on soil samples from the bridge site using the EFA (Erosion Function Apparatus), the scour rate ($\dot{z}$) versus the shear stress (τ) is obtained; this $\dot{z}$ vs. τ curve is the erosion function. The critical shear stress (τ_c) is the shear stress imposed by the water on the soil when scour is initiated.

The equation for the maximum shear stress occurring around a cylindrical pier was developed by performing three-dimensional numerical simulations. The results of a series of analyses lead to the following equation:

$$\tau_{\max} = 0.094\rho \cdot V^2\left(\frac{1}{\log Re} - \frac{1}{10}\right) \qquad (5)$$

where $\tau_{\max}$ is the maximum shear stress around a pier for a flat river bottom condition (N/m^2), ρ is the density of water (kg/m^3), V is the mean flow velocity (m/s), $Re = VD/\nu$ is the pier Reynolds number, D is the pier diameter, and ν is the kinematic viscosity of water (10^{-6} m^2/s at 20°C).

If $\tau_{\max}$ is larger than the critical shear stress for the soil (τ_c), scour will be initiated in regions where $\tau > \tau_c$. The initial scour rate ($\dot{z}_i$) is then read on the $\dot{z}$ versus τ curve, obtained from the EFA tests on the soil sample, at the value of $\tau_{\max}$.

The equation for the maximum scour depth ($z_{\max}$) was developed from a number of flume tests. The results of the experiments lead to the following equation which was also found to be valid for sand (Briaud et al., 1999a and b).

$$z_{\max}(mm) = 0.18Re^{0.635} \tag{6}$$

The following hyperbolic equation was selected as the best fitting model to describe the scour depth (z) versus time (t) curve obtained in the flume tests:

$$z = \frac{t}{\frac{1}{\dot{z}_i} + \frac{t}{z_{\max}}} \tag{7}$$

where $\dot{z}_i$ is the initial slope of the scour depth (z) versus time (t) curve, $\dot{z}_i$ is obtained at $\tau_{\max}$ from the $\dot{z}$ versus τ curve generated with the EFA on samples from the site, and $z_{\max}$ is the ordinate of the asymptote. The parameter $z_{\max}$ represents the maximum depth of scour at $t=\infty$.

This method was based on the assumption that the soil is uniform and the velocity is constant. The primary objective of this study was to improve the SRICOS method and develop the SRICOS program so that it could handle multi-flood and multi-layer systems, verify this method against full-scale scour measurements, and propose it as a safe and economic method for foundation design and maintenance against scour.

2. SRICOS Program

The SRICOS program was developed to predict the scour depth (z) versus time (t) curve around a bridge pier (Briaud et al., 1999b and Kwak, 2000). This program automates all the procedures of the SRICOS method including calculations of the maximum shear stress, the initial scour rate, and the maximum scour depth, as well as transformation of discharges into velocities. The techniques to handle multi-flood and multi-layer systems are also automated in the SRICOS program.

The SRICOS program is a user-friendly interactive code that guides the user through a step by step data input procedure except velocity or discharge data. Generally, the number of velocity or discharge data could be at least several thousands if the duration of a scour analysis is several years on daily basis. The velocity or discharge data should be prepared in the format of an ASCII file or a text file before running the program. The input to the SRICOS program is as follows: geometry of the pier, soil stratigraphy around the pier, erosion function of the soil layers, scour rate ($\dot{z}$) versus hydraulic shear stress (τ) curve for each layer, discharge or velocity hydrograph, and the relationship between discharge and velocity if discharge hydrograph is known but the velocity hydrograph is unknown as is often the case. The output of the SRICOS program is the scour depth (z) versus time (t) curve corresponding to the actual velocity hydrograph. The output format is a table with the velocity, maximum shear stress, maximum scour depth, and scour depth corresponding to each time step. The basic procedure of the SRICOS program is shown in Fig. 1 and explained in detail in the following sections.

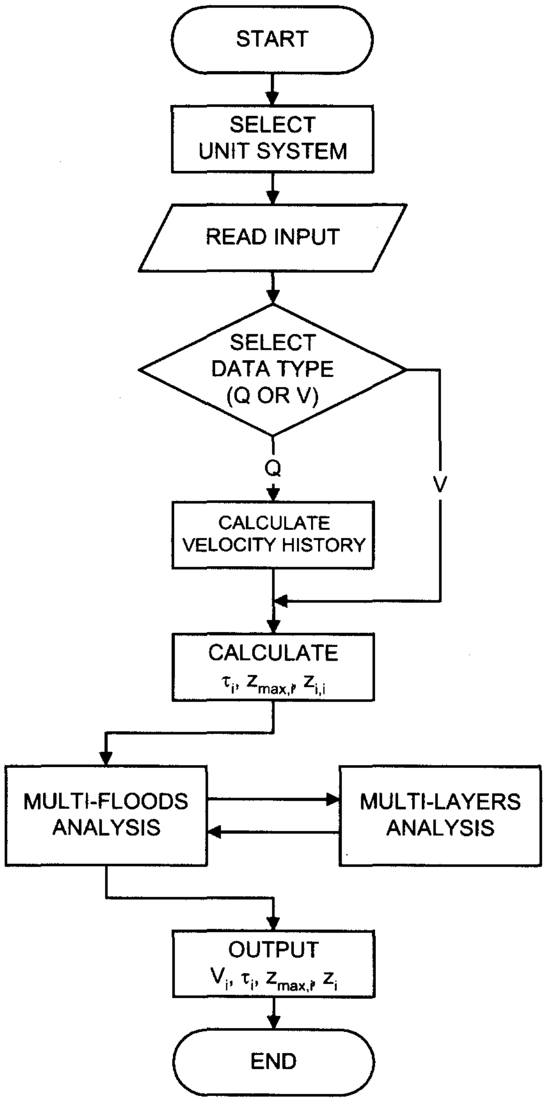


Fig. 1 Basic procedures of SRICOS program

2.1 Erosion Function

The purpose of the EFA test is to obtain the curve that relates the scour rate ($\dot{z}$) to the shear stress (τ) induced by the flowing water. This erosion function is prepared for each soil layer.

For the input of the erosion function, the number of soil layers is determined from the boring log, the thickness and the critical shear stress for each soil layer are entered as directed on screen, and the regression equation for the relationship between the erosion rate and the shear stress should be determined among 20 types of equations included in this program and the coefficients of the selected equation are typed as directed, otherwise sufficient points representing the relationship should be typed directly and the interpolation technique would be used. This procedure is repeated for the transformation of the discharge hydrograph into the velocity hydrograph and the water depth history explained in next section.

2.2 Hydrograph

The hydrograph that shows daily mean discharges at a specific location should be obtained. The most influential hydrologic parameters in scour are the velocity of the water and the shear stress that the water generates at the soil-water interface. Therefore, it is necessary to determine the velocity hydrograph during the life of the bridge. To do so, a flood analysis should be performed at the bridge location.

In this study, the computer program entitled Hydrologic Engineering Center's River Analysis System (HEC-RAS, 1997) developed by the United States Army Corps of Engineers is used for flood analysis. The HEC-RAS program is used to obtain the hydrological parameters and the relationship between discharge (m^3/s) and velocity (m/s) at each bridge location. In order to run HEC-RAS, several geographical features such as average slope of channel bed (obtained from surveying record), and the Manning's roughness coefficient (obtained from site investigation) are needed.

After running this program by applying the hydraulic and geographic features for many selected discharges, the relationship between velocity and discharge can be obtained by regression. Using this relationship, the discharge hydrograph, which is the flow discharge versus time curve, is transformed into the velocity hydrograph or velocity versus time curve. The water depth history or water depth versus time curve is also obtained at the same time.

2.3 Bridge Pier Parameters

The bridge parameters affecting local pier scour are pier width, pier shape, attack angle of the flow, and the water depth to pier width ratio also called the wide pier effect. The correction factors for pier shape and attack angle of the flow exist in HEC-18 (1995). In the SRICOS program, these effects are incorporated by multiplying the maximum scour depth ($z_{\max}$) at each time step by the HEC-18 factors.

Various studies have shown that the scour depth at wide piers is somewhat less than that predicted from pier scour equations. Melville and Coleman (1999) determined the following equation for wide piers based on laboratory experiments.

$$\begin{aligned} K_w &= 1.0 \quad \text{for} \quad \frac{y}{b} > 1.43 \\ K_w &= 0.83\sqrt{\frac{y}{b}} \quad \text{for} \quad 0.2 < \frac{y}{b} < 1.43 \\ K_w &= 1.875\frac{y}{b} \quad \text{for} \quad \frac{y}{b} < 0.2 \end{aligned} \tag{8}$$

where K_w is the correction factor for wide piers, y is the water depth, and b is the pier width.

In this program, the Melville and Coleman's equation (8) was chosen for the wide pier effect. The Melville-Coleman correction factor for wide pier effect is also applied as a multiplier to the maximum scour depth ($z_{\max}$) for each time step.

2.4 Mechanism of Internal Calculation

The SRICOS method was developed initially to predict the local scour depth versus time curve around a bridge

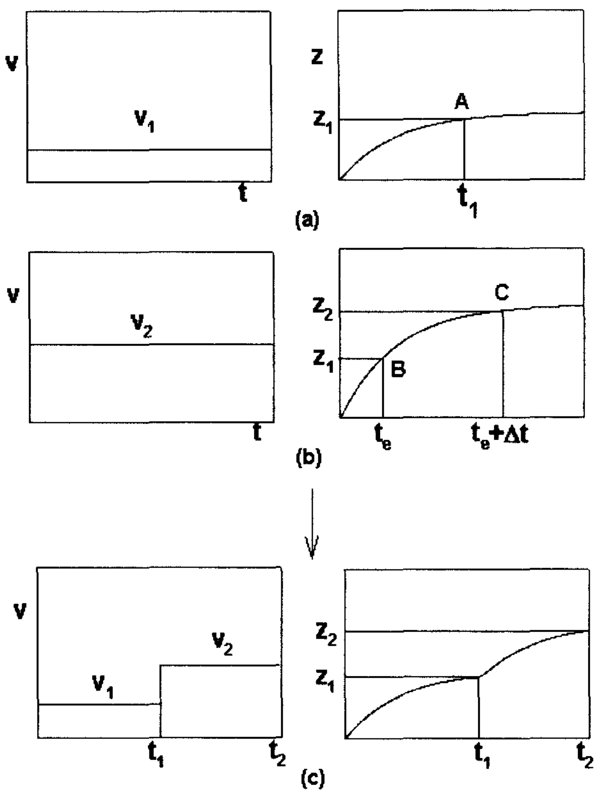


Fig. 2 Scour due to a sequence of two flood events

pier subjected to a flow of constant velocity. The SRICOS program models the flow velocity vs. time curve as a series of small steps where the flow velocity is constant.

First the unit system for the input and output is selected. Then, the input data is entered including the discharge hydrograph read from a gage station. Then, the discharge hydrograph is transformed into the velocity hydrograph and water depth history for the analysis duration by using the relationship obtained from HEC-RAS (1997). Then, the maximum shear stress ($\tau_{\max}$) and the maximum scour depth ($z_{\max}$) are calculated at each time step by using equations (5) and (6), respectively. In calculating $z_{\max}$, the correction factors for pier shape, attack angle of the flow, and wide pier effect are included as previously described.

Now, the scour depth (z) at each time step needs to be calculated by using equation (7). An example of the scour depth calculation for 2 velocity steps is shown in Fig. 2. First, the scour depth versus time curves for the two velocities v_1 and v_2 can be obtained respectively (Fig. 2 (a) and (b)). In the case of multi-floods, flood 1 has a velocity v_1 and lasts t_1, while flood 2 occurs after flood 1, has a velocity v_2 and lasts $t_2 - t_1$ or $\triangle t$ (Fig. 2 (c)). After flood 1, a scour depth z_1 is reached at time t_1 (point A on Fig. 2 (a)). This depth z_1 would have been reached in an equivalent time, t_e (point B on Fig. 2 (b)) if v_2 had been the velocity instead of v_1. Therefore when flood 2 starts, it is as if flood 1 had not taken place but instead flood 2 had been flowing for a time t_e. Then the time $\triangle t$ of flood 2 is added to t_e and the scour depth after the two floods is z_2 corresponding to point c on Fig. 2 (b). The z versus t curve for the two floods can be assembled as shown in Fig. 2 (c).

In addition, the calculated scour depth is also compared with the thickness of the layers at each time step. If the scour depth (z) exceeds the thickness of the first layer, the scour rate ($\dot{z}$) versus shear stress (τ) curve is automatically switched to the curve of the second layer

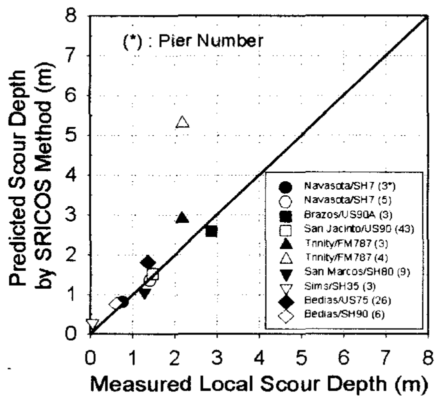


Fig. 3 Predicted vs. measured local scour for the SRICOS method

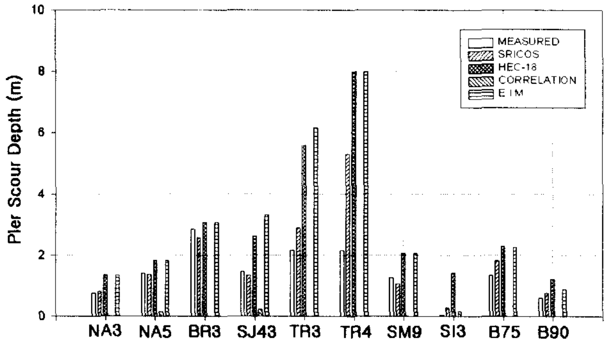


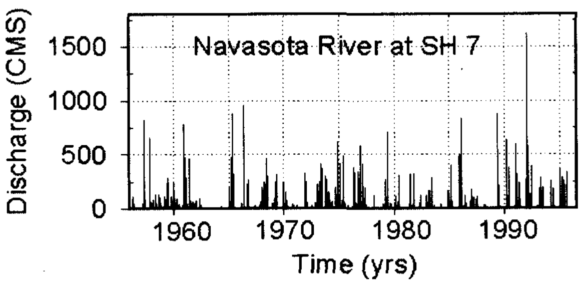
Fig. 4 Comparison of methods

Table 1. Selected cases for parametric study by flow characteristics

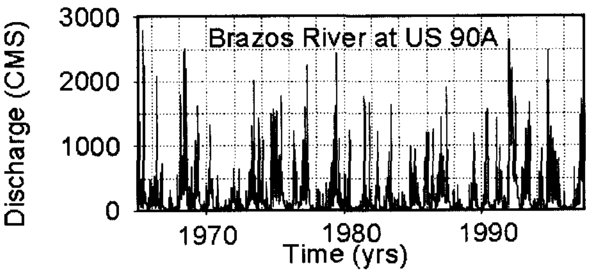
Bridge	Velocity	Flow	Period of Investigation (yrs)
Navasota River Bridge at SH 7 (Bent 3)	High	Only big floods	41
Brazos River Bridge at US 90A (Bent 3)	High	Always	33
Sims Bayou Bridge at SH 35 (Bent 3)	Low	Always	3

in the SRICOS program. This procedure is extended to n layers.

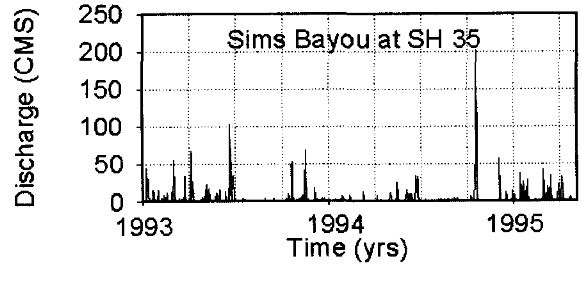
The SRICOS method was verified against 10 cases of full scale scour measurements from 8 bridges in Texas. Fig. 3 shows the comparison between the SRICOS predicted scour depths and the measured scour depths at the 8 bridge piers (Briaud et al, 1999b). For comparison purposes, a couple of methods that have been developed recently are applied to these bridge cases. They are HEC-18 (Richardson and Mueller, 1993), the Erodibility Index method (Annandale et al., 1998), and the correlation method (Molinas et al., 1999). Details for these methods are explained in previous section. The results of the final scour depth using SRICOS method are compared with measured values as well as the results using other methods in Fig. 4. In some cases that the available stream power curve and the required stream power curve does not intersect each other, the scour depth values of HEC-18 are taken as the final scour depth of the Erodibility Index Method as directed. The correlation method underestimates the final scour depth in most cases and the Erodibility Index method and the HEC-18 seems to overestimate the scour depth in all cases.



(a) Navasota river at SH 7



(b) Brazos river at US 90A



(c) Sims bayou at SH 35

Fig. 5 Discharge hydrographs

3. Parametric Analysis

Three cases are selected to perform a parametric analysis: Navasota River Bridge at SH 7, Brazos River Bridge at US 90A, and Sims Bayou Bridge at SH 35 (Table 1).

The cases are selected because they cover wide range of flow conditions. In each case, the scour depth versus time curve is predicted with SRICOS as a response to the actual velocity hydrograph for the bridge. The discharge hydrographs for the three cases are shown in Fig. 5.

3.1 Effect of Critical Shear Stress

First, the influence of the critical shear stresses τ_c is investigated by making runs for a critical shear stress equal to τ_{co} , $0.2\tau_{co}$, $0.5\tau_{co}$, $2\tau_{co}$, and $5\tau_{co}$. In each case, the change in τ_c forces the $\dot{z}$ versus τ curve to be translated in the horizontal direction. The scour rate ($\dot{z}$) versus shear stress (τ) curves are shown in Fig. 6. Note that when the curves translate horizontally, the scour rates also change slightly.

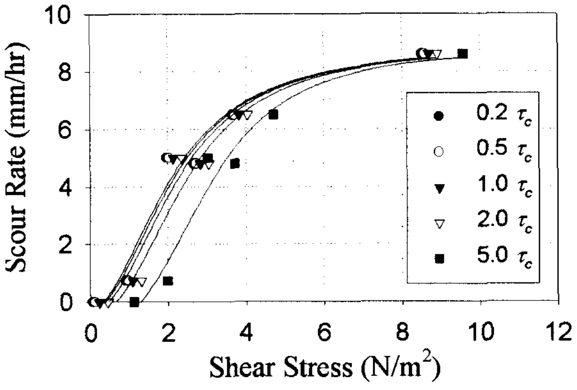


Fig. 6 Erosion functions according to variation of critical shear stress (Case 1 : Navasota river bridge, bent 3)

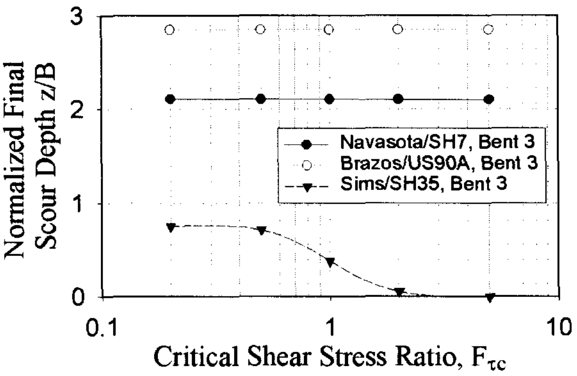


Fig. 7 Comparison of scour depths according to critical shear stress ratios

The normalized scour depth (scour depth over pier width, z/B) as a function of the critical shear stress ratio is presented in Fig. 7. The critical shear stress ratio is the ratio of the critical shear stress (τ_c) considered for a given run divided by the reference critical shear stress, τ_{c0}. In the cases of the Navasota River Bridge at SH 7 and the Brazos River Bridge at US 90A, the final scour depths and the shapes of the scour depth (z) versus time (t) curves are almost the same (Fig. 7) even though the critical shear stresses (τ_c) are changed as shown in Fig. 6. The results for the Sims Bayou Bridge at SH 35, however, show that the scour depth decreases as the critical shear stress increases. Only in the range of low critical shear stresses is the trend of the results for this case the same as in the other two cases. The Sims Bayou Bridge at SH 35 has two distinct differences compared to the other two cases. First, the Sims Bayou Bridge did not experience high velocity floods over the period investigated (1993 to 1995). Second, the critical shear stress of the soil is relatively high and is not exceeded in the cases of high critical shear stress.

These results lead to the following conclusion: As long as the critical shear stress is either much higher or much lower than the range of shear stresses generated by the flow hydrograph, slight changes in critical shear stress do not affect the scour depth.

If, on the other hand, the critical shear stress is within the range of shear stresses generated by the flow hydrograph, then slight changes in critical shear stress can change the scour depth significantly.

3.2 Effect of Scour Rate

In order to isolate the effect of the scour rate on the local scour depth, the scour rate ($\dot{z}$) versus shear stress (τ) curve is transformed by multiplying $\dot{z}$ by factors equal to 0.01, 0.05, 0.2, 0.5, 2.0, and 5.0, while keeping the critical shear stress (τ_c) fixed. An example of the

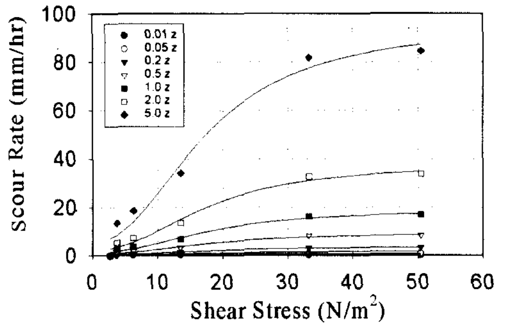


Fig. 8 Erosion functions according to variation of scour rate (Case 3 : Sims bayou bridge at SH 35, bent 3)

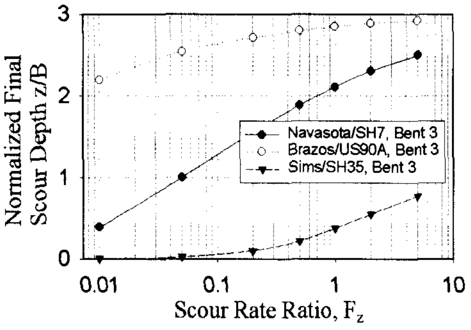


Fig. 9 Comparison of scour depths according to scour rate ratios

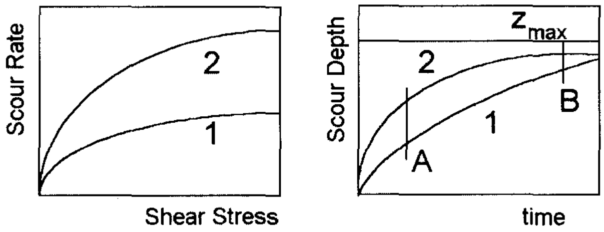


Fig. 10 Effect of scour rate on scour depth

scour rate ($\dot{z}$) versus shear stress (τ) curves used in the parametric study is shown in Fig. 8.

The normalized scour depth (z/B) as a function of the scour rate ratio is presented in Fig. 9. The scour rate ratio is the ratio of the scour rate ($\dot{z}$) considered for a given run divided by the reference scour rate, $\dot{z}_o$. All the results indicate that the scour depth increases as the scour rate increases regardless of the flow characteristics. However, the increase is not proportional. The cases of the Navasota River Bridge at SH 7 and the Sims Bayou Bridge at SH 35 show a high rate of scour depth increase with the scour rate ratio, while the Brazos River Bridge at US 90A shows a relatively low rate of increase of scour depth. The reason is as follows:

As shown in Fig. 10, if the scour rate is doubled, the initial slope of the scour depth versus time curve is doubled, the shape of the curve changes, but the maximum scour depth is not changed. Therefore, the effect of changing the initial scour rate is large at the beginning of the scour depth versus time curve (A on Fig. 10) but small towards the end of the curve (B on Fig. 10). This is why the influence of changing the initial erosion rate has a more drastic influence on the Sims Bayou Bridge at SH 35 than on the other two bridges. Indeed the Sims Bayou hydrograph is only 3 years long while the other two hydrographs are 33 and 41 years long.

3.3 Effect of Pier Width

In order to see the effect of pier width on the scour depth, the original pier width is multiplied by factors equal to 0.2, 0.5, 2.0, and 5.0. All the parameters related to the soil and the water are kept equal to the original bridge cases. The results of the scour depth versus pier width ratio are shown in Fig. 11. The pier width ratio is the ratio of the pier width B for a given run divided by the reference pier width B_o.

As expected, most of the results show that the final scour depth increases as the pier width increases. However, in the case of the Sims Bayou Bridge at SH 35, the scour depth increases with the pier width ratio at the beginning, and then decreases. The reason is as follows. For large water depth (z/D > 2), the maximum shear stress (τ_{max}) caused by the flowing water around a pier depends on the pier Reynolds number Re according to equation (5) (Briaud et al., 1999a and b). If V and ρ are constant, the maximum shear stress (τ_{max}) decreases as the pier width increases (eq. (5)). In the case of the Sims Bayou Bridge at SH 35, most of the velocities are very low and lie around the value which creates the critical shear stress (τ_c). As the pier width increases, the shear stress becomes smaller than the critical shear stress and the

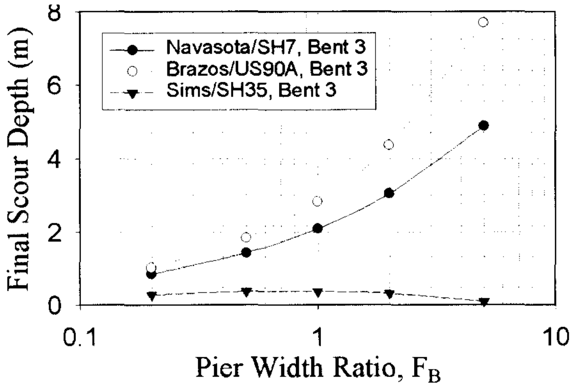


Fig. 11 Comparison of scour depths according to pier width ratios

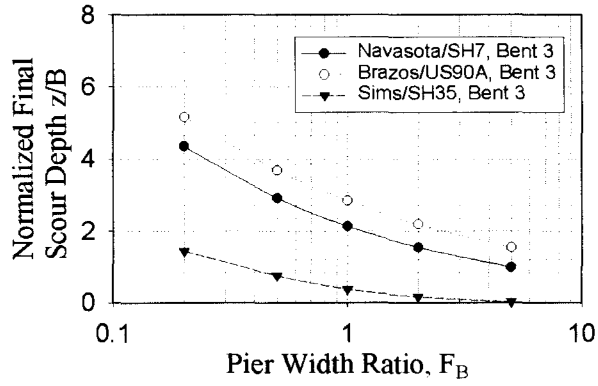


Fig. 12 Comparison of normalized scour depths according to pier width ratio

overall scour depth decreases. In the other cases, the shear stresses are higher than critical and the overall result is an increase in scour depth.

Therefore, two factors affect the impact of an increase in pier width: first, the maximum shear stress around the pier decreases as the pier width increases, second, the maximum scour depth increases with the pier width. The combination of these two non-linear influences can lead to an increase or a decrease in the final scour depth.

The normalized scour depth (z/B) versus pier width ratio is shown in Fig. 12. As expected from the maximum scour depth equation (2), all the results show that the normalized scour depth decreases as the pier width increases. The normalized scour depths vary from 1.5 to 5.2 in the low range of pier width, while, in the high range of pier width, the normalized scour depths vary from 0.02 to 1.0.

4. Conclusions

(1) The SRICOS program is presented to predict the local scour depth versus time curve around bridge piers. The SRICOS program can handle a real hydrograph and a multi-layer soil system. Correction factors for pier shape, attack angle of the flow, and wide pier effects are also included in the SRICOS program.

(2) If the velocity hydrograph around a bridge pier is such that the velocities generate shear stresses much higher or much lower than the critical shear stress, slight changes in the critical shear stress, τ_c do not affect the local scour depth. However, if the velocities generate shear stresses similar to the critical shear stress of the soil, increases in the critical shear stress will decrease the final scour depth significantly.

(3) The final scour depth increases as the scour rate of the soil increases. The increase in scour depth due to an increase in scour rate depends on the time length of the hydrograph. The longer the time length of the hydrograph is, the smaller the influence of the scour rate.

(4) Generally, the scour depth increases as the pier width increases. However, the scour depth also can decrease as the pier width increases since there are two opposite factors: first, the shear stress decreases as the pier width increases, second, the maximum scour depth increases with the pier width. The combination of these two non-linear influences can lead to an increase or a decrease of the scour depth as the pier width increases

References

1. Annandale, G. W. (1998). "Estimation of bridge pier scour using the erodibility index method", *ASCE Compendium of Conference Scour Papers (1991 to 1998)*, Reston, Virginia, USA, pp.83-97.
2. Briaud, J.-L, Ting, F., Chen, H. C., Gudavalli, S. R., Perugu, S., and Wei, G. (1999a). "SRICOS: Prediction of scour rate in cohesive soils at bridge piers", *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 125, No. 4, ASCE, Reston, Virginia, USA, pp.237-246.
3. Briaud, J.-L., Ting, F., Chen, H.C., Gudavalli, R., Kwak, K., Philogene, B., Han, S.-W., Perugu, S., Wei, G., Nurtjahyo, P., Cao, Y., Li, Y. (1999b), SRICOS: *Prediction of scour rate at bridge piers, Report No. 2937-1*, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, USA.
4. Kwak, K. (2000), "Prediction of scour depth versus time for bridge piers in cohesive soils in the case of multi-flood and multi-layer soil systems", *Ph.D. Dissertation*, Texas A&M University, College Station, Texas, USA.
5. Melville, B. W. and Coleman, S. E. (1999), *Bridge scour*, Water Resource Publications, LLC, Highlands Ranch, Colorado, USA, pp.196-199.
6. Molinas, A., Jones, S., and Hosny, M. (1999), "Effect of cohesive material properties on local scour around piers", *Transportation Research Board, 78th annual Meeting*, Washington, DC, USA.
7. Richardson, E. V. and Davis, S. M. (1995), *Evaluating scour at bridges, Pub. No. FWHA-IP-90-017, HEC No.18*, U.S. Department of Transportation, Washington, DC, USA.
8. *HEC-RAS River Analysis System* (1997). *User's manual, Version* 2.0, Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA, USA.

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