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Comparison Between Predictions and Measurements

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Results from Prediction Response

The Prediction Request lead to 5 responses, dealing with some or all 8 prediction cases. The prediction results are compared with the measurements from the flume tests or the field data in Table 1. The methods used by the predictors are described briefly in the following.

Table 1 Results from Prediction Response

Scour Case	Measurement	1	2	3	4	5
		Ferrando	**Link**	**Piepers**	**Wu**	**Jia**
Case 1 (mm)	183		150	230	182	323
Case 2 (mm)	185		170	233	205	
Case 3 (mm)	161			182.6		
Case 4 (mm)	83			109.2		
Case 5 (mm)	152			233.3		
Case 6 (mm)	177			281		
Case 7 (m)	7.1	10.72 (8/3/93 Flood)	10.06 (8/3/93 Flood)	7.3		
Case 8 (m)	1.25	5.42	1.76 (5/1/91 flood) 2.52 (500 years flood)	1.0-1.3		

Ferrando and Cian predicted Bridge Case 7 and 8 based on the HEC-18 equation for constant velocity. In the calculation, the scour depths for uniform cylindrical and non-uniform cylindrical pier cases are compared and the larger one is selected. Link and Zanke calculated the pier scour depth in non-cohesive soils by using a semi-empirical approach for hydrographic flood. In their approach, the maximum scour depth is calculated by HEC-18 equation and the time effect of scour development is evaluated by the method developed by Zanke. Piepers used Breussers's, Teramoto's and the SRICOS method separately to predict the scour depth; the largest value from the three methods is shown in Table 1. Wu and Wang conducted a numerical simulation by CCHE2D to predict the scour depth for Flume Case 1 and 2. Jia, Xu, and Wang conducted a numerical simulation by CCHE3D to predict the scour depth for Flume Case 1.

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Results from Commonly Used Equation

Commonly used equations for pier scour are summarized in Table 2. The symbols used in the equations are defined in Table 3. The scour depth predicted by these equations is the ultimate scour depthfor a pier subjected to a constant velocity. The results are summarized in Table 4. For Bridge Case 7 and 8, the selected parameters are defined in Table 5, 6 and 7.

Table 3 Definitions of the Symbols Used in the Scour Equations

B:	Pier projection width
B1:	Approaching flow width
Comp:	Soil compact ratio
D_{50}:	Median diameter of the bed material
Fr:	Flow Froude Number directly upstream of the pier = $V/\sqrt{gH}$
Fr_c:	Critical Froude Number of the bed material = $V_c/\sqrt{gH}$
g:	Acceleration of gravity
H:	Flow depth directly upstream of the pier
IWC:	Initial water content
K:	Correction factors for specific conditions.
q:	Unit flow rate
Su	Undrained shear strengthof soil
V:	Mean velocity of flow directly upstream of the pier
V_c:	Critical velocity of the bed material
Z_{max}:	Ultimate scour depth
ρ_f:	Flow density
γ_s:	Unit weight of bed material

Table 4 Prediction Results from Commonly Used Equations

Equations	Case 1 (mm)	Case 2 (mm)	Case 3 (mm)	Case 4 (mm)	Case 5 (mm)	Case 6 (mm)	Case 7 (m)	Case 8 (m)	Case 8* (m)
6	539.2						26.2		
7	309.9						12.7	9.6	10.6
8	190.7						1.52	1.6	1.6
9	191.2						5.7	4.0	5.3
10	249.8						12.3	6.6	9.2
11	265.6						3.8	4.1	4.1
12	583.8						45.2	14.5	22.6
13	148						3.54	0.33	1.2
14	228.2						9.2	6.2	7.9
15	384						13.3	15	15
16	225.4						12.8		
17		51.4							
18		180.6							
19		125.3							
20	185.9	186	163.3	94.3	153.2	186.3	7.3	3.6	5.5
Measured	183	185	161	83	152	177	7.1	1.25	----

Table 2 Commonly Used Equation for Pier Scour

Number	Reference	Equation
6	Inglis (1949)	$\frac{Z_{max}}{B} = 2.32 \cdot \left(\frac{q^{2/3}}{B}\right)^{0.78}$
7	Laursen and Toch (1956)	$\frac{Z_{max}}{B} = 1.5\left(\frac{H}{B}\right)^{0.3}$
8	Basak, et al (1975)	$Z_{max} = 0.558 \cdot B^{0.586} (meter)$
9	Shen, Schneider, and Karaki (1969)	$Z_{max} = 0.00022 \cdot \mathrm{Re}^{0.619}$
10	Jain and Fisher (1979)	$\begin{cases} Z_{max} = 2.0B(Fr - Fr_c)^{0.25}\left(\frac{H}{B}\right)^{0.5} \\ Fr - Fr_c > 0.2 \end{cases}$ $\begin{cases} Z_{max} = 1.85B \times Fr_c^{0.25}\left(\frac{H}{B}\right)^{0.5} \\ Fr - Fr_c < 0 \end{cases}$
11	Larras (1963)	$Z_{max} = 1.05 \cdot B^{0.75}$
12	Froehlich (1987)	$\frac{Z_{max}}{H} = 0.32K_* \left(\frac{B'}{B}\right)^{0.62}\left(\frac{H}{B}\right)^{0.46} Fr^{0.2}\left(\frac{B}{D_{50}}\right)^{0.08} + 1$ K_* = 1.0 for round-nosed pier
13	Abdou (1993)	$Z_{max} = 144.5H \times F_r^{3.47}$
14	HEC-18 (1996)	$\frac{Z_{max}}{H} = 2.0K_1K_2K_3K_4\left(\frac{B}{H}\right)^{0.35} F_r^{0.43}$
15	Melville and Sutherland (1988)	$Z_{max} = 2.4K_sK_\theta B$
16	Kothyari, Garde, et al (1992)	$\frac{Z_{max}}{B} = 0.66\left(\frac{B}{D_{50}}\right)^{-0.25}\left(\frac{H}{B}\right)^{0.16}\left(\frac{V^2 - V_c^2}{D_{50} \times (\Delta\gamma_s / \rho_f)}\right)^{0.4}\left(\frac{B1 - B}{B1}\right)^{-0.3}$
17	Hosny (1995)	$Z_{max} = 0.9B(IWC)^{-2/3} \cdot Fr^{3/2} \cdot Comp^{-2}$
18	Molinas *et al.* (1999)	$\frac{z_{max}}{B^{0.66}H^{1.13}} = \begin{cases} 0 & \begin{pmatrix} Fr \le 0.2 \\ Comp \ge 0.85 \end{pmatrix} \\ 45.95(IWC)^{-0.36} Fr^{1.92} Comp^{1.62} & \begin{pmatrix} Fr \le 0.2 \\ Comp < 0.85 \\ Fr > 0.2 \end{pmatrix} \end{cases}$
19	Ivarson (1998)	$\frac{Z_{max}}{H} = 2.0K_1K_2K_3K_4\left(\frac{B}{H}\right)^{0.35} F_r^{0.43}$ $K_4 = 0.677\log\left(500\frac{B}{S_u}\right)$
20	SRICOS-EFA	See details below

Table 5: Parameters for Bridge Case 7

Velocity (m/s)	2.43
Average Pier Width (m)	4.63
Average Pier Length (m)	13.41
Skew Angle (°)	4
Q (m^3/sec)	26561.2
Critical Velocity (m/s)	1.07
Water Depth (m)	22.52
Fr	0.163
Fr_c	0.072

Table 6: Parameters for Bridge Case 8 and for the 5/1/91 flood

Velocity (m/s)	1.2
Pier Width (m)	3.05
Equivalent Pier Length (m)	8.23
Skew Angle (°)	25
Q (m^3/sec)	1410.2
Vc (m/s)	0.66
Water Depth (m)	6.9
Fr	0.15
Frc	0.08

Table 7: Parameters for Bridge Case 8 and for the 500-year flood

Velocity (m/s)	1.9
Pier Width (m)	3.05
Equivalent Pier Length (m)	8.23
Skew Angle (°)	25
Q (m^3/sec)	4190.9
Vc (m/s)	0.7
Water Depth (m)	9.6
Fr	0.2
Frc	0.07

Result from SRICOS-EFA Method

The SRICOS-EFA method (Briaud, 2002) was developed at Texas A&M University on the basis of flume tests, numerical simulation, and laboratory testing of the soil erodibility. This method predicts the scour depth as a function of time for a given hydrograph. The maximum scour depth for pier scour is calculated by using an empirical equation based on flume test results:

$$Z_{\max}(m) = 0.00018 \cdot K \cdot \mathrm{Re}^{0.635}\,(\mathrm{m}) \tag{1}$$

Where Re is the pier Reynolds Number, and K denotes the correction factors for different pier installation cases. The scour depth is a function of the scouring time t, and for a constant velocity and a uniform soil, it is given by the Hyperbola model:

$$z(t) = \frac{t}{\dfrac{t}{Z_{\max}} + \dfrac{1}{\dot{z}_i}} \tag{2}$$

where $\dot{z}_i$ is the initial scour rate corresponding to the initial shear stress $\tau_{\max}$ when scour starts. The initial scour rate $\dot{z}_i$ is obtained from the erosion function of the bed soil (measured with the Erosion Function Apparatus (EFA)) at the value corresponding to the initial shear stress $\tau_{\max}$. The initial shear stress $\tau_{\max}$ is given by the following equation based on a series of numerical simulations:

$$\tau_{\max} = 0.094\rho V^2 \cdot k \cdot \left(\frac{1}{\log(\mathrm{Re})} - 0.1\right) \tag{3}$$

where k represents the correction factors for shear stress caused by different pier installation cases.

For scour under a complex hydrograph and for a layered soil system, the scour depth vs. time curve can be calculated by accumulating the individual hyperbolas generated by incremental single floods and uniform soils. For more details on the SRICOS –EFA method refer to Briaud et al (1999, 2001a, 2002)

Based on the SRICOS-EFA method, the time histories of the scour development for the flume cases 3, 4, 5, and 6 are predicted in FIG 1, 2, 3 and 4 respectively. Because the maximum scour depth in sand can be developed in a very short time, the time histories for Case 1 and 2 are not presented here. For Bridge Case 7 and 8, because the EFA curves are not available, only the ultimate scour depths according to equation (1) are calculated with the parameters specified in Table 5-7. The scour depths given by SRICOS-EFA method are also listed in Table 4 on Line 14.

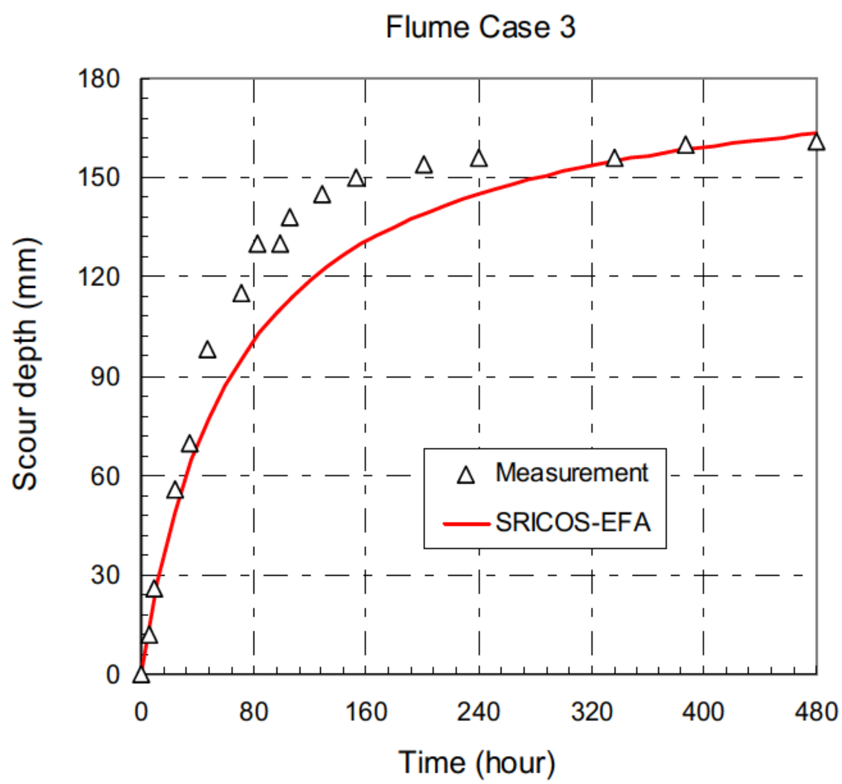

FIG 1 Comparison Between SRICOS –EFA Method and Measurement for Flume Case 3

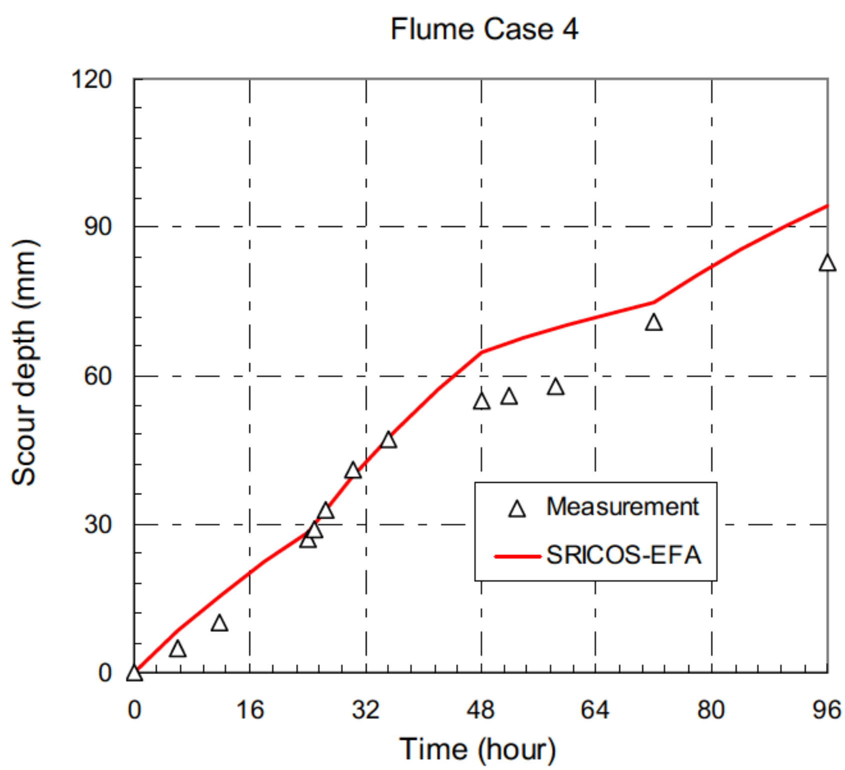

FIG 2 Comparison Between SRICOS –EFA Method and Measurement for Flume Case 4

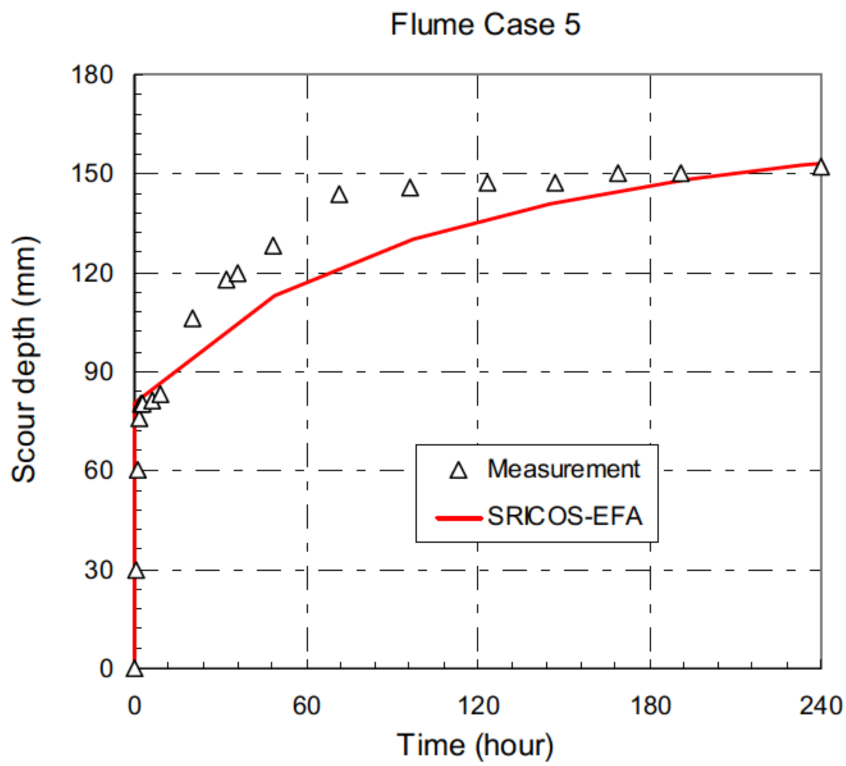

FIG 3 Comparison Between SRICOS –EFA Method and Measurement for Flume Case 5

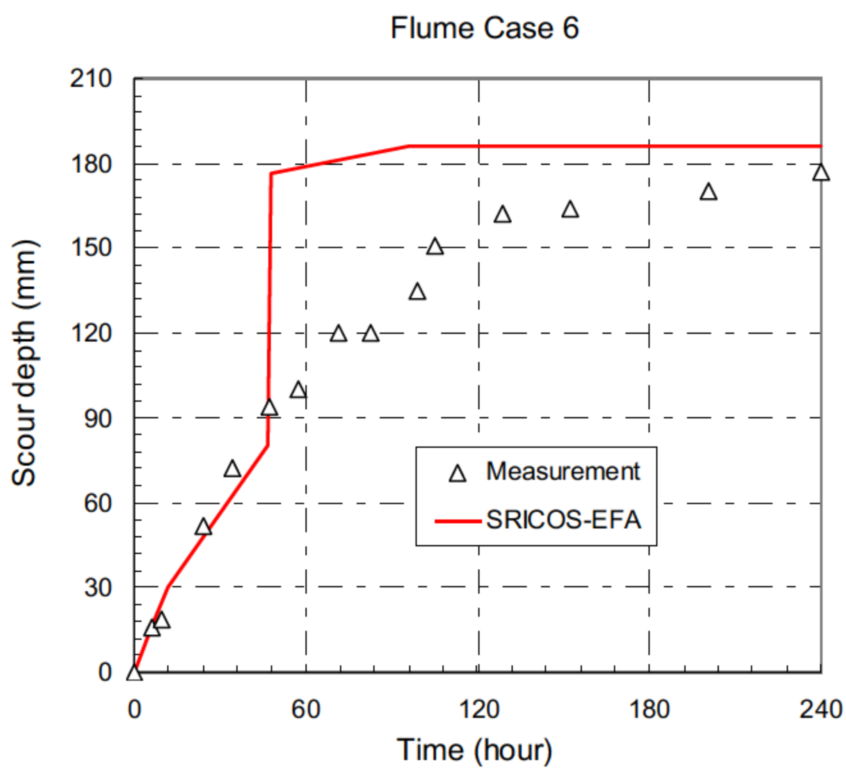

FIG 4 Comparison Between SRICOS –EFA Method and Measurement for Flume Case 6

Prediction Comparison and Conclusion

For comparison purposes, the 5 responses to the prediction request as well as the 15 predictions according to the equations of Table 2 are given in Tables 1 and 2. FIG 5-13 compare the measured scour depths and the predicted scour depths for the 20 methods. The following conclusions can be reached:

1. Pier scour in a uniform sand and subjected to a constant velocity can be well predicted by a variety of equations.
2. Only several approaches are available to handle pier installed in uniform sand but subjected to a changing velocity. The predictions by these approaches are satisfactory.
3. Very few approaches deal with pier scour developed in clay or layered soil systems and with the influence of time.
4. For the bridge case histories, when the case is limited to uniform sand and constant velocity, most predictions give a relatively conservative result.

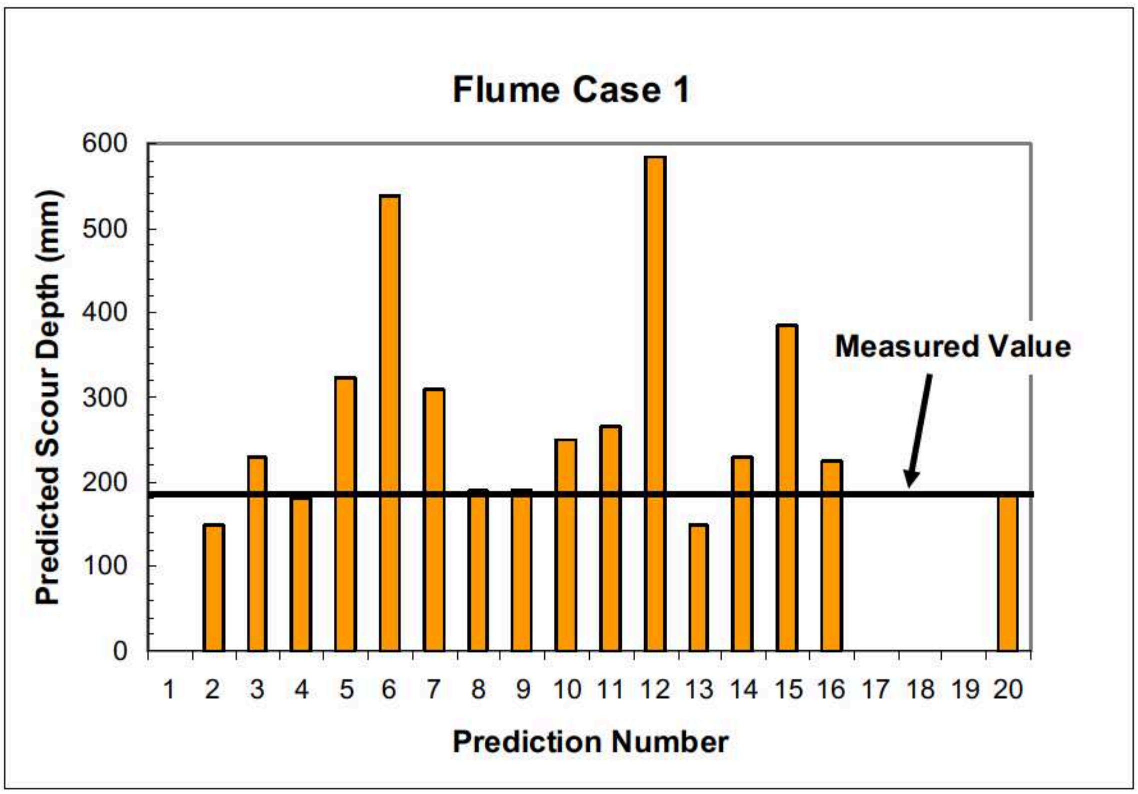

FIG 5 Comparison for Flume Test Case 1

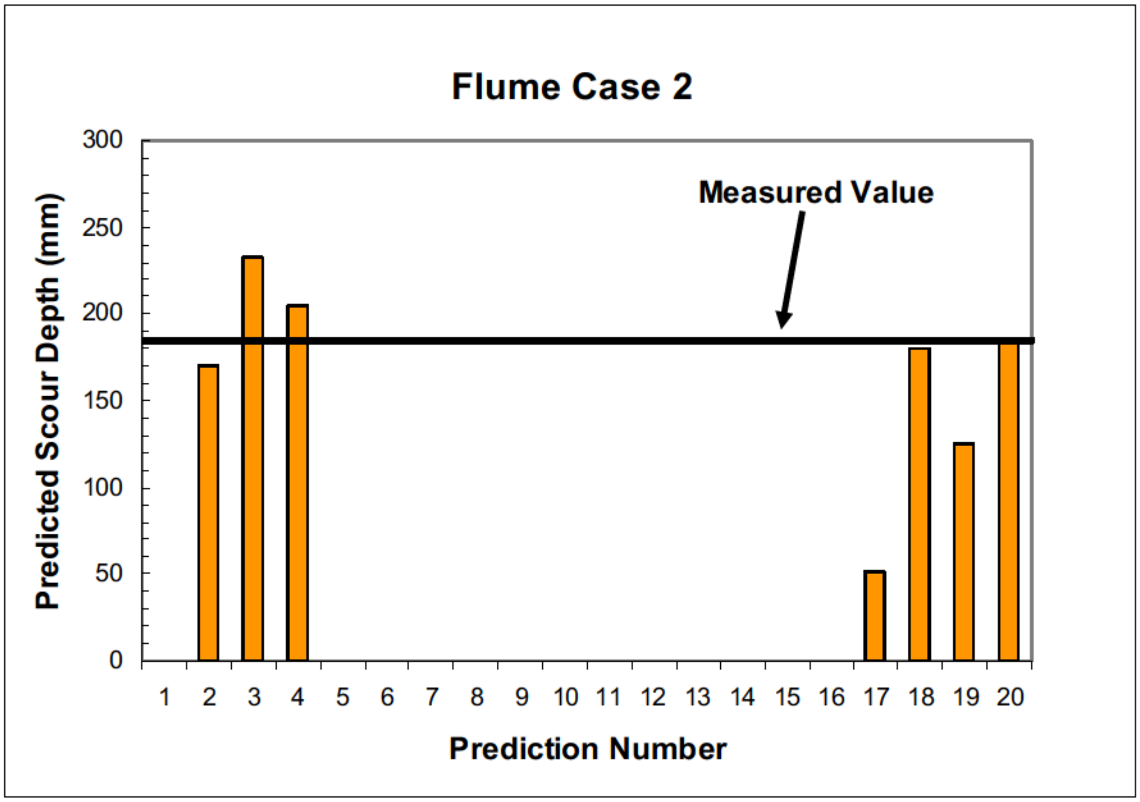

FIG 6 Comparison for Flume Test Case 2

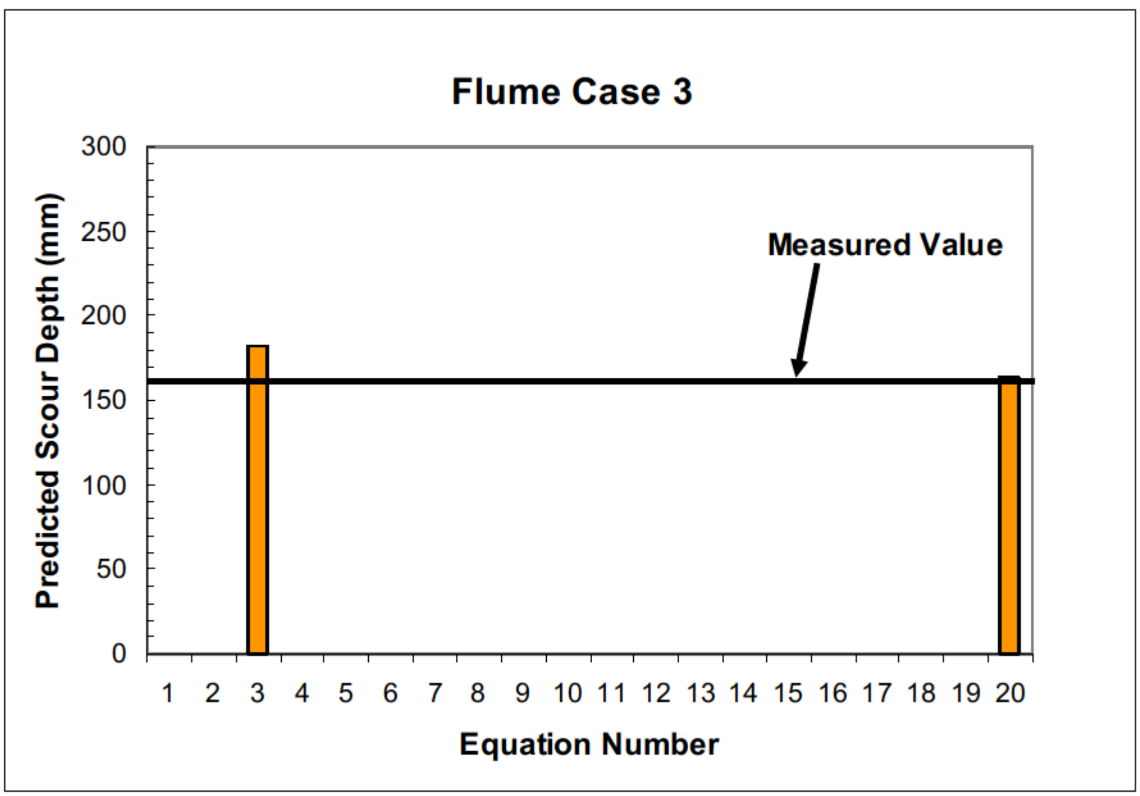

FIG 7 Comparison for Flume Test Case 3

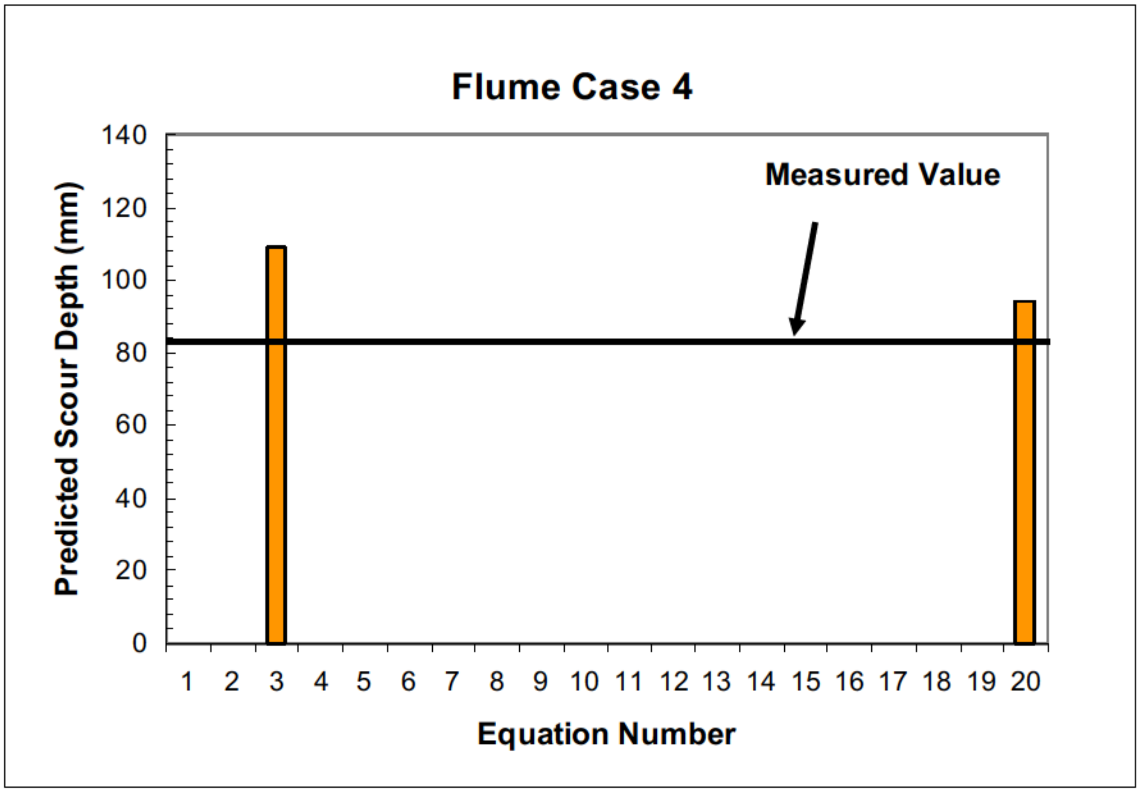

FIG 8 Comparison for Flume Test Case 4

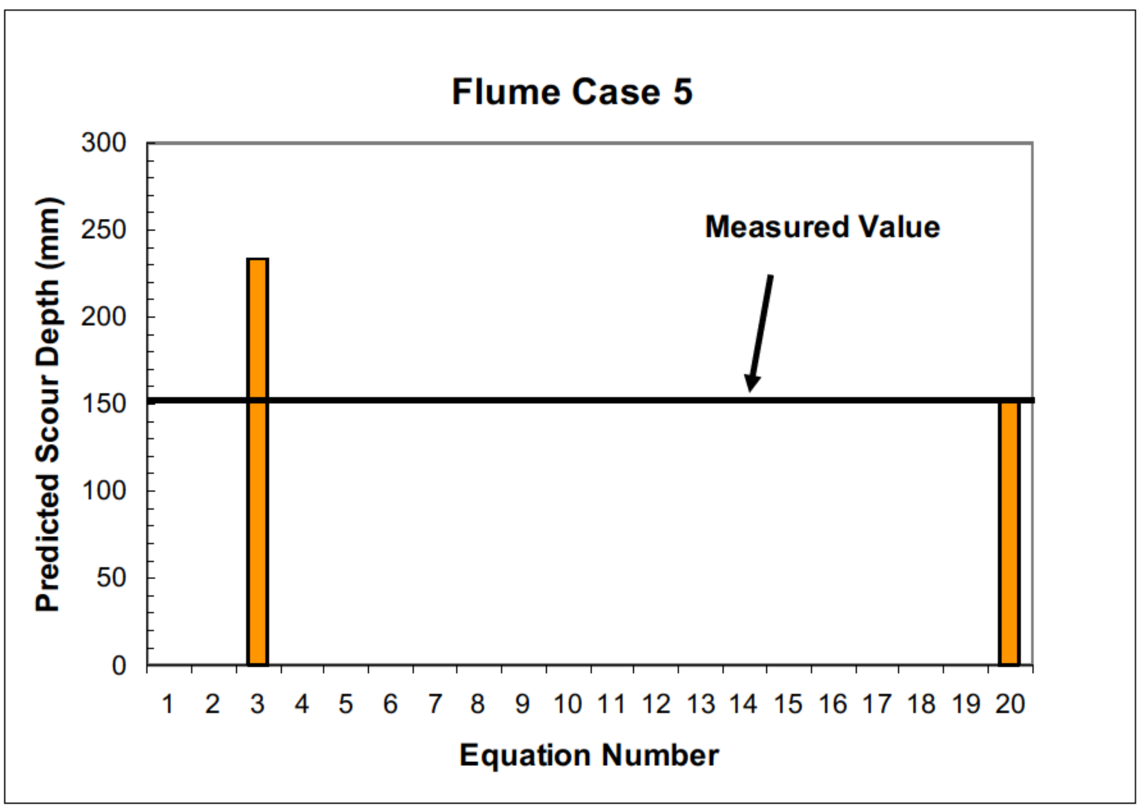

FIG 9 Comparison for Flume Test Case 5

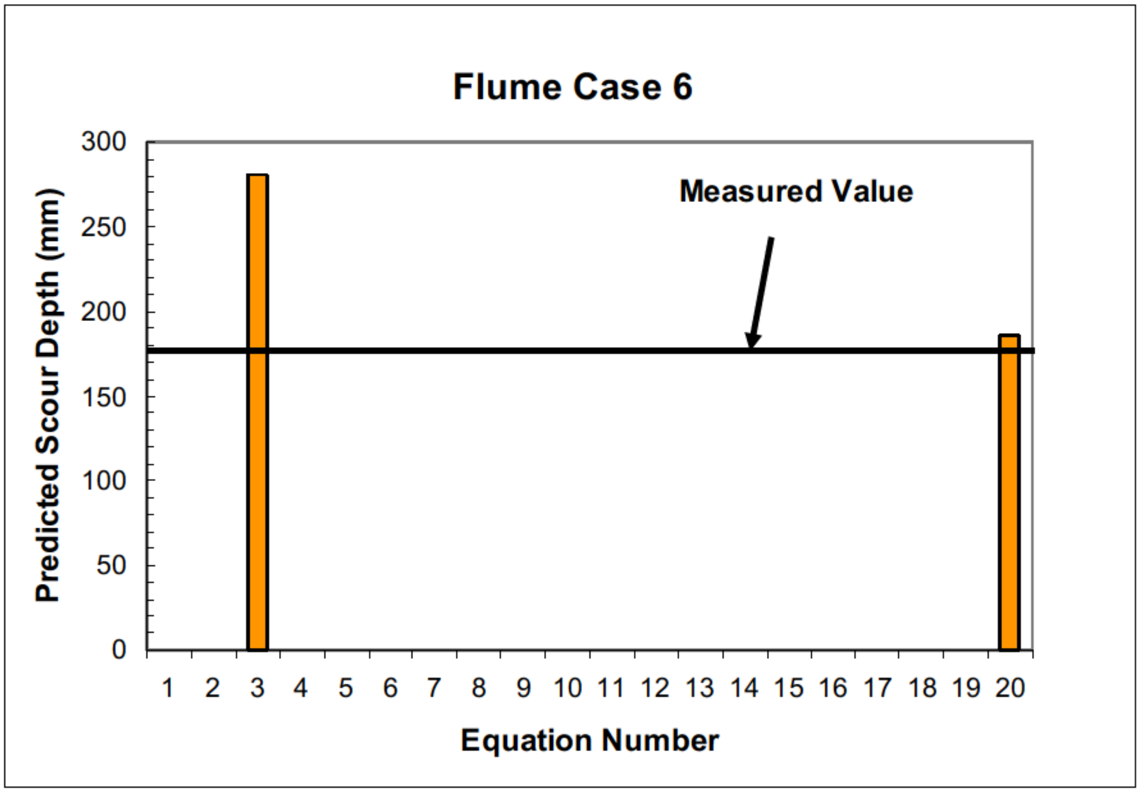

FIG 10 Comparison for Flume Test Case 6

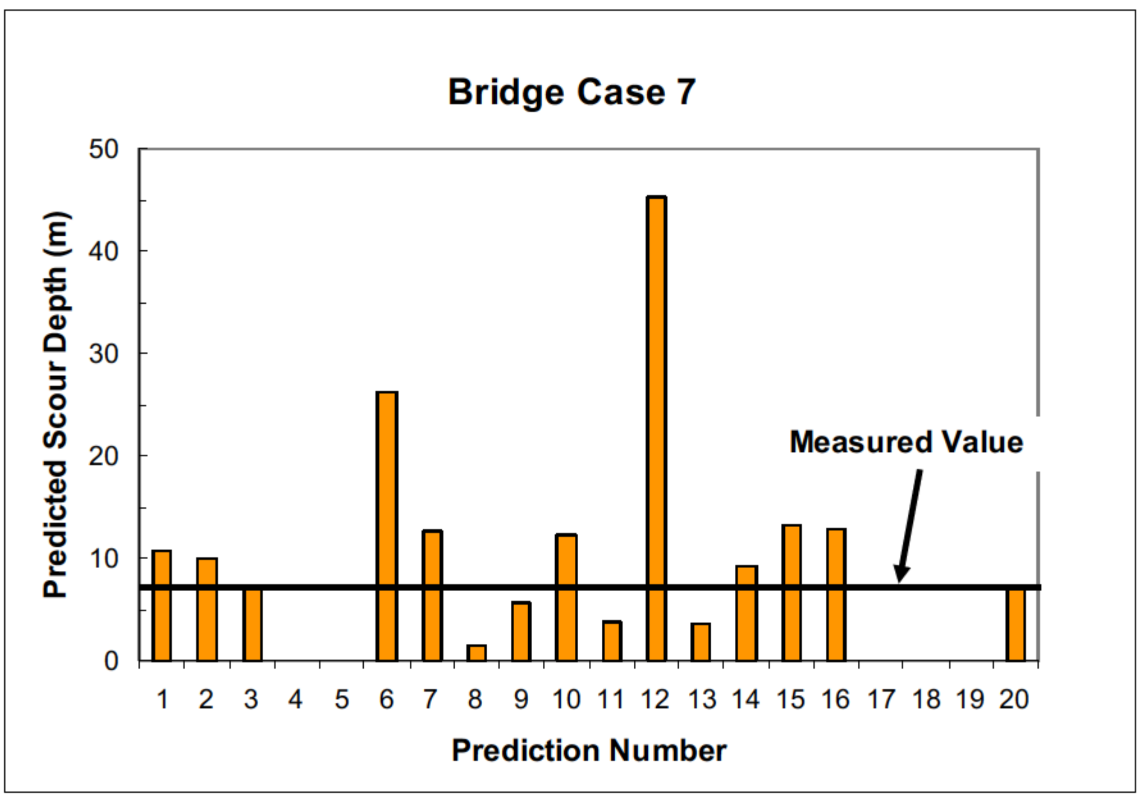

FIG 11 Comparison for Bridge Case 7

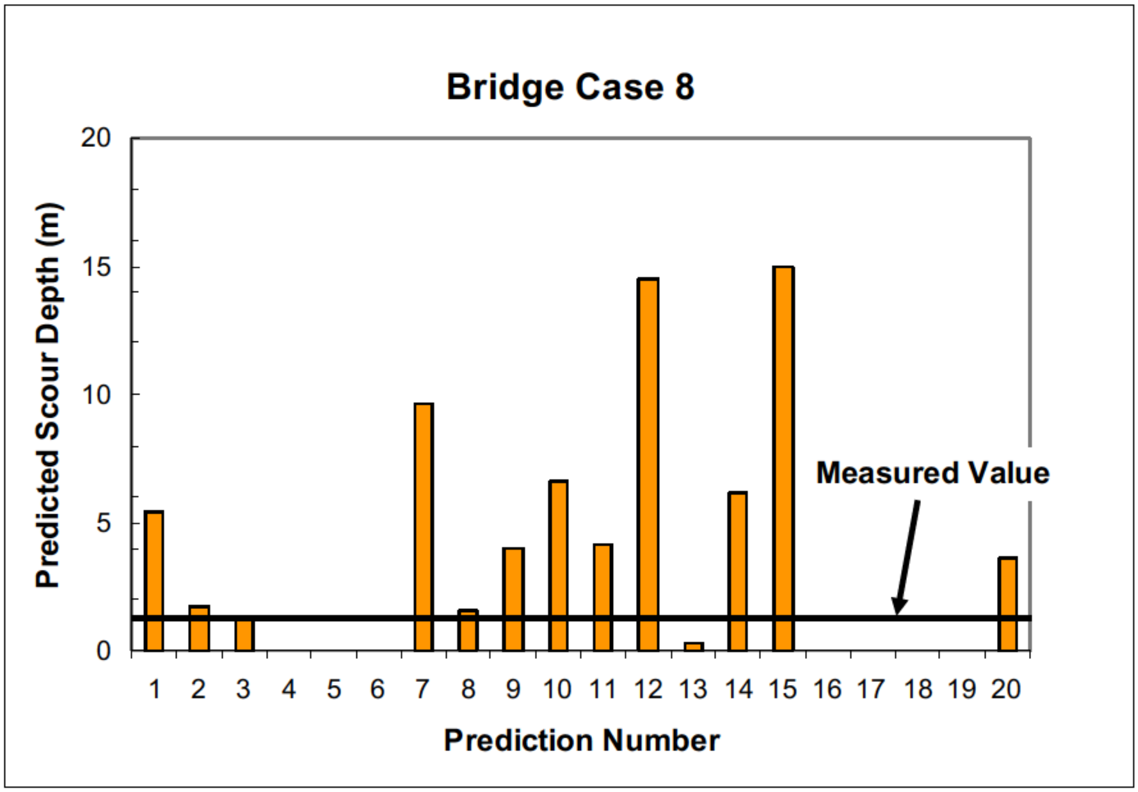

FIG 12 Comparison for Bridge Case 8 and the 5/1/91 Flood

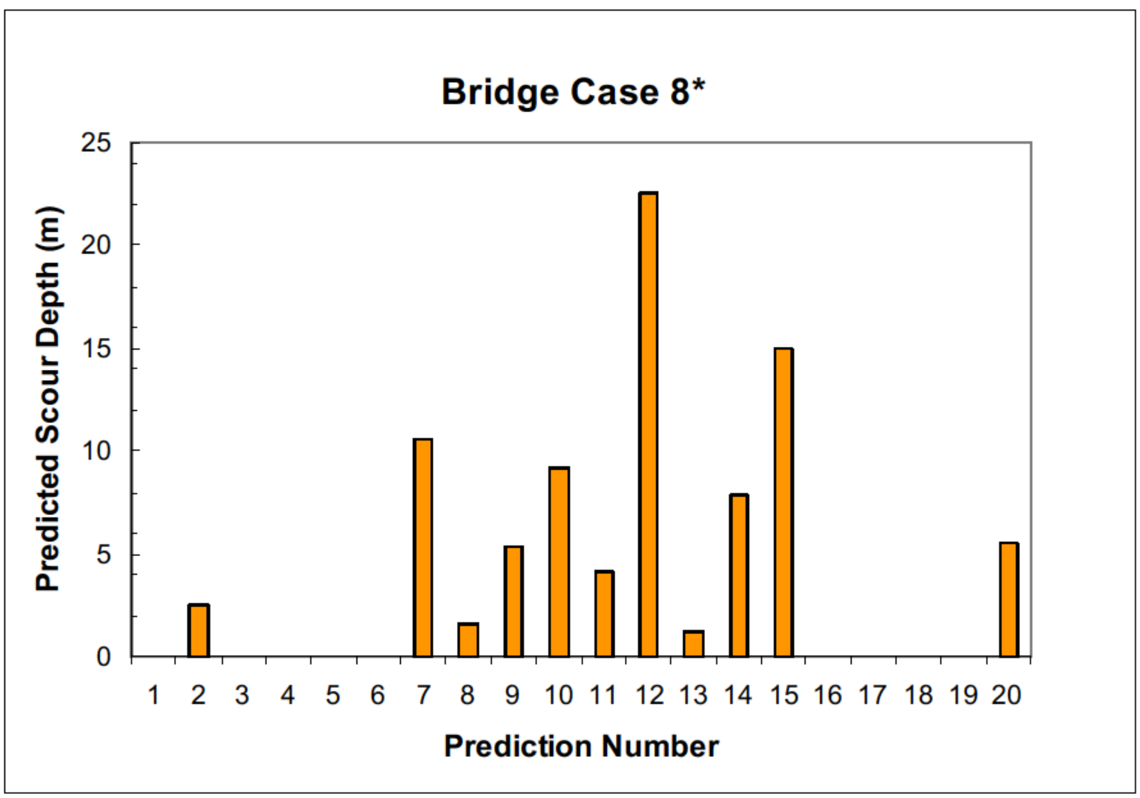

FIG 13 Comparison for Bridge Case 8 and the 500-Year Flood

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