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Full Length Research Paper

Epipremnum aureum: An environmental approach to reduce the impact of integral bridge scour

Shatirah Akib*, Ismail Othman, Faridah Othman, M. M. Fayyadh, Lawal Abdul Qayoom Tunji and S. M. Shirazi

Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.

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The main objective of this study is to show that *Epipremnum aureum* could be used as an alternative approach to reduce the scour rate of an integral bridge. Integral bridges, also referred to as integral bent bridges or rigid-frame bridges, reduce initial construction costs and long-term maintenance expenses. Most bridge failures around the world occurred due to scour at the bridge foundations during heavy floods. Many previous local scour studies concentrate on piers, abutments, or combined piles separately. Since the concept of the integral bridge is similar to a portal frame, there is a need to combine superstructure and substructure together in two floodplains, representing the real situation which involves complex structure and complex flow. This study is a unique blend of hydraulics, structures, and related environmental issues. An alternative scour countermeasure for integral bridges must be low in maintenance, and visually pleasing. This research contributes a new approach to the control of scour by using a specific plant (*E. aureum)* that could preserve nature and promote biodiversity. *E. aureum* is a tough, aesthetically pleasing plant with green and yellow heart-shaped leaves, environmentally friendly, practical, and very economical. The roots propagate easily from stem cuttings, or layering in water or soil. This study involves all parts of the bridge, floodplains, and the main channel, thereby emphasizing the real situation in the river. A statistical approach was used to summarize experimental results and to investigate the relationship between calculated and observed values.

Key words: *Epipremnum aureum,* environmentally friendly, integral bridge, scour, time evolution.

INTRODUCTION

The advantages of an integral bridge include the reduction of initial construction cost, and long-term maintenance expenses. Integral bridges also improve seismic resistance, and extend long-term serviceability (Kunin and Alampalli, 2000). An improved understanding of the water-structure interaction of integral bridge abutments, piers, and combined piles is necessary, given the increasing number of integral bridges being built in Malaysia in recent years. Integral bridges (also called integral abutment bridges or joint less bridges), have continuous construction and they are constructed without movement joints at the junction of the deck and the abutments (England et al., 2000).

Underestimation of scour depth could lead to excessive maintenance expenses. Laursen and Toch (1956), Laursen (1963), Shen et al. (1969), Breusers et al. (1977), Raudkivi (1986), and Breusers and Raudkivi (1991) conducted several studies to examine the effects of scour on the pier and abutment at a bridge foundation. Local scour studies focusing on the effect of time have been presented by Kwan (1988), Lauchlan et al. (2002), and Melville and Chiew (1999). Sheppard (2003) proposed a methodology for estimating current-induced, equilibrium of local scour depths at complex piers that are composed of up to three components (column, pile cap, and pile group). Sungai Muda is a river which acts as a divider between the states of Kedah and Penang. Sand mining has been a popular activity along this river because the river contains huge volume of sand. High demand for sand has negatively affected the ecosystem

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*Corresponding author. E-mail: Shatirahakib@yahoo.co.uk. Tel: +60379677651. Fax: +6037967316.

Abbreviations: K_{yB}, Depth size; K_I, flow intensity; K_d, sediment size; K_s, pier or abutment shape; K_θ, pier or abutment alignments; K_G, channel geometry; K_t, time factor.

Figure 1. Bridge pile exposure due to sand extraction at Jambatan Baru Kuala Ketil (Ab Ghani et al., 2003, quoted by Abdullah, 2002).

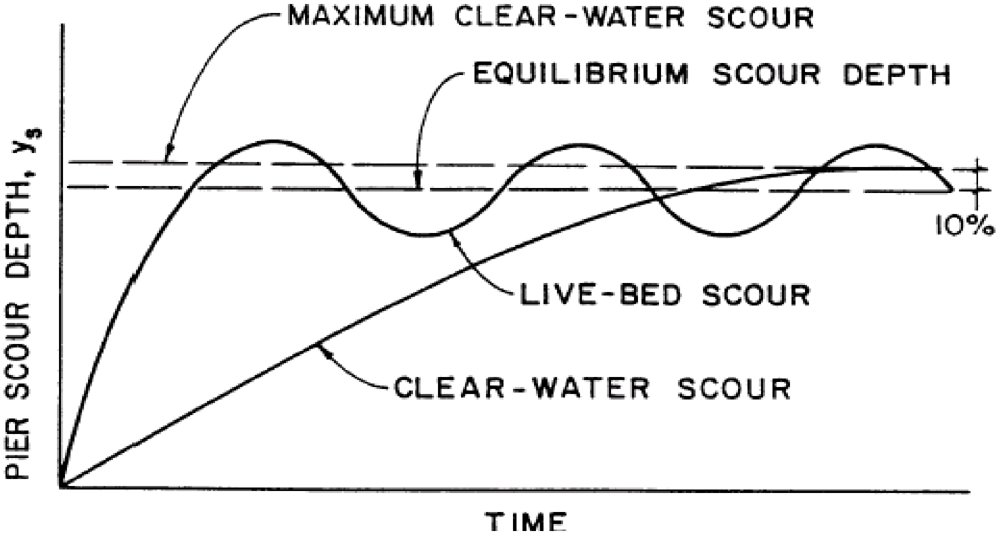

Figure 2. Scour depths in a sand-bed stream as a function of time.

and river morphology due to unorganized sand extraction. Furthermore, without appropriate guidance from the authorities, the sand mining operation could change the natural river geometry due to erosion and scour phenolmenon. As a result, scour phenomenon of the main bridge structure exposed the public to danger if structural failure were to occur (Ab Ghani et al., 2003). Figure 1 shows the sand mining operation, and bridge pile exposure due to scouring action.

Research by the Federal Highway Administration of the U.S. Department of Transportation, "Evaluating Scour at Bridges, 2001" shows that clear water scour reaches its maximum over a longer period of time than live bed scour (Figure 2).

This is because clear water scour may not reach a maximum until after several floods. Maximum local clear water pier scour is about 10% greater than the equilibrium local live bed pier scour. Research is needed to study the flow interaction with integral bridges to improve engineering knowledge of scour. Conventional engineering approaches in stabilizing slope and controlling erosion normally relies only on structural components. Vegetation is treated as incidental landscaping, is rarely included in engineering designs, and the benefits

Figure 3. Large and small leaves of *E. aureum* in Darul Ehsan Club, Kuala Lumpur.

of its role in scour control are poorly appreciated (Menashe, 2001). Though the role of vegetation in reducing scour rate is inadequately understood by the engineering community, its value in controlling erosion is well documented by Beeson and Doyle (1995), Bradbury et al. (1995), Burckhardt and Todd (1998), Davies-Colley (1997), Dwyer et al. (1997), Gatto (1984), and Gray and MacDonald (1989). Samani and Kouwen (2002) showed that the amount of deformation of a grass channel lining due to flow can be used to estimate the erosion rate, and indicate channel stability. Ahmed Mohammed et al. (2006) confirmed that bio-composite block can reduce scour rate, while at the same time be friendly to the environment and provide a good appearance.

Epipremnum aureum can be classified as Pothos, Silver Vine, and Devil's Ivy. It can reach a height of two meters or even more with suitable supports. It is synonymous with *Pothos aurea* and *Scindapsus aureus* and its family name is Araceae. It is native to Southeast Asia with a height of 6 to 20 m, and can spread from 0.9 to 1.8 m. It roots very easily from stem cuttings or layering, and cuttings will root in water or soil. This ancient tropical plant, shown in Figure 3, is one of the most popular and easy to care for houseplants.

Figure 3 shows the plant with large and small leaves. It needs bright filtered light but will be fine in lower light, although it may lose its variegation. It requires average temperatures of about 25°C.The experimental results can be used to develop guidelines for preventing integral bridge failure due to ongoing scouring. The general objective of the study is to assess the temporal development of local scour depths in three uniform sand beds. The specific objectives are:

a. To develop an alternative approach to reduce the scour rate at an integral bridge foundation in three uniform sand beds using *E. aureum;*
b. To investigate the effect of sediment size on scour depth;
c. To explore the time evolution of scour for a range of water depths and flow velocities; and
d. To establish a new modified scour formula for the specific characteristics of integral bridges, taking into account the actual conditions in the river.

Local scour formula

Observed data, and predicted data by Melville and Coleman's formula were compared. The formula is based on the following relation for the depth of local scour:

Table 1. Factors Influencing local pier-scour depth (Coleman and Melville, 2001).

Factor	K	Method of estimation
Flow depth pier size	K_{yb}	$b_e = b$ for b uniform over the scoured flow depth (y_s) at the pier. $b_e = b^*$ for b^* uniform over the scoured flow depth (y_s) at the pier. $b_e = b\,[(y_s + Y) / (y_s + b^*)] + b^*[(b^* - Y) / (b^* + y_s)]$ for the pier width increasing from b to b^* over the scoured flow depth (y_s) at the pier $K_{yb} = 2.4\,b_e$ for $b_e/y_s < 0.7$. $K_{yb} = 2\sqrt{y_s b_e}$ for $0.7 < b_e/y_s < 5$. $K_{yb} = 4.5y_s$ for $b_e/y_s > 5$.
Flow intensity	K_I	For uniform sediments: $d_{50a} \equiv d_{50}$ and $V_a \equiv V_c$. For non-uniform sediments: $d_{50av} = d_{max}/1.8 \approx d84/1.8 = \sigma_g d50/1.8$; and $Va = 0.8V_{ca}$, where V_{ca} is calculated for d_{50a} using $[5.75\log(5.35\,(y/D_{50a}))]^*u_{*ca}$ and $u_{*ca} = 0.00115 + 0.0125D_{50a}^{1.4}$ $K_I = [V - (V_a - V_c)] / V_c$ for $[V - (V_a - V_c)] / V_c < 1$. $K_I = 1$ for $[V - (V_a - V_c)] / V_c \geq 1$.
Sediment Size	K_d	$K_d = 1$ for $b_e/d_{50a} > 25$.
Foundation shape	K_s	$K_s = 1.0$ for circular pier shape. $K_s = 1.0$ for a noncircular pier skewed to the flow.
Foundation alignment	K_θ	$K_\theta = 1.0$ for circular piers. $K_\theta = ((l/b_e)^*\sin\theta + \cos\theta)^{0.65}$ for noncircular piers.
Equivalent size for non-uniform piers	Be	be = b (case I). $be = b\left(\frac{y+Y}{y+b^*}\right) + b^*\left(\frac{b^* - Y}{b^* + y}\right) \quad Y \leq b^*, -Y \leq y$ (cases II and III). Be = b* (case IV).
Approach channel geometry	K_G	$K_G = 1.0$ if values of y_s and V are selected to be representative of the flow approaching the particular pier.
Time	K_t	$t_e(\text{days}) = 30.89\,b_e / V\,(V/V_c - 0.4)(y/b_e)^{0.25}$ for $y_s/b_e < 6$, $V/V_c > 0.4$. $t_e(\text{days}) = 48.26\,b_e / V\,(V/V_c - 0.4)$ for $y_s/b_e > 6$, $V/V_c > 0.4$. $K_t = 1.0$ for $V/Vc \geq 1$. $K_t = \exp[-0.03\,\{(V_c/V)\ln(t/t_e)\}^{1.6}]$ for $V/V_c < 1$.

$$d_s = K_{yB}\, K_I\, K_d\, K_s\, K_\theta\, K_G\, K_t \tag{1}$$

where the K factors are empirical expressions accounting for the various influences on scour depth (d_s); K_I includes sediment gradation effects as well as flow velocity effects. $K_{yB} = f(y, B)$ and d_s have the dimension of length, while the other K factors are dimensionless. The critical velocity V_c can be determined from the logarithmic form of the velocity profile

$$V_c/u^*_c = 5.75 \log (5.53\, y/d_{50}) \tag{2}$$

Here u^*_c = critical shear velocity based on the median particle size, d_{50}

The shear velocities are determined using the Shields diagram for the respective sizes. A useful approximation to the Shields diagram for quartz sediments in water at 20ºC is

$$u^*_c = 0.0115 + 0.0125d_{50}^{1.4}, \quad 0.1\text{ mm} < d_{50} < 1\text{ mm} \tag{3}$$

$$u^*_c = 0.0305\, d_{50}^{0.5} - 0.0065\, d_{50}^{-1}, \quad 1\text{ mm} < d_{50} < 100\text{ mm} \tag{4}$$

where u^*_c is in m/s and d_{50} is median size of bed material (by weight) in mm.

Detailed formulas for the K factors are summarized in Table 1.

METHODOLOGY

Experimental installation

The laboratory works involved different flow rates for median particle sand sizes $d_{50} = 0.8$ mm (course), $d_{50} = 0.26$ mm (fine), and $d_{50} = 0.13$ mm (very fine) and were conducted at the Hydraulics Laboratory of University Malaya, Kuala Lumpur, Malaysia. Scour depth measurements were generally taken at 10 intervals of 1 min., followed by readings at 10 intervals of 10 min., 5 times for every 1 h. and 40 min., and the final reading was taken after 24 h. A total of 750 maximum scour data readings and 5250 scour data readings for every pile were collected for different sediment sizes, flow rates, and time duration, with and without *E. aureum*.

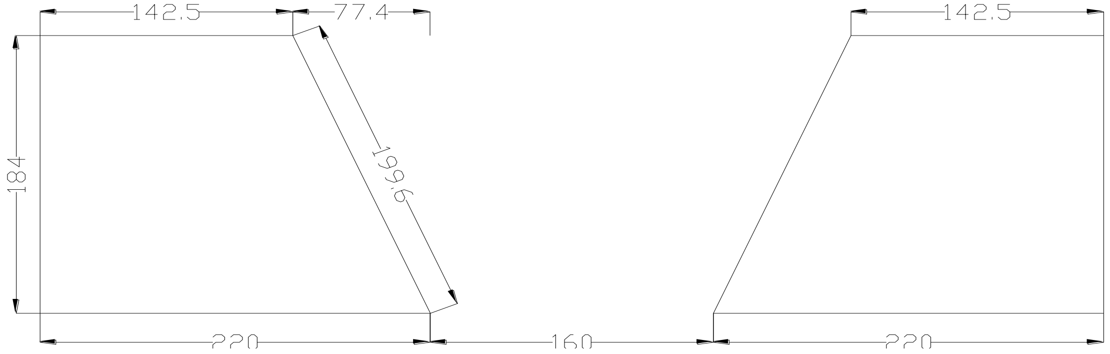

Figure 4. Cross sections of floodplains (in mm).

Figure 5. Cross section of double row integral bridge model (in mm).

The difference between this experiment and those of other researchers is the application of an integral bridge model with a scale of 1:45. Piles were embedded in 2 m long floodplains at both sides of the flume. The dimensions of the flume are 16 m long, 0.60 m wide and 0.57 m deep. The bed was filled with uniform sediment and flattened before each run. Figures 4 and 5 show the integral bridge model and test flume used in this experiment.

The main criteria in choosing this plant are that *E. aureum* propagates very easily in both soil and water. In addition, *E. aureum's* scale can be fixed to 1:45 as shown in Figure 6. The plants can grow up to 20 m tall, with stems up to 4 cm diameter, compared to the 0.08 cm diameter of plants studied in this experiment. Figure 7 shows the arrangement of the scour countermeasure experiment by planting *E. aureum* in each floodplain.

Figure 8 shows the position of scour measurements taken at abutments and combined piles during the experiment. Several preliminary runs were done upstream of the flume to measure the initial velocity of the flow.

The integral bridge model is a complex structure consisting of abutments and piles (Figure 9). The model was made from Perspex material. Vertical depth scales were used to measure the scour depth at the abutments and piles. The bed of the flume was embedded in a river sand layer of about 0.13 m in depth. Three types of uniform sand texture, coarse, fine, and very fine were used as bed material. Sieve analyses tests were carried out at the Soil Mechanics Laboratory in the Civil Engineering Department, University of Malaya, Kuala Lumpur, Malaysia. The procedure for determination of particle size distribution in the sieve analyses was done in accordance with BS1377: Part 2: 1975.

Experimental procedure

The integral bridge model was embedded in two floodplains. Three uniform sediments with median particle size, d_{50} = 0.8 mm, d_{50} = 0.26 mm, and d_{50} = 0.13 mm were carefully compacted and leveled, and initial readings were taken as a control experiment before the compound channel was flooded with water. Five discharges and flow depths were obtained by adjusting the valve on the main inlet pipe. For scour countermeasure experiments, approximately 250 *E. aureum's* leaves, together with stems, were counted and planted in the floodplains. The vegetation chosen in this experiment was scaled from matured real plant at Darul Ehsan Club, Kuala Lumpur (Figure 3). The length of leave of the matured plant was 13.5 cm and the leave length of plant used in the experiments was 3 cm. The stem's diameter was 4.5 cm for real plant and 1 mm for plant used for the experiments. The ratio of the size of vegetation for experiment to size of vegetation in real life is 1:45.

Scour depth measurements were generally taken at 10 intervals of 1 min., followed by readings at 10 intervals of 10 min, 5 times for every 1 h and 40 min. and the last readings were taken after 24 h by using a stop watch. The velocity, water depth and temperature were recorded during the experiment. Throughout the experiment, the development of scour at abutments and piles was monitored. This research did not only focus on the maximum scour depth, but

Figure 6. Large and strong stems of *E. aureum*.

Figure 7. Integral bridge model with *E. Aureum* planted along floodplains.

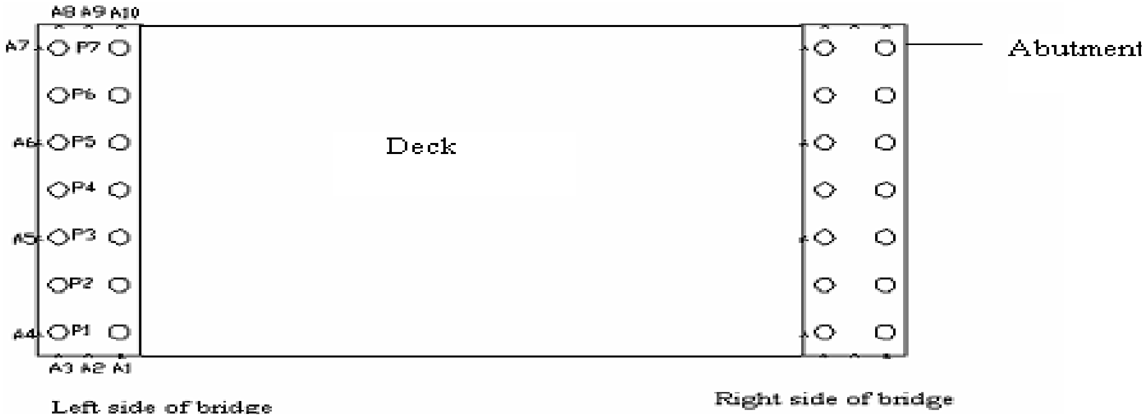

Figure 8. Plan view of scour measurement label at abutments and piles for double row pile integral bridge.

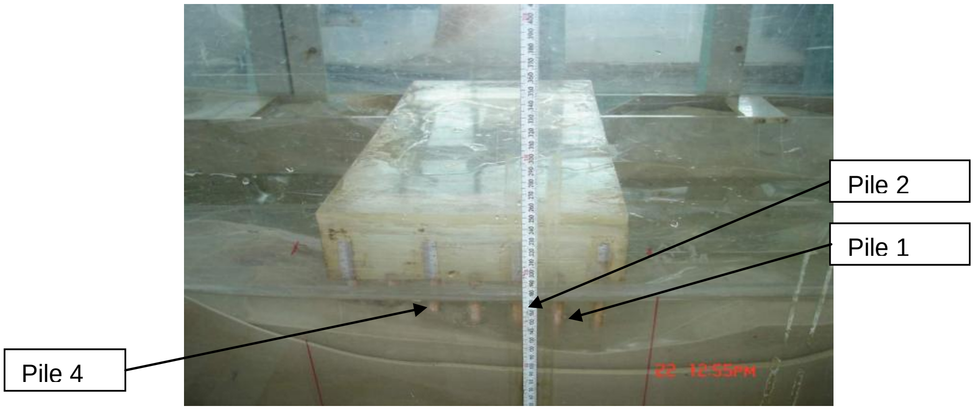

Figure 9. Local scour depth after 24 h (d_{50} = 0.13 mm).

also on the time development of scour. The degree of uniformity of the particle size distribution of sediment of a sample is defined by the value of geometric standard deviation, σ_g, which is less than 1.4 for uniform sediments (Dey and Barbhuiya, 2004).

Thus, the tests with uniform sand would eliminate the reduction of local scour that would be expected to occur in non-uniform sand, because of the armouring effect which might allow the down-flow to penetrate through the voids among particles, and reduce the effect of spiral action by dissipating some of the flow energy. In this study, a compound channel was used with two adjacent flood-plains and a main channel, similar to the condition in an actual river. Scour readings were taken at the abutments and combined piles.

RESULTS AND ANALYSIS

The interference of the bridge structure with the floodplains and the flow contributed the complex scour phenomenon in this study. The experimental results differed from most of the other experiments that only focused on the separated bridge substructure such as abutments, or the pier itself. The integral bridge model was tested in a two stage channel for both clear water and live-bed scour, referring to real condition in the river.

Experimental results showed that scour process typically began at the front side of the abutment where the approach velocity first hit the bridge structure, as shown in Figure 10, position A1, A2, and A3.

The sediments were continuously displaced by the flow hitting the obstacles. Main scour holes started to form at abutments located upstream of the flow. The scour process mainly took place at the bottom of the scour holes and progressively moved to the side of abutment, and finally reached the piles.

Time evolution graphs of the maximum scour, d_s for continuous scour depth for abutment, and piles are shown from Figures 11 to 19. In the initial phase, the sediment pick-up rate was very high, resulting in a rapid growth of the scour depth. As the scour depth increased, the sediment pick- up rate of the scour hole progressively decreased. Kwan and Melville (1994) described how the scour hole at an abutment forms beneath the primary vortex that sinks into the scour hole as scouring progresses. The hydrodynamic forces (namely drag and lift forces) induced on the sediment particles due to the vortex flow remove the sediment particles from the scour

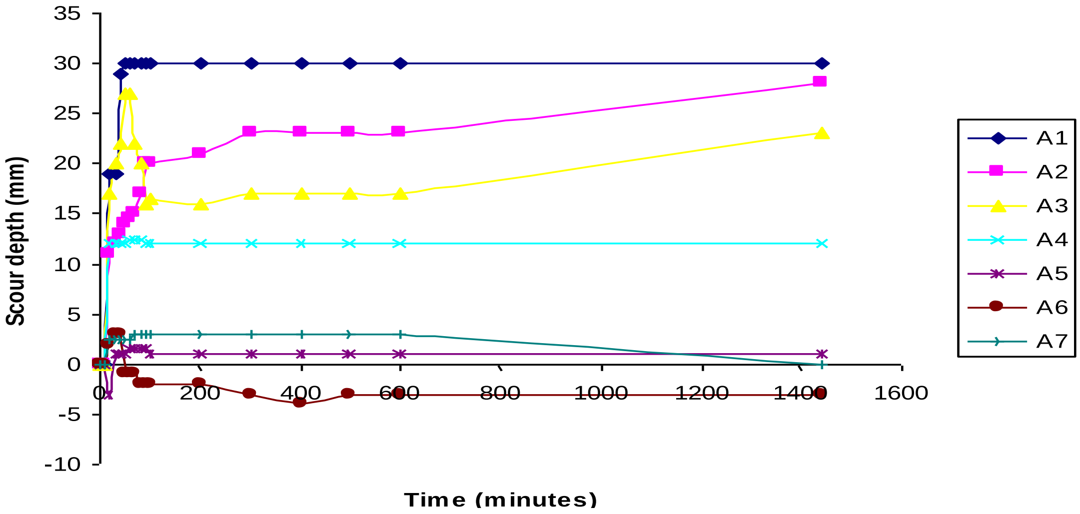

Figure 10. Effect of time on local scour depth at abutment (d_{50} = 0.8 mm, y = 41.25 mm).

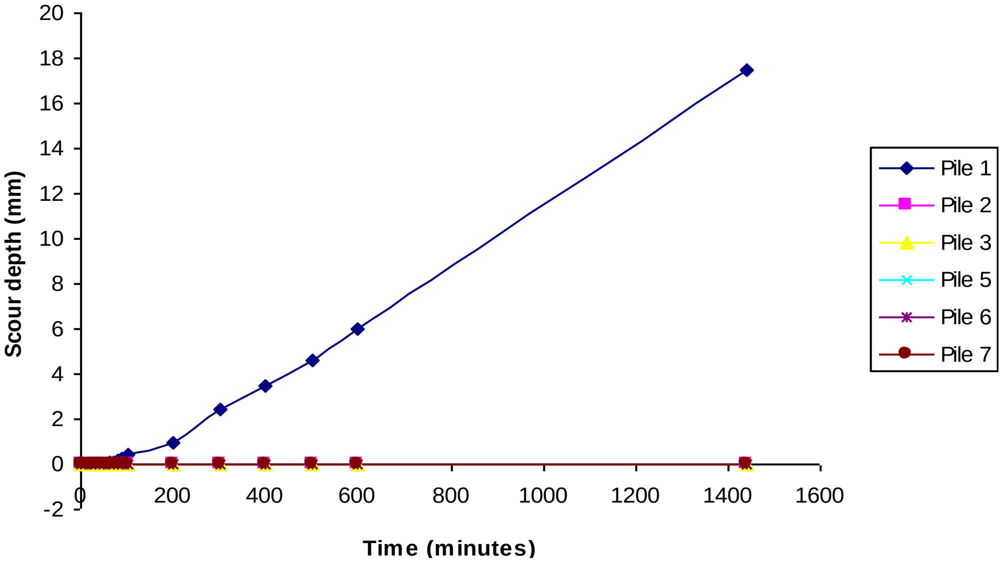

Figure 11. Effect of time on local scour depth at piles (d_{50} = 0.8 mm, y = 41.25 mm).

hole. These forces decrease as scour depth increases. Thus, as the scour hole increases, the scouring process decreases. Theoretically, when the scour depth reaches its equilibrium value, the pick-up rate becomes zero, producing a horizontal curve of scour depth versus time.

Aggradation and degradation are long-term streambed elevation changes due to natural or man-induced causes which can affect the reach of the river on which the bridge is located. Aggradation involves the deposition of bed material eroded from the channel or watershed upstream of the bridge; whereas, degradation involves the lowering, or scouring, of the streambed due to a deficit in upstream sediment supply. The fluctuated scour results shown in the figures may be due to the aggradation and degradation phenomenon as the scour holes moved to form scour phase equilibria. Live-bed scour also contributed to the fluctuation of scour results, since this experiment involved clear water and live-bed scour. The negative results showed that the scour readings were above the initial level. Two phases were found from the graph of scour depth versus plotted against time which was initial, and equilibrium phases, although equilibrium phase was insignificant.

Based on this study results, *E. aureum* was shown to delay the time for scour to occur. For very fine sand (without vegetation), scour started to approach the pile

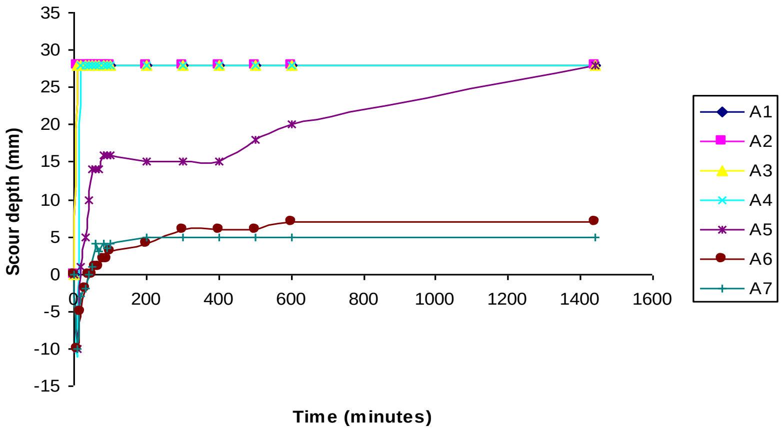

Figure 12. Effect of time on local scour depth at abutment (d_{50} = 0.8 mm, y = 47.3 mm).

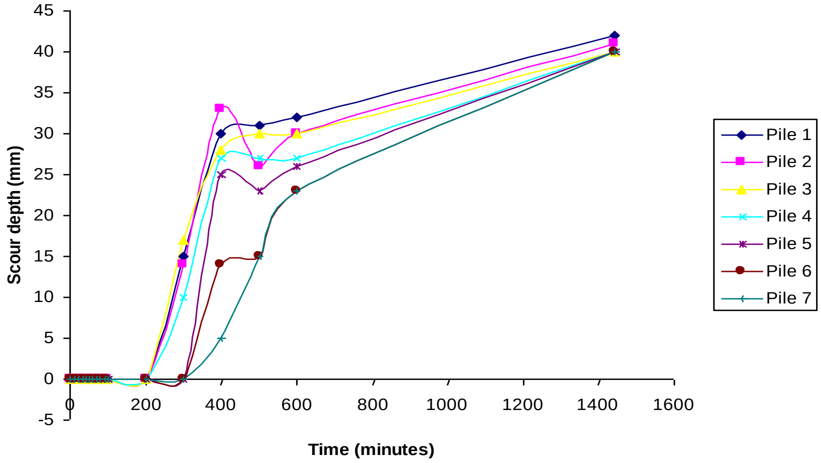

Figure 13. Effect of time on local scour depth at piles with *Epipremnum aureum* (d_{50} = 0.8 mm, y = 47.3 mm).

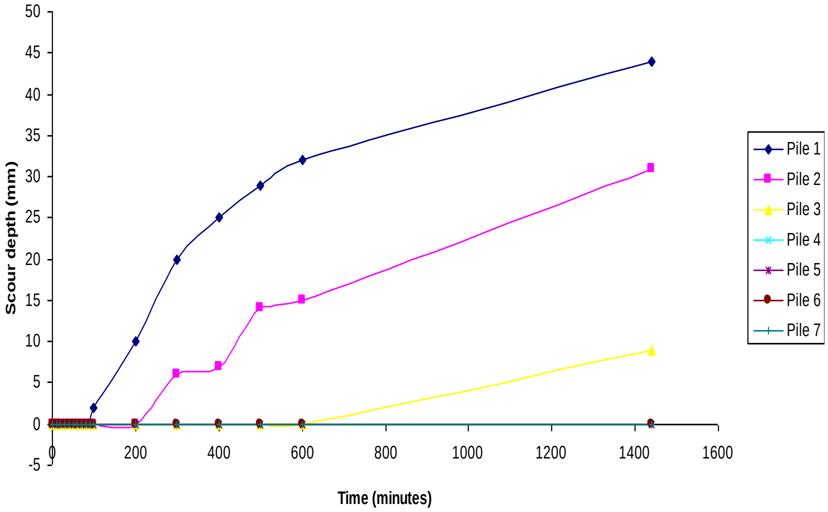

Figure 14. Effect of time on local scour depth at piles (d_{50} = 0.13 mm, y = 34.1 mm).

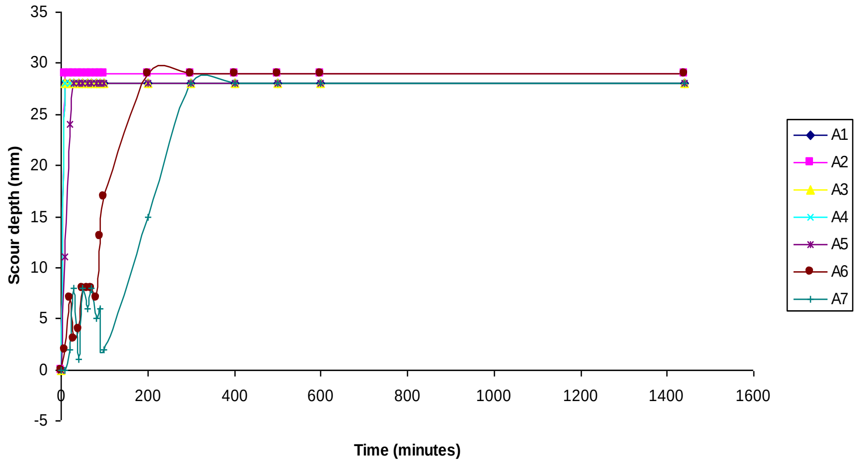

Figure 15. Effect of time on local scour depth at abutment (d_{50} = 0.13 mm, y = 47.3 mm).

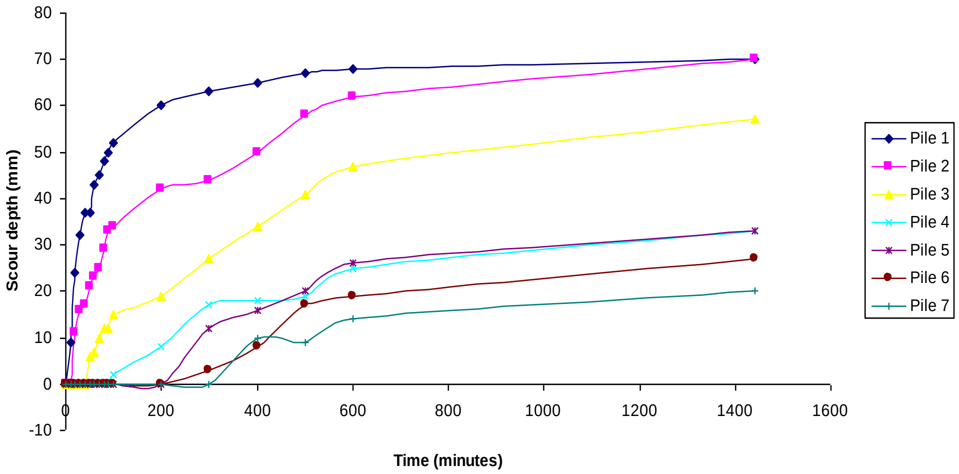

Figure 16. Effect of time on local scour depth at piles (d_{50} = 0.13 mm, y = 47.3 mm).

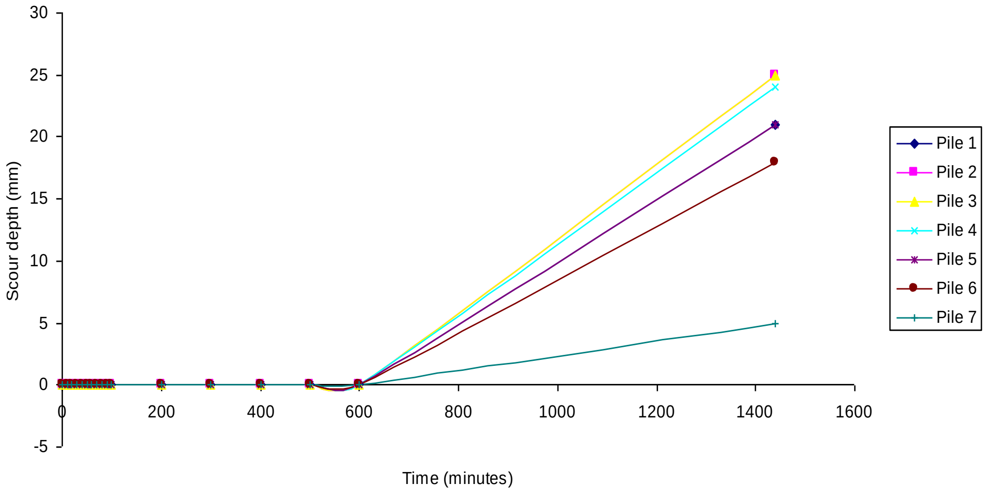

Figure 17. Effect of time on local scour depth at piles with *E. aureum* (d_{50} = 0.13 mm, y = 44 mm).

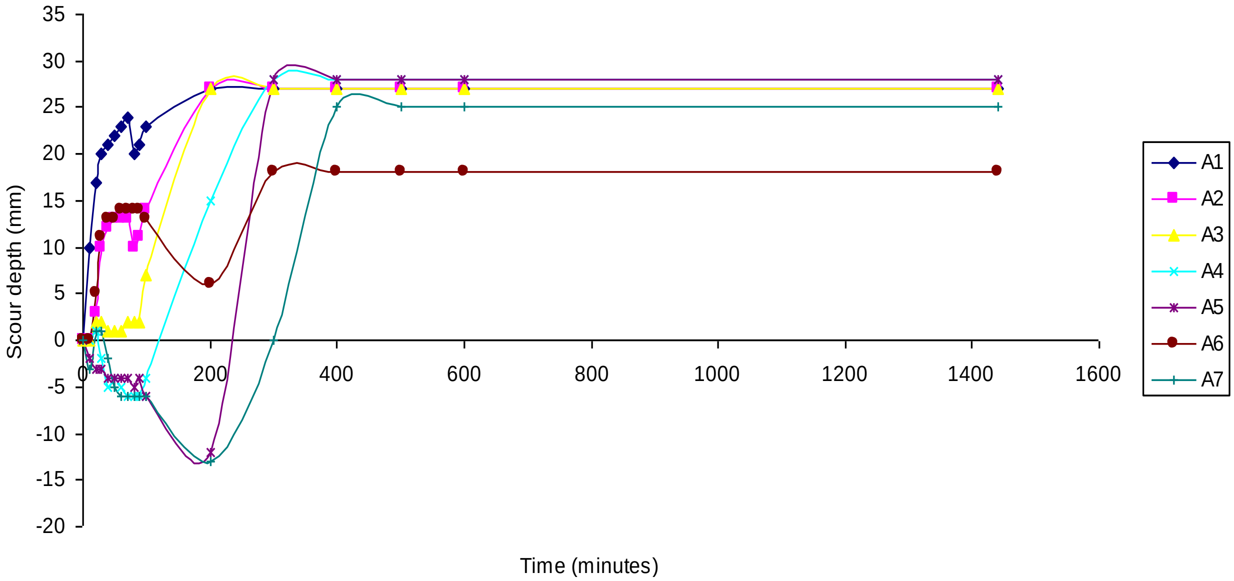

Figure 18. Effect of time on local scour depth at abutment with *Epipremnum aureum* (d_{50} = 0.13 mm, y = 47.3 mm).

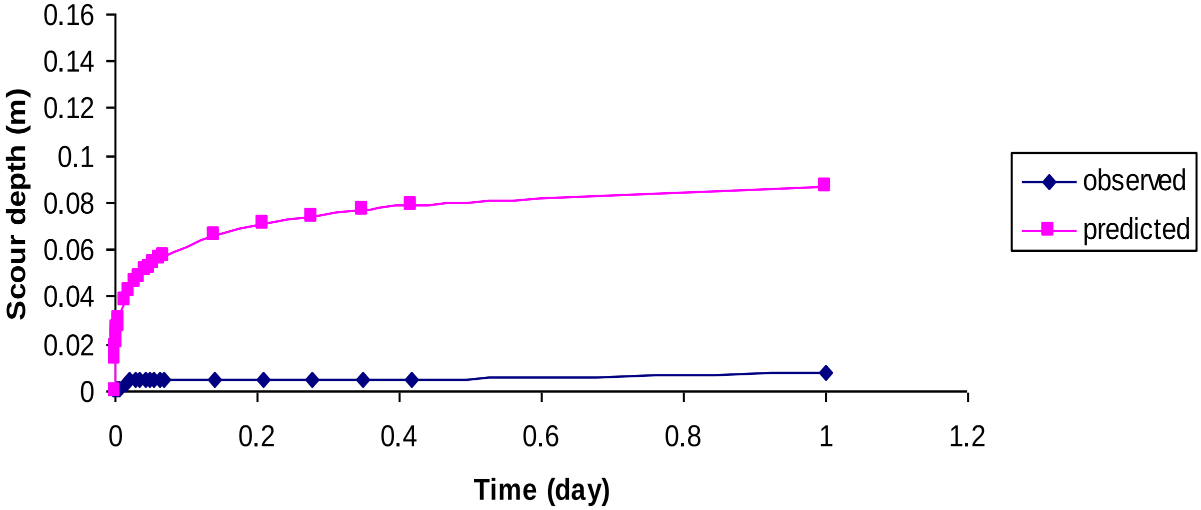

Figure 19. Comparison between observed and predicted scour depth without *E. aureum* (d_{50} = 0.8 mm, v = 0.16 m/s).

when y = 34.1 mm, and with vegetation, scour started to approach the pile when y = 44 mm. For course sand (without vegetation), scour started to approach the pile when y = 41.25 mm, and with vegetation, scour started to approach the pile when y = 47.3 mm. For fine sand, (without vegetation), scour started to approach the pile when y = 41.25 mm, and with vegetation, scour started to approach the pile when y = 44 mm.

Statistical test

In order to investigate the relationship between the experimental and predicted scour depth using Melville and Coleman's formula, simulation studies were performed. Scour depth on an integral bridge for very fine, fine, and course sand with and without vegetation were studied. A statistical approach was used to summarize the results and to investigate the relationship between predicted and observed values.

Results show that observed values parallel predicted values for the same group, as illustrated in Figures 20 to 26.

In other words, there is a possibility for estimating the difference constant between means of observed and predicted values, *d*. The differences between means

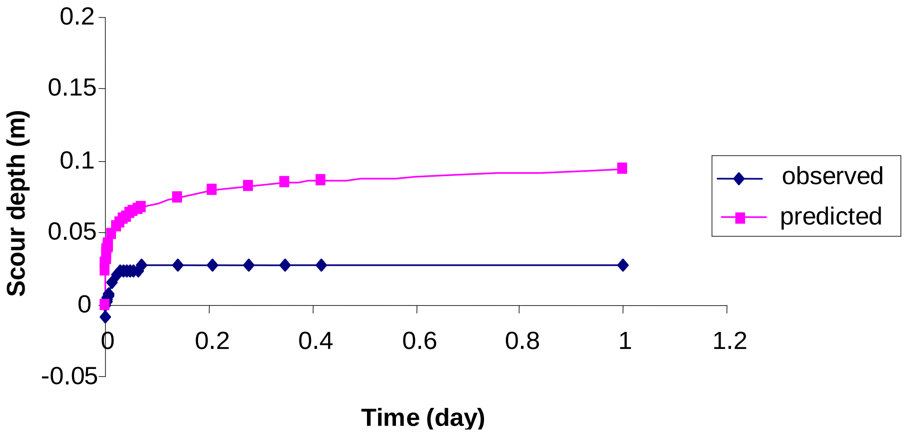

Figure 20. Comparison between observed and predicted scour depth without *E. aureum* (d_{50} = 0.13 mm, v = 0.16 m/s).

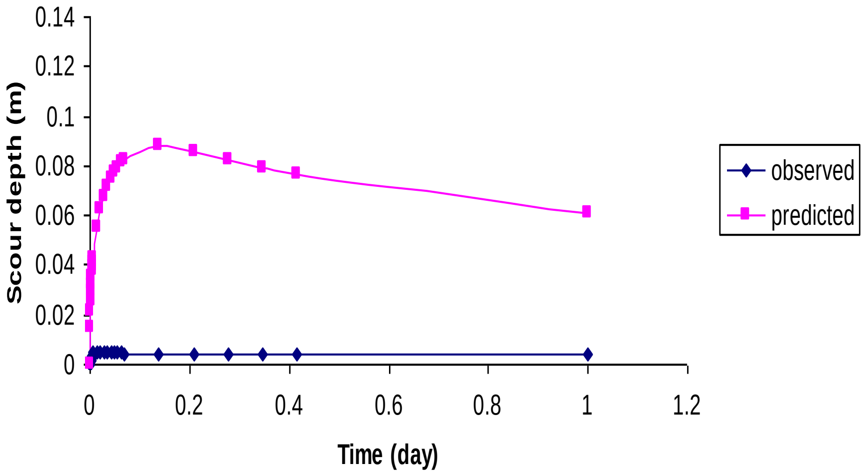

Figure 21. Comparison between observed and predicted scour depth with *E. aureum* (d_{50} = 0.8 mm, v = 0.12 m/s).

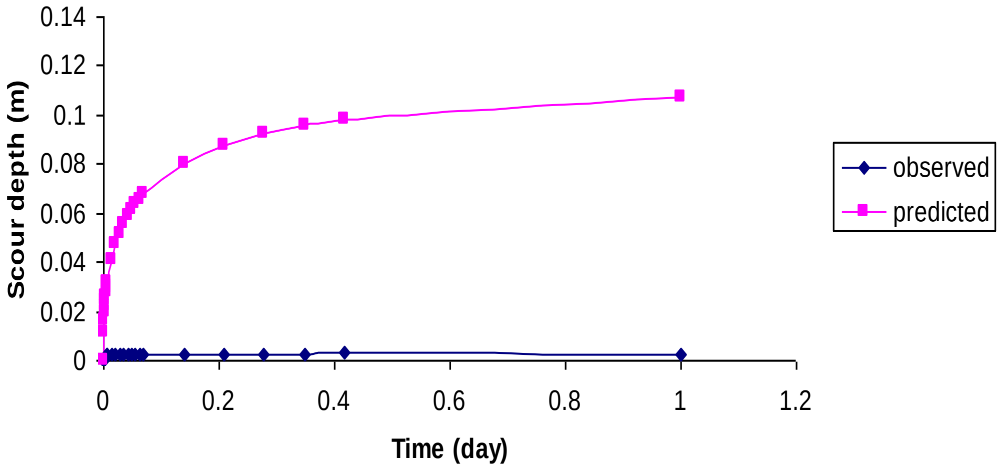

Figure 22. Comparison between observed and predicted scour depth with *E. aureum* (d_{50} = 0.8 mm, v = 0.15 m/s).

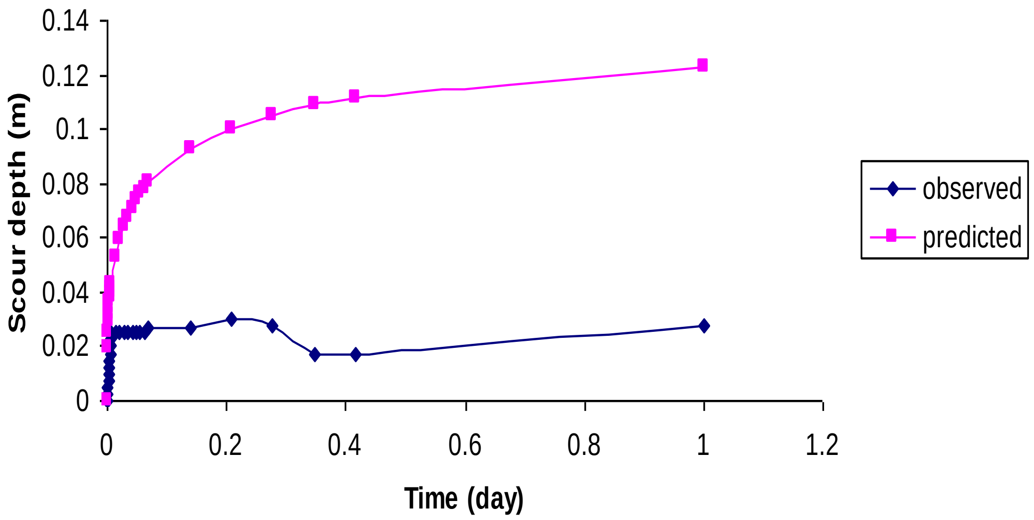

Figure 23. Comparison between observed and predicted scour depth with *Epipremnum aureum* (d_{50} = 0.8 mm, v = 0.18 m/s).

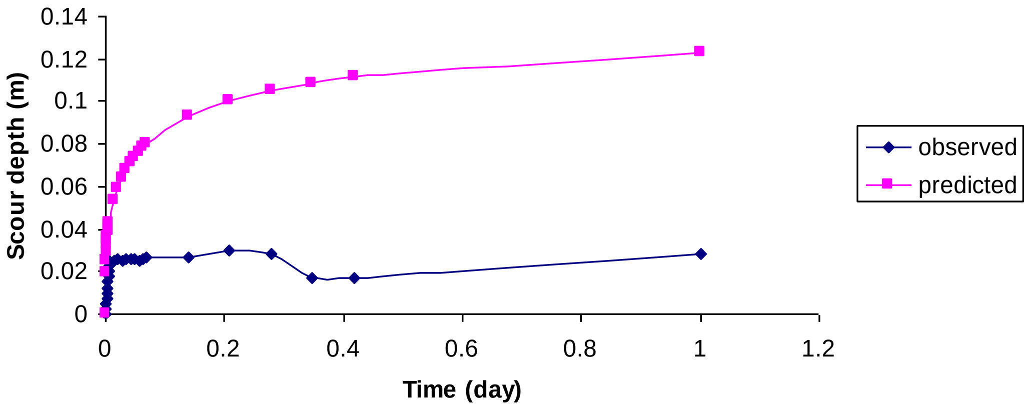

Figure 24. Comparison between observed and predicted scour depth with *E. aureum* (d_{50} = 0.8 mm, v = 0.21 m/s).

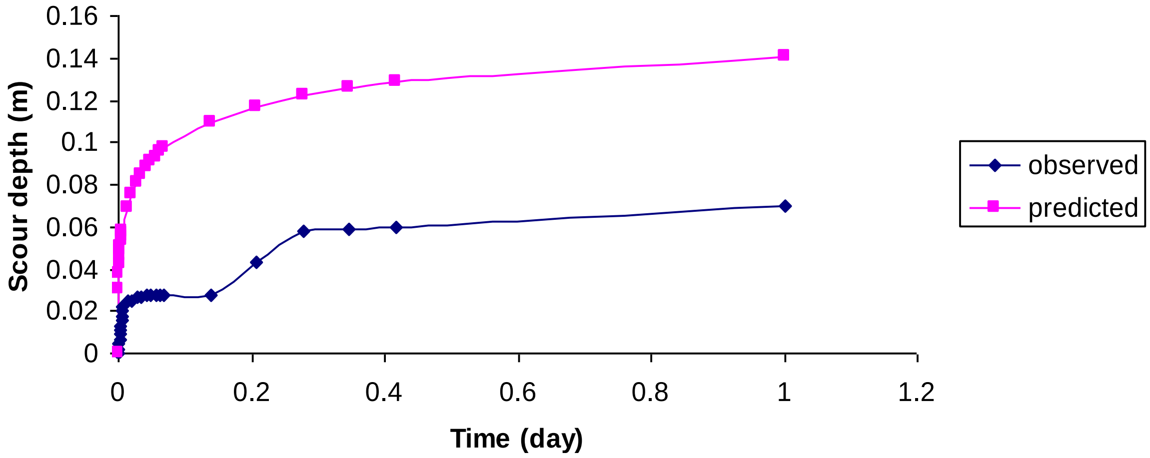

Figure 25. Comparison between observed and predicted scour depth with *E. aureum* (d_{50}= 0.26 mm, v = 0.09 m/s).

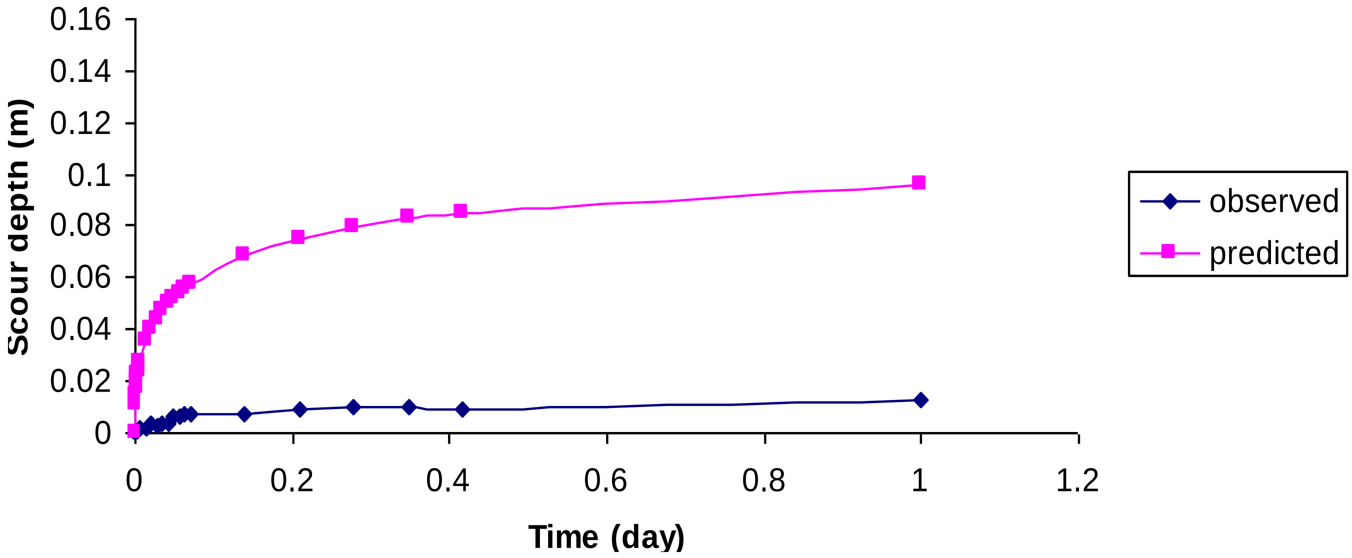

Figure 26. Comparison between observed and predicted scour depth with *E. aureum* (d_{50} = 0.26 mm, v = 0.12 m/s).

$\Delta\mu$ were calculated for each case; the mean of all differences means *d* was computed and considered as the difference constant.

To test difference of means between two groups, the t-test was used to investigate the accuracy and efficiency of the proposed difference constant for each case. We test the null hypothesis $H_0 : \mu_{predicted} - \mu_{observed} = d$ versus the alternative hypothesis, $H_1 : \mu_{predicted} - \mu_{observed} \neq d$; the decision taken was based on p-value and confidence interval at 95% level of significance (Rice, 1988). The S-plus 2000, statistical software package was used to carry out the analysis.

Table 2 gives the suggested groups and cases included, the actual difference between mean, $\Delta\mu$, the proposed difference d, the p-value, confidence intervals, and the final conclusion at a 95% level of significance.

Since the P-value for all cases in different each group is larger than 0.05, statistically we accept H_0. In other words, the proposed difference d is expressing the actual difference at a 95% level of significance. Moreover, the confidence intervals in all cases include the proposed difference, d which confirms this study's conclusion. Therefore, the functional relationship between observed and predicted values for each group can be summarized as shown in Table 3.

Conclusion

This study was limited to local scouring of an integral bridge in uniform sand beds. Development of scour depth was dependent on the duration of the scouring process. The sediment pick-up rate was very high initially, resulting in rapid growth of the scour depth. As the scour depth increased, the sediment pick- up rate of the scour hole progressively decreased. Sediment sizes also affected the scour rates, as the course sand took longer to reach the same scour depth as fine, and very fine sand. The highest flow rates and flow shallowness contributed the highest results in scour depth. Live-bed scour contributed to the fluctuation of scour results since this experiment involved clear water and live-bed scour.

The most significant finding in this study is that *E. aureum* can be used as an environmentally friendly scour countermeasure for long term integral bridge scour control. About 750 scour depth data were tested to obtain the relationship between observed and predicted scour depth using Melville, and Coleman's formula. Furthermore, a new method is proposed to predict depth for integral bridge scour. A statistical approach was applied to summarize the obtained results and to investigate the relationship between predicted and observed values. Decision was taken based on p-value and confidence interval at 95% level of significance. From this relationship, a new modified formula, which depends on the entire integral bridge structure with floodplain (with and without *E. aureum*) referring to the actual conditions in the river, was successfully established.

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Table 2. Actual difference between mean, $\Delta\mu$, proposed difference, d , p-value, confidence intervals and the final conclusion at 95% level of significance for each case.

Group	Case	$\Delta\mu$	d	P-value	Confidence interval		Conclusion
					Lower bound	Higher bound	
Without vegetation	A1	0.05258878	0.052	0.618	0.04250406	0.05867350	Accept H_0
	A2	0.05058878	0.052	0.7218	0.04250406	0.05867350	Accept H_0
	A3	0.05872115	0.052	0.1456	0.04949742	0.06794489	Accept H_0
	A4	0.05178462	0.052	0.9565	0.04371999	0.05984924	Accept H_0
	A5	0.05579095	0.052	0.1248	0.05087163	0.06071027	Accept H_0
	A6	0.04978414	0.05	0.9484	0.04297788	0.05659039	Accept H_0
	A7	0.05000687	0.05	0.9983	0.04353949	0.05647425	Accept H_0
	A8	0.05178462	0.05	0.7565	0.04371999	0.05984924	Accept H_0
	A9	0.04677434	0.05	0.2135	0.04156505	0.05198363	Accept H_0
	A10	0.04711756	0.05	0.6981	0.03196361	0.06227150	Accept H_0
	A11	0.03982705	0.039	0.6922	0.03556700	0.04408709	Accept H_0
	A12	0.03934093	0.039	0.9072	0.03336687	0.04531499	Accept H_0
	A13	0.04253732	0.039	0.2055	0.03692752	0.04814712	Accept H_0
	A14	0.03492135	0.039	0.2171	0.02828019	0.04156250	Accept H_0
	A15	0.04342112	0.039	0.664	0.02267701	0.06416523	Accept H_0
With vegetation	A16	0.04718985	0.049	0.1873	0.04443751	0.04994219	Accept H_0
	A17	0.05388253	0.049	0.2849	0.04467011	0.06309496	Accept H_0
	A18	0.05055024	0.049	0.7866	0.03886558	0.06223490	Accept H_0
	A19	0.04370739	0.049	0.3156	0.03305098	0.05436380	Accept H_0
	A20	0.05245934	0.049	0.2889	0.04587590	0.05904277	Accept H_0
	A21	0.05058878	0.062	0.7218	0.04250406	0.05867350	Accept H_0
	A22	0.0491625	0.062	0.3807	0.037358	0.0642546	Accept H_0
	A23	0.05887862	0.062	0.5303	0.04876272	0.06899452	Accept H_0
	A24	0.06307341	0.062	0.8253	0.05314604	0.07300079	Accept H_0
	A25	0.06480491	0.062	0.3807	0.05832229	0.07128753	Accept H_0
	A26	0.04077156	0.042	0.868	0.03501023	0.04553289	Accept H_0
	A27	0.0357886	0.042	0.1373	0.02745054	0.04412667	Accept H_0
	A28	0.04077156	0.042	0.7468	0.03301023	0.04853289	Accept H_0
	A29	0.04563272	0.042	0.3011	0.03853832	0.05272712	Accept H_0
	A30	0.04437842	0.042	0.2862	0.03987796	0.04887888	Accept H_0

Table 3. New proposed scour formula based on statistical test.

Group d50 = mean sediment size	Formula	New proposed scour formula d_s=scour depth
d50 = 0.8 mm without vege	Observed = Predicted – 0.052	$d_s = K_{yB} K_I K_d K_s K_\theta K_G K_t - 0.052$
d50 = 0.26 mm without vege	Observed = Predicted - 0.05	$d_s = K_{yB} K_I K_d K_s K_\theta K_G K_t - 0.05$
d50 = 0.13 mm without vege	Observed = Predicted – 0.039	$d_s = K_{yB} K_I K_d K_s K_\theta K_G K_t - 0.039$
d50 = 0.8 mm with vege	Observed = Predicted – 0.049	$d_s = K_{yB} K_I K_d K_s K_\theta K_G K_t - 0.049$
d50 = 0.26 mm with vege	Observed = Predicted – 0.062	$d_s = K_{yB} K_I K_d K_s K_\theta K_G K_t - 0.062$
d50 = 0.13 mm with vege	Observed = Predicted – 0.042	$d_s = K_{yB} K_I K_d K_s K_\theta K_G K_t - 0.042$

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