SCOUR AROUND BRIDGE PIERS APPLYING STREAM POWER APPROACH

Abdelkawi A. Khalifa[1], Khaled A. Kheireldin[2], and Abdelhamid H. Eltahan[3]

1- Prof. of Hydraulics, Faculty of Engineering, Ain Shams University, Abbasia, Cairo, Egypt
2- Prof. of Water Engineering, International Water Engineering Consultant, Egypt. E-mail: kzurich22@gmail.com
3- Assistant Lecturer, British University in Cairo, Egypt

ABSTRACT

The current research aims introducing the problem of scour around bridge piers from a new point of view. The classical approach for tackling this problem usually depends on applying empirical equations developed from the analysis of experimental results with the use of dimensional analysis. Thus, in the current research an intensive study for evaluating the existing scour predictor was performed. The comparison processes through comparing the results of some laboratory experiments performed for scour around bridge piers and the predicted scour depth from some selected available predictor equations. About 156 experiments were carried out to perform the current study in accordance with 15 predictor equations. The results show that the scour predictors have a low reliability for following a specific trend or giving accurate results. Thus, it has been considered that it is of great importance to study the scour problem around bridge piers through a new approach. Stream power approach has been selected for achieving this objective. A one dimensional numerical model for open channel hydraulic was selected to stimulate the problem of flow and scour around bridge piers. Stream power variation is studied versus several parameters such as scour depth, sediment type and flow conditions. Several laboratory experimental studies were tested and stream power values in these different cases were analyzed. Results show that there is a significant relationship between scour depth escalations and stream power value. The relationship between stream power and scour depth was found to have a specific trend through which a new predictor could be developed. The new predictor was applied on some experiments and the estimated scour depth was compared to the experimental results. It was found that there was a good agreement between the experimental results and the scour calculated using the stream power approach. Finally, it can be concluded that the new approach is considered more reliable than the classical methods for estimating the scour depth at bridge piers. However more studies are needed to perform an inclusive idea about the application of stream power approach for pier and abutment scour problem.

INTRODUCTION

Bridges are designed to accommodate floods of certain magnitudes. Designing of bridge foundations is based on an insufficient knowledge or inaccurate estimation about the local scour around bridge piers may lead to the bridge failure at a discharge much smaller than the design magnitude. Moreover, it leads to very expensive construction cost if the estimation is too large than the real one.

Scour holes around bridge piers created by the flowing water is a major cause of bridge foundation failure which are usually supported by piles or deep foundation bases. The knowledge concerning the magnitude of maximum scour depth around bridge piers and how this depth is related to different flow condition and bed sediment properties for the river is essential in the design of bridges to withstand scour damage. The flow pattern and scour expected hole at a pier are illustrated in Figure 1. The upstream section of the scour hole resembles a frustum of an inverted cone. The principal features of the flow, which are discredited in the diagram for simplicity, are the down flow ahead of the pier, the horseshoe vortex at the base of the pier, the surface roller a head of the pier and the vortices, downstream of the pier. The down flow is a consequence of f1ow deceleration ahead of the pier.

The associated stagnation pressures on the face of the pier are highest near the surface, where the deceleration is greatest, and decrease downwards. The resulting downwards pressure gradient at the pier face generates the down flow. The down flow impinging on the bed acts like a vertical jet in eroding a groove immediately adjacent to the front of the pier. The formation of the groove undermines the scour whole slope above the slope into the erosion zone, thus maintaining the slope at the local repose angle of the sediment. The development of the scour hole around the pier also creates a vortex, known as the horseshoe vortex. Dislodged particles are transported away past the pier by the horseshoe vortex. The down flow and horseshoe vortex together are primarily responsible for the scouring. The wake vortices arise from flow separation at the sides of the pier. These vortices are trails downstream, by the mean flow and act like vacuum cleaners transfer up sediment from the bed and also transporting sediment entrained by the down flow and horseshoe vortex.

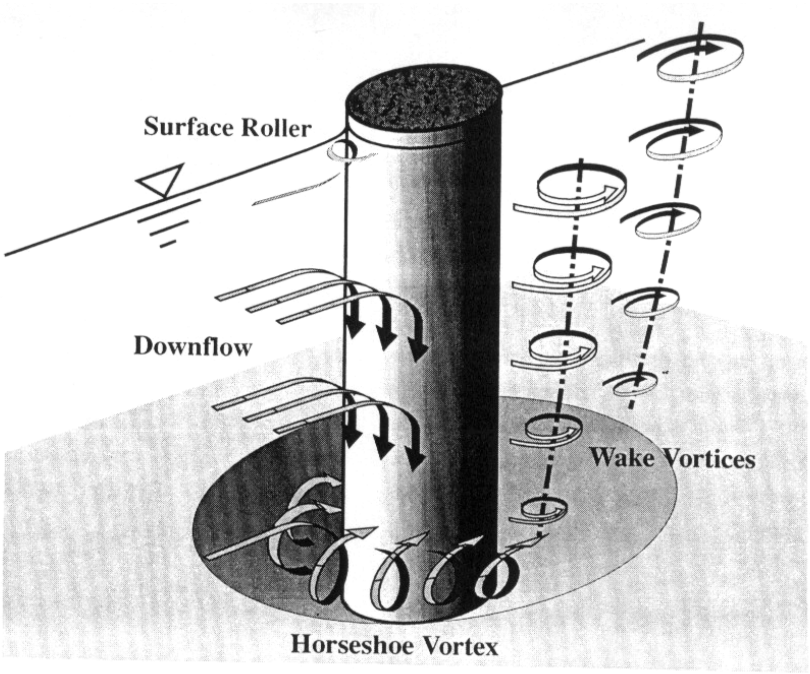

Figure 1 Kinds of vortices and water flow directions that surround piers

STUDY OBJECTIVES

Scour prediction equations are being used for estimating the value of maximum scour depth that will exist around bridge pier. The reliability of these equations has to be studied to identify the ranges or the fidelity for application of these equations. According to the results of this reliability a conclusion regarding the need of using a new approach will be drawn. Then, the selection and use of a new approach can be applied. The current study has three major objectives that can be summarized as follows:

1. Evaluate reliability of the existing scour predictor equations.
2. Study the problem of scour prediction around bridge piers by applying stream power approach.
3. Develop a new predictor using stream power approach and test the reliability of the obtained results by comparing it with the experimental one. Also, these results will be compared with the other ones obtained by applying the available prediction equation.

APPLIED METHODOLOGY

For achieving the first objective some experimental results for scour around bridge piers has been collected and tested versus the available predictor equations. Some of 156 experiments and fifteen predictor equations were tested.

For achieving the second objective a numerical simulation for the problem is performed. Analysis of different parameters that relates the scour escalation and the stream power will be performed.

For achieving the third objective a new predictor is to be developed based on the numerical results analysis and its relationship to the experimental analysis. The new developed predictor will be based on the flow stream power.

EVALUATION OF SCOUR PREDICTORS

The study performed through applying the input data for some scour experiments on the different available predictors. Then, the output results were compared to the results of the experimental data sets. A comprehensive analysis was performed to study the reliability of the different predictors. The evaluation of scour predictors can take place by reviewing scour predictors and the available predictor equations which are classified according to the parameters used, the circumstances and the approach used to derive each of these equations. The next step in the evaluation process is the collection of data that can be used to calculate scour using the scour equations and then to compare the calculated scour depth and the measured in some laboratory experiments for measuring the scour depth scour depth.

Applied Data Sets A and D

Data sets A and D are collected after Abed (1991). 10 experiments were conducted in a 200 ft, long 8 feet width, and 4 feet depth (60m x 2.4m x 1.2m) tilting type flume. The scour experiments were conducted in 40 feet long area which was covered by a well graded pea size gravel bed material. The pier was a model, scale 1:10, it had a well rounded Plexiglas nose and the rest of the material was plywood. The pier model dimensions were 6 feet long and 0.5 foot wide and 3.5 feet height. Velocities were measured using a March- Mcbirney 2-d magnetic velocity meter. The scour depth was measured using a point gauge which was mounted on a moving carriage. The range of Froude no. is 0.1-0.6, the velocities range is 0.8-2 ft/sec and the approach depth range is 0.8 - 2 ft/sec.

Applied Data Sets B and E

Data sets B and E are collected after Abdou (1993).The experimental progress consisted of three major series that were conducted in the flume as of Abed (1991) experiments. Three identical piers were fixed in the flume along the same center line and equally spaced along the flume length. This first set was performed using a graded sand mixture with a geometric standard deviation σ_g of 2.43 and d50 of 0.75 mm. The second set was performed using the same sand with σ_g of 2.43 and d50 of 0.75 mm as the bed material around pier 1. Around piers 2 and 3 the size of coarse material fraction in the original sediment mixture corresponding to 10 % (around pier 2) and to 5 % (around pier 3) was increased. The gradation coefficient, σ_g and d50 were kept constant at 2.43 and 0.75 mm respectively. The third set, was conducted using a sediment mixture with σ_g of 3.4 and d50 of 0.75 mm as the bed material around pier 2 and increasing the coarse fraction above d90 in the same sediment mixture as the bed material around pier 1. For 3, uniform sand with σ_g of 1.38 and d50 of 0.75 mm was used.

Applied Data Sets C and F

For the experimental work a 60 ft long, 2 ft wide and 4 ft deep flume was used. The flume is a recirculation tilting type, the bed slope can be adjusted by a screw jack at the downstream end as shown in fig 4.4 (Elgamal 1991). A an instrument carriage runs longitudinally along the flume rails, and laterally as well a point gage with an accuracy of 0.001 ft is mounted on the instrument carriage. Measurements were taken at fifteen different sections along the flume including a section just upstream of each pier. Three plexi-glass piers of diameters 2.0, 2.0 and 2.75 inches were installed in the flume, equidistant from the walls.

CLASSIFICATION OF DIFFERENT PREDICTORS

The available predictor equations have been classified into six groups. This classification is based on the required information needed to feed the predictors. For example, a predictor may need the bed material gradation while another predictor needs just the mean grain diameter. Accordingly, based on the compatibilities between the available laboratory data and the predictors, the classification of the data and equations is based on the following:

1. Compatibility between the bed gradations for the laboratory set and developed empirical predictors.
2. Compatibility between the flow conditions and Froude number in the laboratory sets and the developed empirical equation.
3. Compatibility between the ratios of the flow depth to pier diameter for the laboratory sets and the developed empirical equations.

ESTIMATION OF LOCAL SCOUR DEPTH AROUND BRIDGE PIERS

Equations describing the conditions of local scour at bridge piers are complex and hence the initial research into the problem was empirical. More recently, attempts have been made at analytical solutions, but they had to rely also on the experimental results.

Equations for estimating local scour are based on two methods of analysis. These methods are:

- a. The regime approach, by using the transport relationships in the approaching flow and in the scour hole.
- b. Regression analysis of the available data, to develop empirical equations.

Regime Approach for Predicting Scour Depth

Regime formulae have been derived empirically from measurements in irrigation canals in India and are supposed to describe the conditions under which these canals are stable for the existing sediment supply.

Algebraic manipulation of regime equations yields the equation:

$$\text{Flow depth} \propto q2/3$$

$$\text{Flow depth} = f\ (\text{flow velocity})$$

It is assumed that the flow depth is the average "flood regime depth" corresponding to average discharge intensity at flood stage "q". Then the maximum scour depth at an obstruction can be estimated by multiplying this flood regime depth by a factor dependent on the geometry of this obstruction, but generally of the order of 2 or 3. An important assumption in the regime approach is that the maximum scour is dependent upon some mean flow intensity. Among the researchers that used this approach to develop the scour prediction equation were Breusers (1965), Blench (1965), Chitale (1944), Inglis- Poona (1938), Inglis-lacey (1949).

Empirical and semi theoretical approach

This approach based on balancing the sediment continuity equation. Fundamental to all attempts to predict local scour based on the sediment continuity equation are:

1. An estimation of the strength of the mechanism of local scour, and the Potential for scour in the vicinity of the pier.
2. An estimation of the sediment transport into the scour hole and its effect on limiting the extent of the local scour.
3. An estimation of the rate at which the hole is deepened.

The success which has been achieved is limited by the number of approximations which must be made in order to get through step 4. Most of the equations were derived by analyzing experimental data and expressed them in a dimensionless form. Among the researchers that used this approach to develop the scour prediction equation were Laursen (1956, 1962, 1963), Shen (1966-1969), Hancu (1971), CSU's equation (1975), Breusers et al. (1977), Baker (1980), Jain and Fisher (1980), Froehlich (1987) and Froehlich (1988).

Prediction accuracy test

The root mean square error (R.M.S.E.) test has been performed for each prediction results versus the laboratory measured data.

The RMSE can be expressed mathematically by the following equation:

$$R.M.S.E = \sqrt{\sum \frac{(Y_M - Y_s)^2}{N}} \qquad (1)$$

in which:

Y_M = measured scour depth in the laboratory experiments.
Y_s = calculated scour depth by any of the selected predictors.
N = total number of observations.

Accordingly, a comparison between the different equations will be based on the value of R.M.S.E. for prediction the whole set of data , the longer the number, the lower the accuracy of prediction will be example of all of the predicted value are exactly equal to the measured data in the laboratory , this indicates that the predictor is perfect. The R.M.S.E. will be equal zero. Figure (2) and Table (1) present samples for results for comparison between the calculated scour depths versus the measured one. It is very clear from Table (1) that the RMSE is indicating high discrepancy between the measured and calculated scour depths. The original study was performed on hundreds of experiments and the scour depths were calculated using different predictor. As a conclusion, it can be strongly stated that none of the available predictors are giving reasonable prediction for scour depth. For example, an equation can give good result in for a certain range of experiments however for another set of experiments the results are completely away from the actual data. This indicates that none of the available predictors are considered reliable and can be applied at different conditions.

Table 1 Values of Root Mean Squared Error for the Predicted Depth of Scour versus the Laboratory Values of Scour Depth Using different predictors for Sets A, B and C

Predictor	Applied Laboratory Set	R.M.S.E.
Breusers	SET A	0.4737
Chitale	SET A	0.6336
C.S.U.	SET A	0.3797
Froehlich 87	SET A	0.3814
Ingles Poona	SET A	0.7983
Ingles Lacey	SET A	0.3786
Laursen	SET A	0.478
Neill	SET A	1.643
Shen	SET A	3.7034
Breusers	SET B	0.518
C.S.U.	SET B	0.343
Ingles Lacey	SET B	4.2778
Shen	SET B	1.0344
Breusers	SET C	0.3941
C.S.U.	SET C	0.3277
Ingles Lacey	SET C	0.4452
Shen	SET C	0.9715

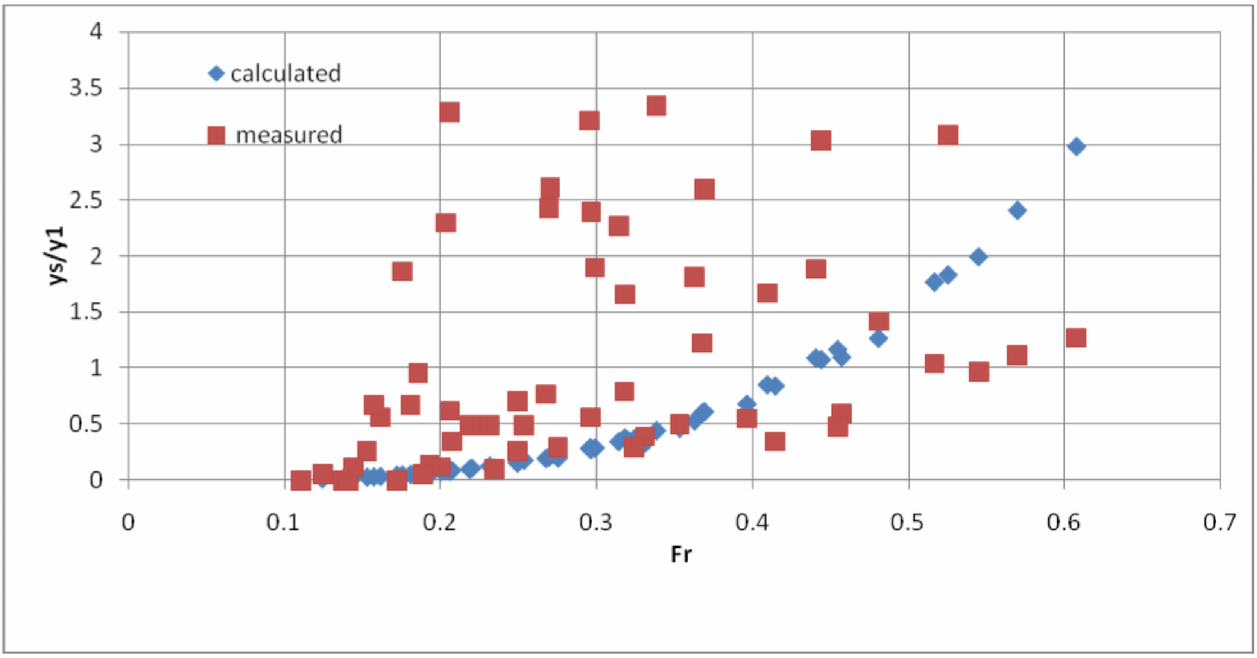

Figure 2 Comparison between y scour measured by Noshi (1993) and y scour calculated using Abed 4.5 equation (1991)

DEVELOPING OF A NEW PREDICTOR FOR ESTIMATING SCOUR AROUND BRIDGE PIERS APPLYING STEAM POWER APPROACH

The current section introduces the developing steps and the application of a new predictor for estimating scour around bridge piers using the stream power approach. In what follows the description of the development steps which starts by simulating some of laboratory experiments for scour around bridge piers on HEC-RAS numerical model. The simulation, calibration and verification of these experiments are introduced then, a proposed flow chart describing how the user will apply the stream power approach to estimate the scour value at bridge piers will be introduced. This step is applied on two different sets of experiments in each set some data points are left for verification and testing the reliability of the new proposed technique. Finally, conclusions regarding the application of the new system on the problem of local scour around bridge piers in the clear water condition are drawn.

Basic assumptions of new prediction development

The major idea for developing a new predictor using stream power approach depends on the principle that can be described as following:

- The major reason that cause scour can be translated through the variation of stream power value around the pier before and after scour.
- Before scour there is a high value of stream power around the pier.
- This value of stream power is higher than the critical stream power that can initiate the sediment movement.

- If this value of stream power is less than the critical stream power for the bed material no scour will be initiated.
- As long as the scour starts, the scour hole enlarges by getting wider and deeper.
- The stream power is varied along with the enlargement of the scour hole. The deeper and wider the hole the lesser is the stream power.
- Scour stops when the stream power value is less or equal the critical stream power of the sediment material.

Development of stream power prediction

For developing the stream power prediction two sets A and B of experimental work are used herein. These experiments have been simulated on HEC-RAS simulation model. Some of experiments are selected for calibration and verification purpose. After being sure that an artificial scour hole around bridge piers are steply developed the artificial scour holes are developed for an imaginary values as a percentage from the final values of scour. Moreover, for research purpose the artificial scour extends behind the final scour values. The stream power charts versus the different values of flow conditions and scour depths are developed. In what follows a complete description for development steps and a comparison between the measured scour depth and the calculated scour depth by the new method is compared.

Numerical model (HEC-RAS)

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities. The HEC-RAS system ultimately contain three one-dimensional hydraulic analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; and (3) movable boundary sediment transport computations. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. The following is a description of the major capabilities of HEC-RAS. The calibration is performed through adjusting the water surface profile in the numerical model and the experimental results. The adjusting of water surface profile is done by changing manning roughness coefficient until the water surface profiles in the model and experimental are coincides.

Applied Data Sets for Developing the New Approach

Ten experiments performed by Abed (1991) are used herein for the purpose of completion the current study. In this set of experiments velocity ranges from 0.93 m/s to 2.79 m/ s while Fr ranges from 0.189 up to 0.433. The minimum scour depth is zero and the maximum scour depth is 25.74 cm. it was assumed that the width of scour hole is constant as the width is one of the factors that affects the variance of stream power so in order that we take in consideration the relationship between stream power and scour depth only so we assumed that the width is constant.

Stream power variation in the scour problem

As mentioned before artificial scour holes are performed and simulated using HEC-RAS. For the current set of data that are selected, only 6 experiments are used for developing the predictor while the remaining 3 experiments are left for testing and verifying the new proposed system. However, it can be said that this number of experiments is too small to develop such new prediction but it can be considered as an inception step for more studying.

At this section the relationship results from the analysis of different experiments and developed relationship between the scour progress and the stream power will be introduced. HEC-RAS simulations for each run of the following runs are performed and listed in the following Table (2).

Table 2 A Summary for the selected experiments that are used in developing the new approach

Run	Y_1(cms)	V_1 (cms/s)	Q (cms^3/s)	F_r	Y_s (cms)
1	24.38	30.48	195.07	0.20	0.00
6	24.38	45.72	292.61	0.29	3.26
7	24.38	60.96	391.67	0.39	10.94
2	24.38	91.44	585.22	0.59	22.28
8	48.77	45.72	587.96	0.21	2.53
3	48.77	60.96	800.71	0.28	12.28
4	48.77	91.44	1214.63	0.43	24.66
9	60.96	45.72	740.66	0.19	1.34
10	60.96	60.96	985.72	0.25	10.30
5	60.96	91.44	1496.87	0.39	25.69

In which Y_1 is the approach depth, V_1 is the approach velocity Q is the discharge passing through the flume and Y_s is the scour depth happened

The ten experiments are simulated through HEC-RAS with the different flow parameters. Artificial scour holes have been proposed around the bridge piers. The scour depth for each case is varied from zero scour to 25.745 cm. The scour depth has 9 different values starts from zero, 7.63, 15.27, 22.91, 30.54, 38.17, 45.81, 53.44, 61.08 cm respectively. In addition, for each depth a complete formation of scour hole around the pier is proposed following the natural shape of the scour hole around the pier. Running the HEC-RAS for each case, the results are presented in the following tables attending with a brief discussion. Tables (3, 4 and 5) present the stream power variation during the scour depth formation at different depths with the same upstream flow depth for approach depth = 24.43 cm.

Table 3 A Sample of Results for stream power calculated by HEC-RAS versus the different values for Y_s for run no. 6

Y_s (cms)	0	7.635	15.27	22.905	30.54	38.175	45.81	53.445	61.08
S.P. N/m.s.	0.21	0.18	0.16	0.14	0.13	0.12	0.11	0.1	0.09

Table 4 A Sample of Results for stream power calculated by HEC-RAS versus the different values for Y_s for run no. 7

Y_s (cms)	0	7.635	15.27	22.905	30.54	38.175	45.81	53.445	61.08
S.P. N/m.s.	0.49	0.42	0.37	0.33	0.3	0.27	0.24	0.22	0.2

Table 5 A Sample of Results for stream power calculated by HEC-RAS versus the different values for Y_s for run no. 2

Y_s (cms)	0	7.635	15.27	22.905	30.54	38.175	45.81	53.445	61.08
S.P. N/m.s.	1.58	1.31	1.11	0.97	0.86	0.77	0.69	0.62	0.57

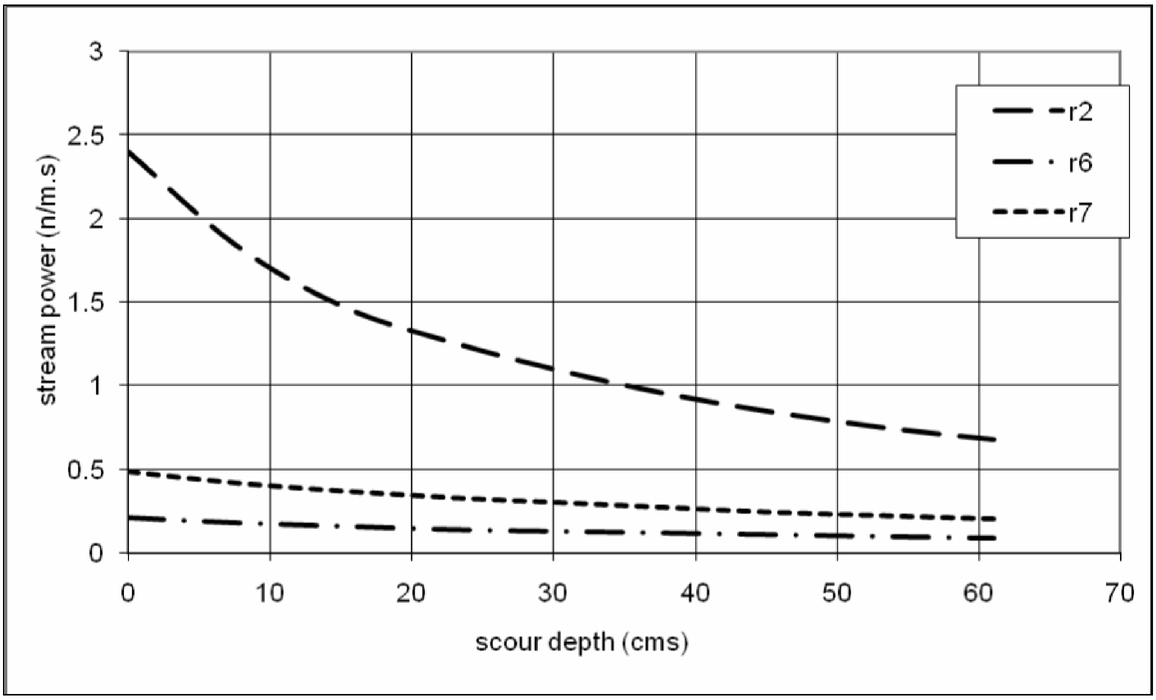

Figure (3) The relationship between scour depth and the calculated stream power for the group of experiments that have the same approach flow depth

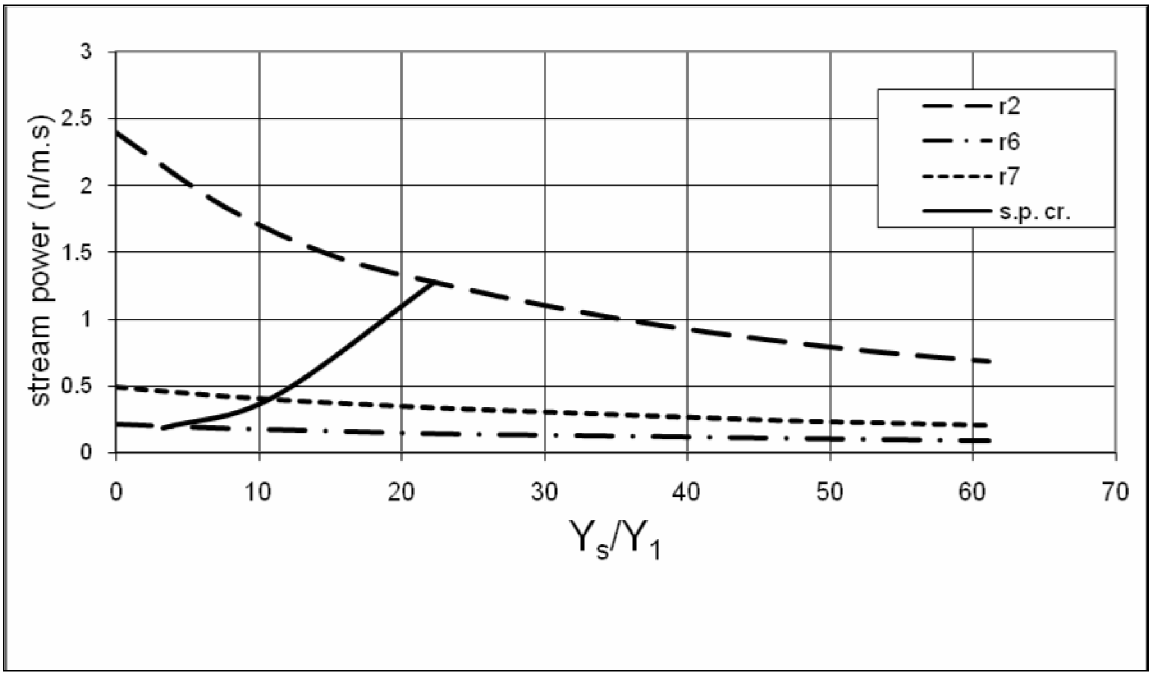

Figure (4) The relationship between scour depth and the calculated stream power for the group of experiments that have the same approach flow depth and shows the critical stream power value at which the scour stopped (calculated using HEC RAS)

Relationship between actual scour and stream power

As mentioned before, the main issue in the current study is to develop a new predictor using the stream power approach. Accordingly, the final scour depth already happened in the experimental work should be pointed out on the stream power versus the scour depth graph. Thus, the point of intersection between the actual scour occurs in the experimental and its adjacent stream power values calculated from HEC-RAS simulation results in a curve that is shown in Figure (3). In Figure (4) the dotted curve indicates the line where the value of the critical stream power is lying on. In other words, this curve presents the line when the scour stops which means that the stream power exists in the flow conditions around the bridge pier reaches to a value less than the value of inception motion. Thus it can be concluded that the intersection of the vertical line results from the actual value of scour and the calculated stream power from HEC-RAS based on the actual depth of scour.

The previous system has been repeated for the other two groups with different approach flow depth of 61.08 and 48.08 respectively. This is presented as follows.

Results of stream power for approach depth 48.08

Table 6 A Sample of results of stream power calculated by HEC-RAS versus the different values for Y_s for run no. 3

Y_s (cms)	0	7.635	15.27	22.905	30.54	38.175	45.81	53.445	61.08
S.P. N/m.s.	0.44	0.42	0.4	0.38	0.36	0.34	0.32	0.31	0.29

Table 7 A sample of results of stream power calculated by HEC-RAS versus the different values for Y_s for run no. 8

Y_s (cms)	0	7.635	15.27	22.905	30.54	38.175	45.81	53.445	61.08
S.P. N/m.s.	0.18	0.17	0.16	0.15	0.14	0.14	0.13	0.12	0.12

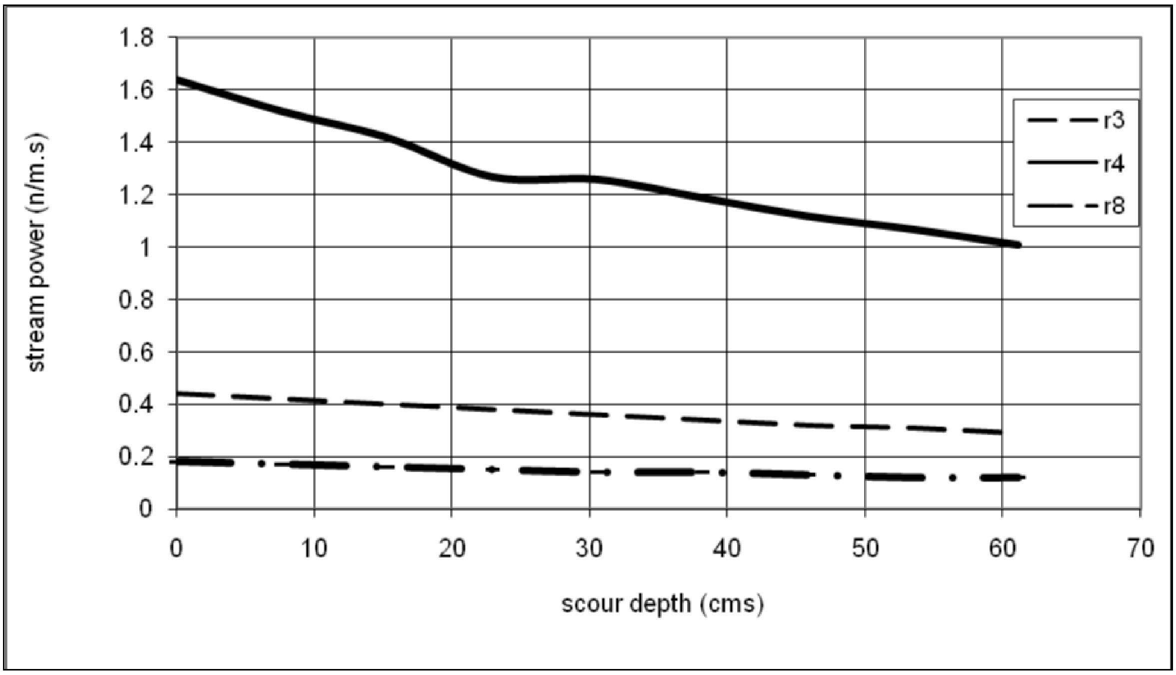

Figure 5

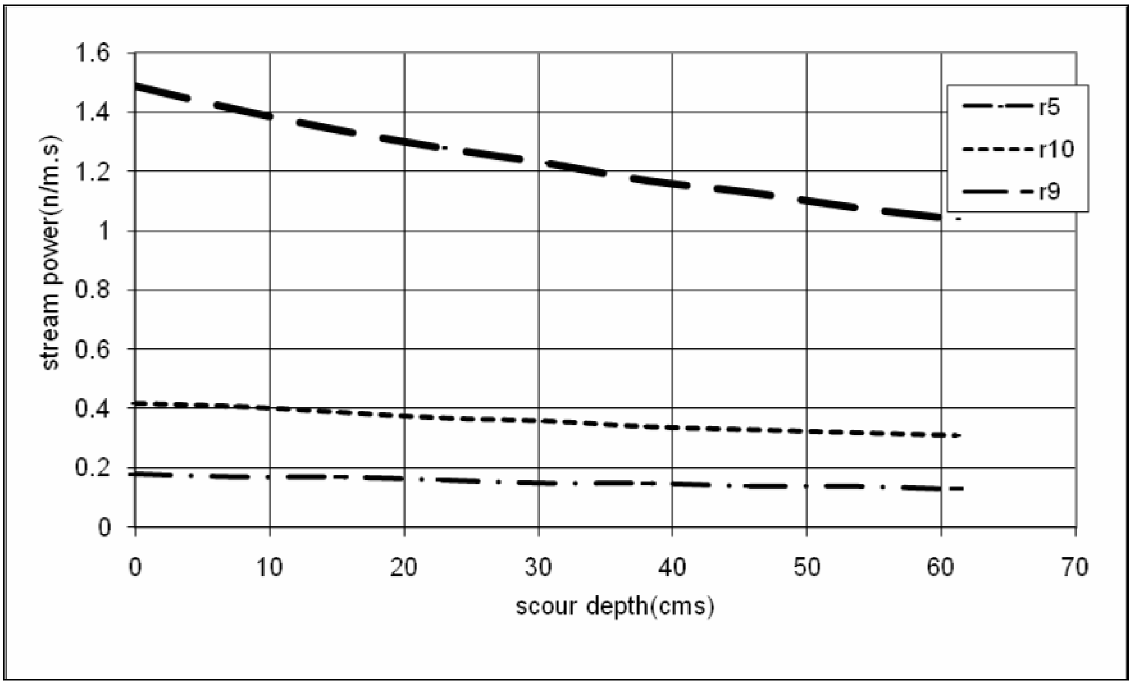

Figure 6

Figure (5), (6) The relationship between scour depth and the calculated stream power for the group of experiments that have the same approach flow depth (R5, R9 and R10) and (R3, R4 and R8)

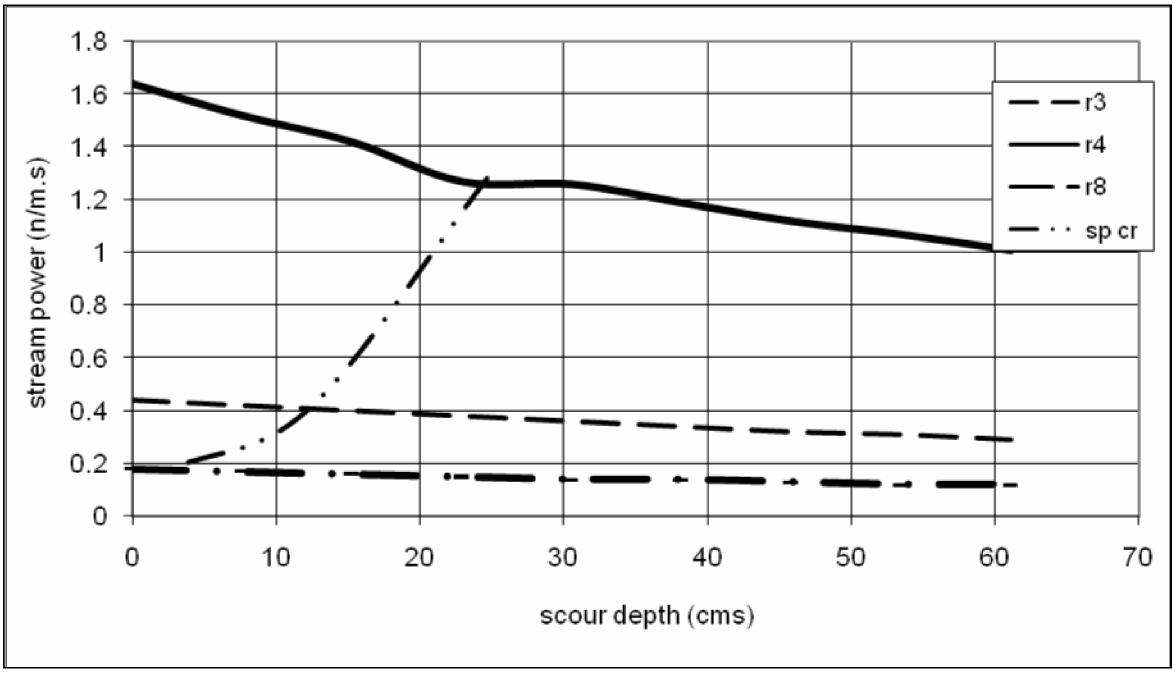

Figure 7

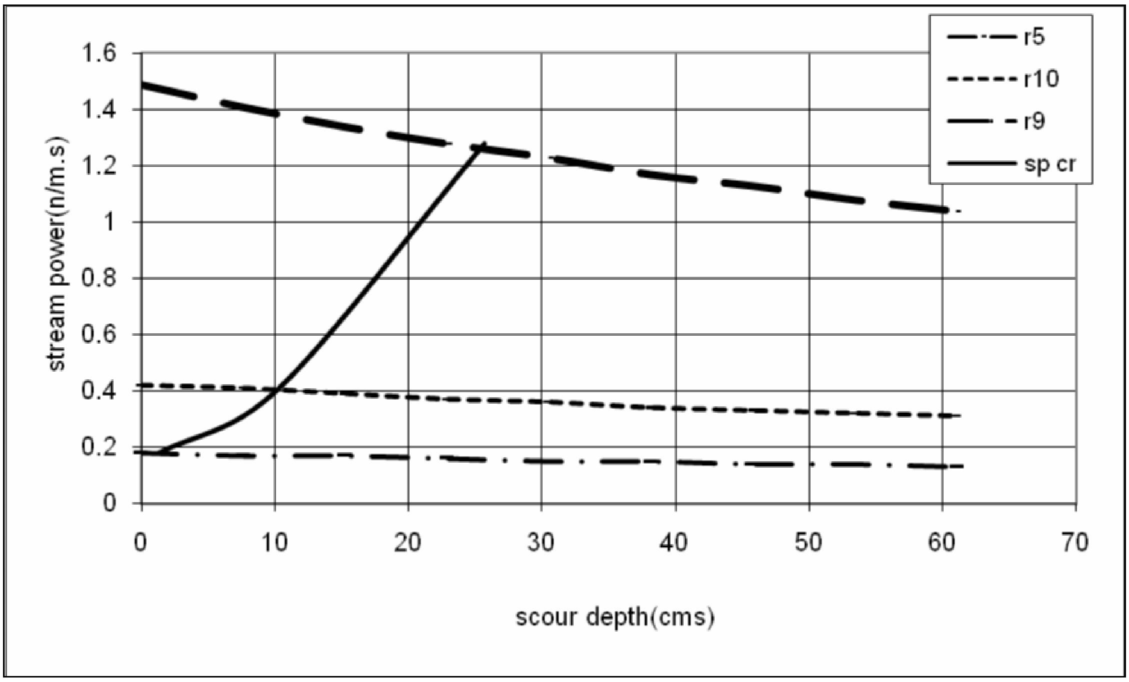

Figure 8

Figures (7), (8) The line of critical stream power for the group of experiments that have the same approach flow depth (R5, R9 and R10) and (R3, R4 and R8)

PREDICTING OF SCOUR DEPTH USING STREAM POWER APPROACH

1. As presented in the previous Figures (4, 5, 6, 7 and 8) and tables (4, 5, 6 and 7) it can be concluded that the stream power has a significant trend during the scour progress. The following Figure 9 represents a schematic diagram showing how the stream power is varied along with the scour progress for a hypothetical three runs a1, a2, and a3. From this Figure the following can be summarized and concluded: Stream power has the maximum value at the initial scour value $Y_s=0$.
2. The stream power decreases while the scour depth increases.
3. The higher the velocity the higher the stream power is.
4. A line named the line of critical stream power can be drawn by joining all the projection of scour depth on the scour-stream power curve for the different values of velocities.
5. For the same velocities there is a horizontal line can be drawn representing the equal-velocities lines where a constant value of stream power is existing?

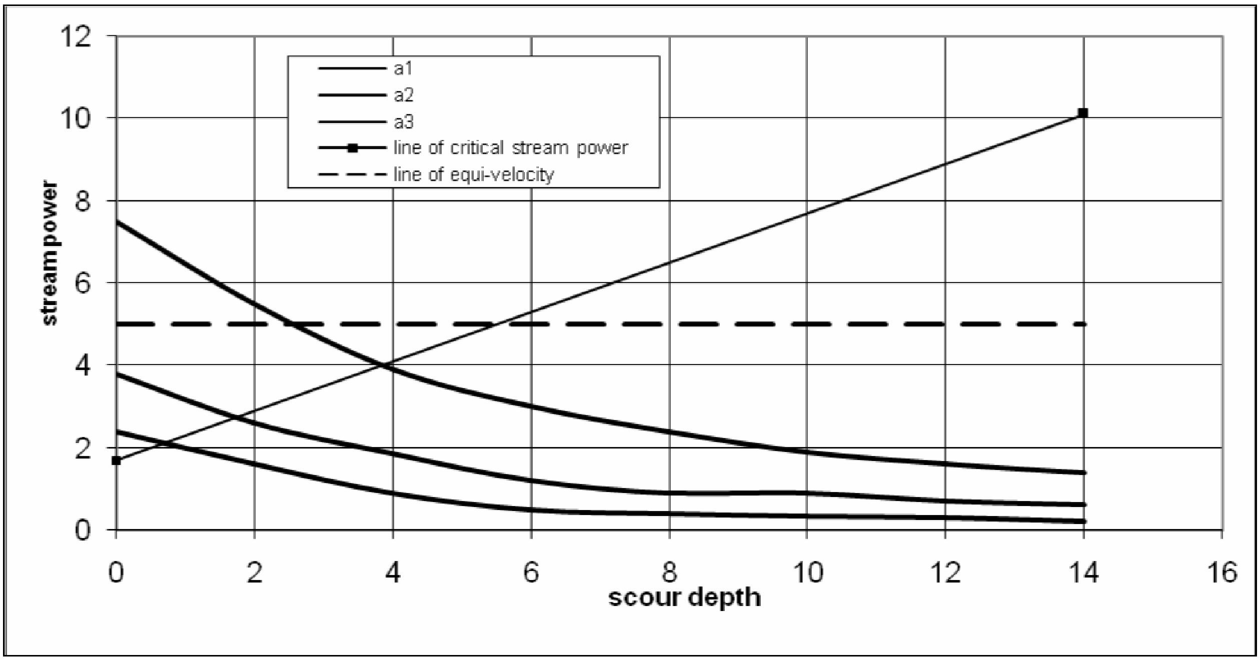

Figure (9) The relationship between scour depth and stream power

Applying the new approach

The application on the predicting of scour values for three runs number R3, R4 and R8 will be introduced.

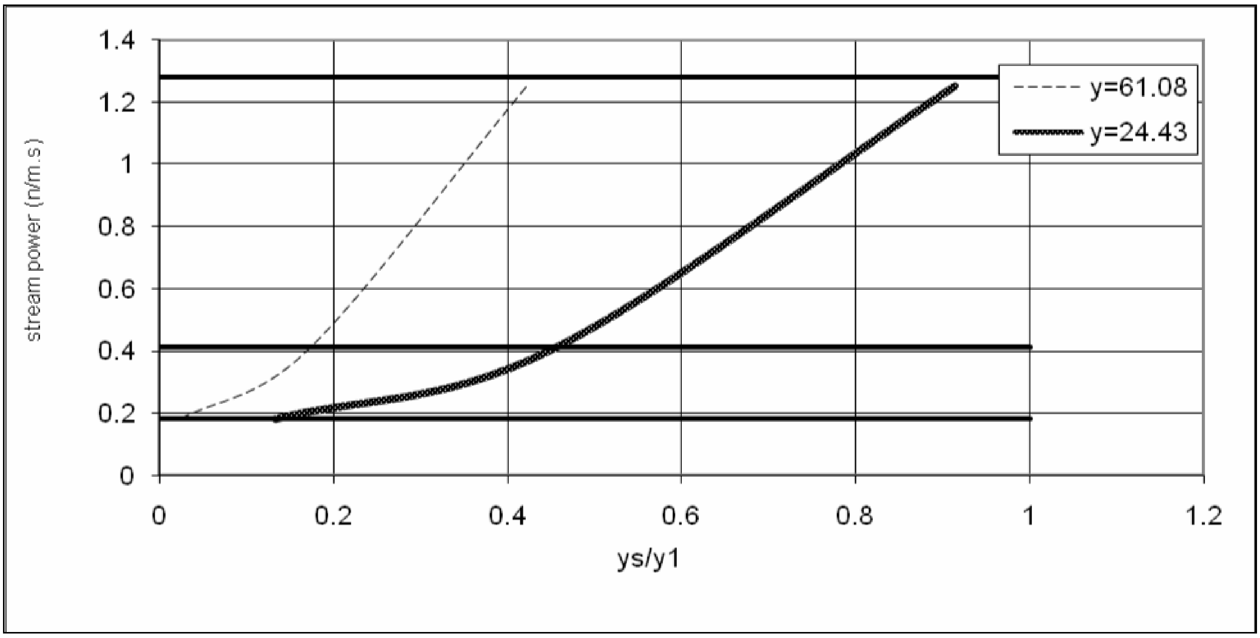

Figure (10) Critical stream power for approach flow depth of 24.43 and 61.08 showing the lines of equivelocities for the same pier dimensions and flume conditions

The prediction starts with the following steps

1. Define the required discharge.
2. Simulate the pier with its surrounding hydraulic condition using HEC-RAS.
3. Getting value of approach velocity and the adjacent stream power value.
4. Go to Figure (10) and by linear interpolation estimate the value of the scour depth from getting the value of Y_s/Y_1.

Example 1

A flume of 2.4 widths, the discharge is 0.549 m^3/s and the approach flow depth is 48.86 cm. The pier is 10 cm diameter and is a circular pier. Estimate the scour depth if you know that the grain size is a fine gravel with d 50 = 3.2 mm and $\sigma_g = 2$.

Solution

1. Simulate flow condition, pier on HEC-RAS simulation model.
2. The approach flow depth is 48.80 cm.
3. Approach flow velocity is 45 cm/s.
4. Stream power (with no scour condition) is 0.175 n/m.s.
5. From Figure (10) the interpolation between the two curves for $Y_1 = 61$cm and $Y_1 = 24.43$ cm respectively and following the equi-velocity line of 45 cm/s. the value of $Y_s/Y_1 = 0.058$.
6. The value of expected scour is = 2.88 cm.
7. The measured scour depth = 2.53 cm.
8. The difference between measured and calculated scour = +13%.

Example 2

A flume of 2.4 widths, discharge is 0.748 m^3/s and the approach flow depth is 48.86 cm. The pier is 10 cm diameter and is a circular pier .estimate the scour depth if you know that the grain size is a fine gravel with d 50= 3.2mm σ_g =2.

Solution

1. Simulate flow condition, pier on HEC-RAS simulation model.
2. The approach flow depth is 48.80 cm.
3. Approach flow velocity is 61 cm/s.
4. Stream power (with no scour condition) is 0.41 n/m.s.
5. From Figure (11) the interpolation between the two curves for Y_1 = 61cm and Y_1 = 24.43 cm respectively and following the equi-velocity line of 60 cm/sec. the value of Y_s/Y_1 = 0.25.
6. The value of expected scour is = 0.25*48.86 = 12.25.
7. The measured scour depth = 12.31 cm.
8. The difference between measured and calculated scour = 0.4%.

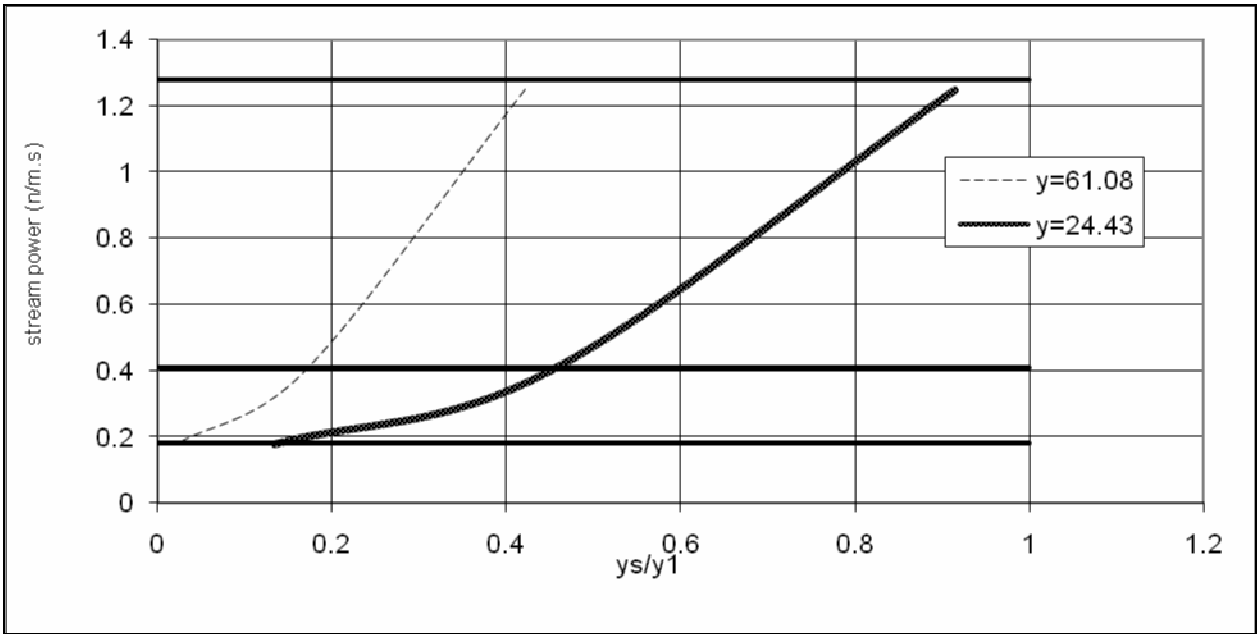

Figure (11) Critical stream power for approach flow depth of 24.43and 61.08 showing the lines of equi-velocities for the same pier dimensions and flume conditions

Example 3

A flume of 2.4 widths, discharge is 1.135 m^3/s and the approach flow depth is 48.86 cm. The pier is 10 cm diameter and is a circular pier. Estimate the scour depth if you know that the grain size is a fine gravel with d 50 = 3.2 mm and σ_g = 2.

Solution

1. Simulate flow condition, pier on HEC-RAS simulation model.
2. The approach flow depth is 48.80 cm.
3. Approach flow velocity is 91.6 cm/s.

4. Stream power (with no scour condition) is 1.28 n/m.s.
5. From Figure (12) the interpolation between the two curves for Y_1 = 61cm and Y_1 = 24.43 cm respectively and following the equi-velocity line of 100 cm/s. the value of $Y_s/Y_1 = 0.56$.
6. The value of expected scour is = 0.56*48.80 = 27.328 cm.
7. The measured scour depth = 24.707 cm.
8. The difference between measured and calculated scour = +10%.

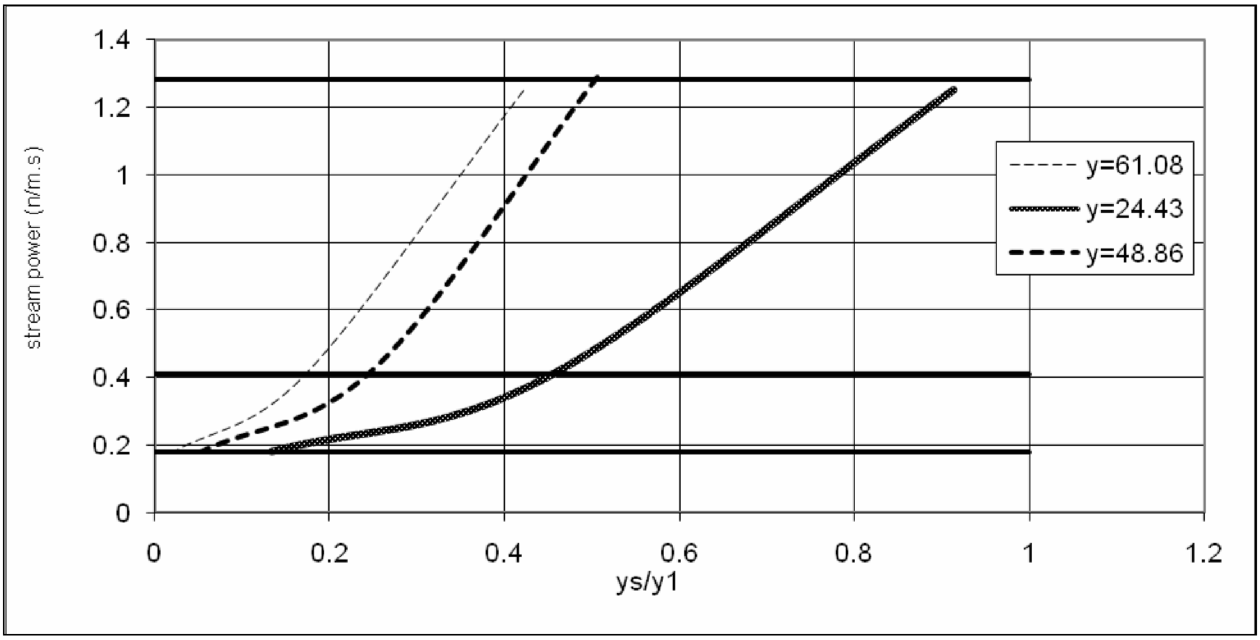

Figure (12) Critical stream power for approach flow depth of 24.43 and 61.08 showing the lines of equi-velocities for the same pier dimensions and flume conditions

CONCLUSIONS

The main conclusions from the current study could be summarized as follows:

1. Testing of 12 common predictors for scour around bridge piers shows that the reliability of applying these predictors is considered very law.
2. Stream power approach has been applied to develop a mew technique for estimating scour value around bridge piers.
3. The new technique using stream power shows a good reliability in estimating the value of scour around bridge piers. However, the study was limited to the clear water scour conditions for cohesive less soil.
4. The new technique has been tested and applied for about 24 experimental results, that were randomly selected, and the output shows remarkable less scattering in prediction compared to the existing empirical predictors.

RECOMMENDATIONS FOR FUTURE STUDIES

On the basis of the results of the current study, the following recommendations for future studies are made:

1. Future research is needed to apply the stream power approach on the pier scour problem for more flow conditions, such as live bed conditions.
2. Further studies are needed until a new prediction equation can be developed.
3. The study can be extended to the problem of scour around bridge abutments and downstream of hydraulic structures.

REFERENCES

Abed, I., (1991), "Local Scour around Bridge Piers in Pressure Flow" PhD. Thesis, Colorado stat University, Fort Collins, Colorado, U.S.A.

Abdou, I. (1993), "Affect of sediment gradation and coarse material fraction on clear-water scour around bridge piers" Ph.D. Thesis, Colorado stat University, Fort Collins, Colorado, U.S.A.

Abdou, M., (1995), "Local scour at Bridge Piers –review and background on Pier scour – compilation of Bridge Scour Data" Report No. 23 Hydraulics Research Institute, National Water Research Center, Qanater, Cairo, Egypt.

Abdou, I., (1995), "Shear stress and stream power distribution around vertical wall abutments" PhD. Thesis, Colorado State University, Fort Collins, Colorado, U.S.A.

Breusers, H. N.C., Nicollet, G. and Shen, H.W., (1977), "Local Scour around Cylindrical Piers", Journal of Hydraulic Research, pp. 211-252.

Eltahan, A. H., (2004) "Scour Around Bridge Piers Applying Stream Power Approach" M.Sc. Thesis, Ain Shams University, Cairo, Egypt.

Froelich, D.C., (1987), "Local Scour at Bridge Piers Based on Field Measurement", U.S. Geological Survey, Water Resources Division. (Quoted from Abed, I., (1991)).

Froelich, D.C., (1988), "Analysis of Onsite Measurements of Scour at Piers", proceedings of ASCE National Hydraulic Engineering conference, Colorado Springs, Co, pp. 534-539. (Quoted from Abed, I., (1991))

Hancu, S., (1971) "Sur le calcul des affouillements locaux dams la zone des piles des ponts" Proc., 14th. I.A.H.R. Congress, Paris, France, Vol. 3, 299-313 (Quoted from Melville, B.W. and Stephen E. Coleman (2001))

Kheireldin, K. A., (1994) "Shear stress and stream power distribution around vertical wall abutments" PhD. Thesis, Colorado stat University, Fort Collins, Colorado, U.S.A.

Laursen, E. M. and A. Toch, (1952), "A Generalized Model study of Scour around Bridge Piers and Abutments", Proceedings Minnesota International Hydraulics Convention, pp. 123-131.

Laursen, E. M. and A. Toch, (1956), "Scour Around Bridge Piers and Abutments", Bulletin No. 4, Iowa Highway Research Board.

Laursen, E. M., (1962), "Scour at Bridge Crossings", Transactions ASCE, Vol. 127, pp. 166-209.

Melville, B.W. and Stephen E. Coleman (2001), "Bridge Scour" Water Resources Publications, llc.

Noshi, H. M., (1993),"Experimental study on the effect of sediment gradation and flow hydrograph on clear water local scour around circular bridge piers", Msc. Thesis, Colorado state University, Fort Collins, Colorado, United States of America.

Neill, C.R. (1964), “River bed scour-A review for engineers,” Canadian Good Roads Association, Technical Publication No. 23. (Quoted from Melville, B.W. and Stephen E. Coleman (2001)).

Shen, H.W. and Schneider, V.R. and Karaki, S.S. (1966) "Mechanics of local scour,"U.S. Department of commerce, National Bureau of Standards, Institute for Applied Technology (quoted from Melville, B.W. and Stephen E. Coleman (2001))

Gary W. Brunner (2002), "HEC-RAS, River Analysis System User's Manual" US Army Corps of Engineers, Hydrologic Engineering Center (HEC), 609 Second Street, Davis, CA 95616-4687.