EVALUATION OF LOCAL SCOUR AROUND BRIDGE PIERS (RIVER NILE BRIDGES AS CASE STUDY)

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ABSTRACT

The construction of any river obstruction has some morphological impacts on the river bed and flow as it implies some disturbance to the river water flow. This disturbance causes local scour to occur due to bridge construction. It is very essential to estimate, measure, monitor, and mitigate (if necessary) these impacts. River Nile has many bridges constructed along its course from Aswan till the Mediterranean Sea. For this research, two bridges were considered as two study cases for bridges constructed along the River Nile; Aswan Bridge and EL Minia Bridge. The two bridges are considered two major bridges and so their impacts should be studied and evaluated. The impacts of the bridge construction are evaluated from the bed survey during different periods including the recent hydrographic survey for the River Nile. Mathematical modeling was used to evaluate the expected local scour. The computer model HEC-RAS (developed by the US Army Corps of Engineers), was used to evaluate local scour around the bridge piers. Conclusions and recommendations were highlighted.

Keywords: River Nile Bridge, local scour, Aswan Bridge, El Minia Bridge

INTRODUCTION

The interference of the flow in any river affects the equilibrium of the river natural flow. This means that the river may react adjusting itself to a new behavior. The construction of any bridge affecting the flow conditions is considered a sort of flow interference. The flow interference may cause some scour and degradation in addition to possible changes in water surface profile.

Local scour

Local scour is the scour of bed materials. Some examples of the local scour are the local scour around piers, abutments, spurs, embankments, bends, and downstream hydraulic structures. In the present research, local scour around bridge piers and abutments was analyzed.

The factors affecting the magnitude of the local scour depths at piers and abutments are listed as follows:

1 - Velocity of the approach flow,

2 - Depth of flow,
3 - Width of the pier,
4 - Discharge intercepted by the abutment and returned to the main channel at the abutment,
5 - Length of the pier if skewed to flow,
6 - Size and gradation of bed material,
7 - The angle of attack,
8 - Shape of pier or abutment, and
9 - Bed configuration.

COMPUTING PIER SCOUR

Estimations of scour depth have been based on the experimental work due to the complexity of evaluating flow pattern around piers and shear forces generated by flow pattern. One of the most widely local scour estimates is the Colorado State University (CSU) equation for predicting maximum pier scour depths, the equation is (ASCE, 1975):

$$Y_s/Y_1 = 2.0\ k_1\ k_2\ k_3\ k_4\ (A/Y_1)^{0.65}\ Fr_1^{0.43} \qquad (1)$$

for round nose piers aligned with the flow:
in which:

Y_s = Scour depth, m
Y_1 = Flow depth directly upstream of the pier, m
K_1, K_2, K_3, and K_4 = Correction factors for pier nose, angle of attack, bed condition, and armoring by bed material size respectively.
A = Pier width, m
L = Length of pier, m
Fr_1 = Froude Number directly upstream of the pier.
$Y_s \leq 2.4$ times the pier width (A) for $Fr \leq 0.8$
$Y_s \leq 3.0$ times the pier width (A) for $Fr > 0.8$

Aswan Bridge

Aswan Bridge was constructed crossing the Nile River, near Aswan city, at a site located 19.07 km to the north of the Old Aswan Dam on 1998. The River Nile at the bridge site is almost straight. The river width is varied from 470 m upstream area the bridge to 750 m at the downstream. However, the channel width at the bridge axis was about 550 m. The bridge is supported on six supports across the river; two main piers at the middle and another two on each side of the river. The width of the two main middle piers is 25 meters while the width of the four other secondary piers is about 8 meters. The span between the two main middle piers is 250 m; however the other spans are 76 m and 49 m respectively on each side. The two main piers and the western piers are located on the main channel while one of the eastern secondary piers is located out of the river channel and another one is located on the shallow eastern area of the river channel. The piles carrying the bridge are 1.10 meters diameter and embedded to a depth of 30 meters under the river bed during construction. The structural factors of safety are computed that the local scour not to exceed 8.00 meters (General Authority of Highway, Bridges and transport, 2006).

El-Minia Bridge

El-Minia bridge was constructed crossing the Nile River, to join old and new El-Minia city, at a site located 243.700 km upstream Roda Gauging Station on 1987. The total length of El-Minia Bridge is about 1803 m; it consists of 15 vents with a width of 40 m. The navigational vents widths are about 62.00, 50 m. The maximum navigational height is 13 m above the highest water level of River Nile. The total road width on the bridge is about 21 m. The bridge piers located in river channel are eight piers. The piles carrying the bridge are 1.20 meters diameter and embedded to a depth of 18 meters under the river bed during construction. The structural factors of safety are computed that the local scour not to exceed 8.00 meters (General Authority of Highway, Bridges and transport, 2006).

LOCAL SCOUR COMPUTATIONS

Computer Model

HEC-RAS computer model (US Army Corps of Engineers, 2001) was used for local scour computations. This model is developed by the US Army Corps of Engineers. It is a one-dimensional model able to simulate steady, unsteady and sediment transport for movable boundary conditions. The model is first calibrated using the actual available data, then it is used to simulate flow conditions and compute local scour due to the construction of the analyzed Bridges. The model data include the following: The actual cross sections before the bridge construction, the bed material grain size distribution, the discharge down stream boundary conditions, bridge geometry, and the analyzed discharges. The analyzed discharges have to be determined from historical data.

Reach One discharges

Figure 1 shows the frequency diagram for the discharges downstream Old Aswan Dam. This diagram is computed from the daily discharge data for the period January 1995 up to December 2005 (NRI, 2007) to include the most recent period of maximum and minimum discharges. It is based on discharge increment of 10 million cubic meters per day. The minimum discharge for this reach is 60 million cubic meters per day, the average discharge for this reach is about 164 million cubic meters per day. The maximum recorded discharge for this period is 275 million cubic meters per day. This discharge is the maximum recorded discharge for this reach for the period after the High Dam construction. From this figure, it can be noticed that the frequency for the discharge 270 million cubic meters per day (265-275) million cubic meters per day is about 2.28 % for this period. This discharge has occurred for about 79 days during the period January 1995 up to December 2005. The discharge 270 is considered for this study as the maximum occurred discharge for the local scour evaluation. The maximum expected future discharge for this reach is 350 million cubic meters per day.

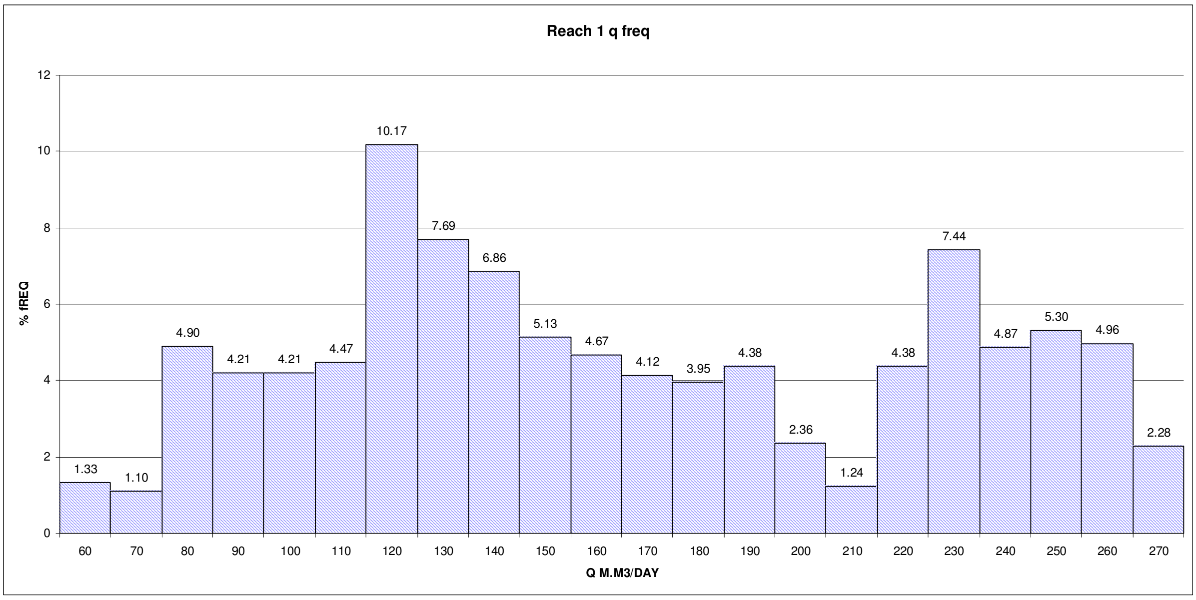

Figure 1. D.S. Aswan Dam discharge Frequency distribution

Reach Four discharges

Figure 2 shows the frequency diagram for the discharges down stream Assiut Barrage. This diagram is computed from the daily discharge data for the period January 2000 up to December 2005 (NRI, 2007) to include the most recent period of maximum and minimum discharges. It is based on discharge increment of 10 million cubic meters per day. The minimum discharge for this reach is 33.5 million cubic meters per day, the average discharge for this reach is about 110.7 million cubic meters per day. The maximum recorded discharge for this period is 184.7 million cubic meters per day. This discharge is the maximum recorded discharge for this reach for the period after the High Dam construction. From this figure, it can be noticed that the frequency for the discharge 180 million cubic meters per day (175-185) million cubic meters per day is about 3.56 % for this period. This discharge has occurred for about 78 days during the period January 2000 up to December 2005. The discharge 180 is considered for this study as the maximum occurred discharge for the local scour evaluation. The maximum expected future discharge for this reach is 350 million cubic meters per day.

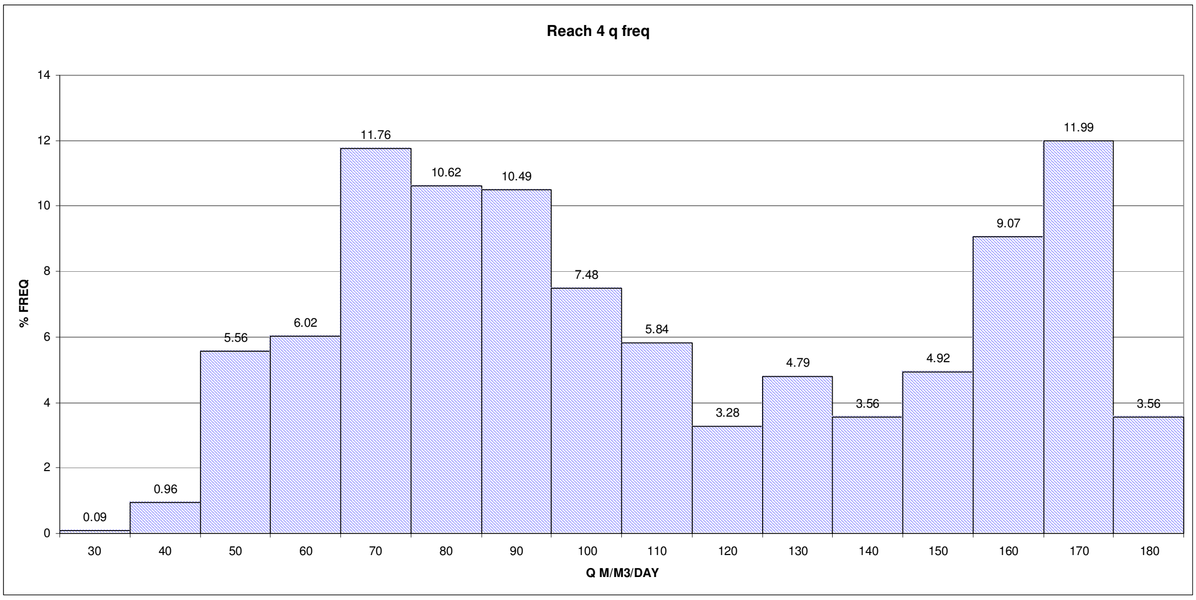

Figure 2. D.S. Assiut Barrages discharge Frequency distribution

MODEL CALIBRATION

Reach One

Figure 3 shows the model calibration for this reach, it shows the measured data and the predicted model results for this reach for the two discharges 250 and 350 million cubic meters per day. Discharge 250 million cubic meters per day was used for model calibration since it is close to the 270 million cubic meters per day and it has occurred with higher frequency 4.96 % and the resulted roughness coefficients can be used for the 270 million cubic meters per day. This figure is illustrating that the predicted results are close from the measured data and the used coefficients can be used for model analysis.

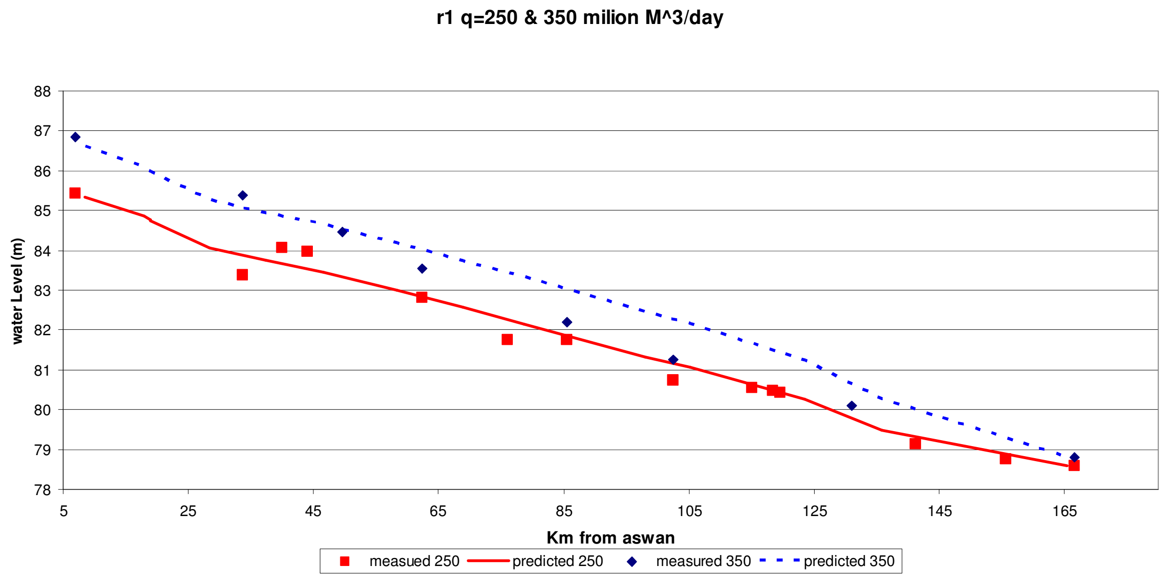

Figure 3. Calibration of Reach 1

Reach Four

Figure 4 shows the model calibration for this reach, it shows the measured data and the predicted model results for this reach for the two discharges 170 and 350 million cubic meters per day. Discharge 170 million cubic meters per day was used for model calibration since it is close to the 180 million cubic meters per day and it has occurred with higher frequency 11.99 % (the maximum frequency for this reach) and the resulted roughness coefficients can be used for the 180 million cubic meters per day. This figure is illustrating that the predicted results are close from the measured data and the used coefficients can be used for model analysis.

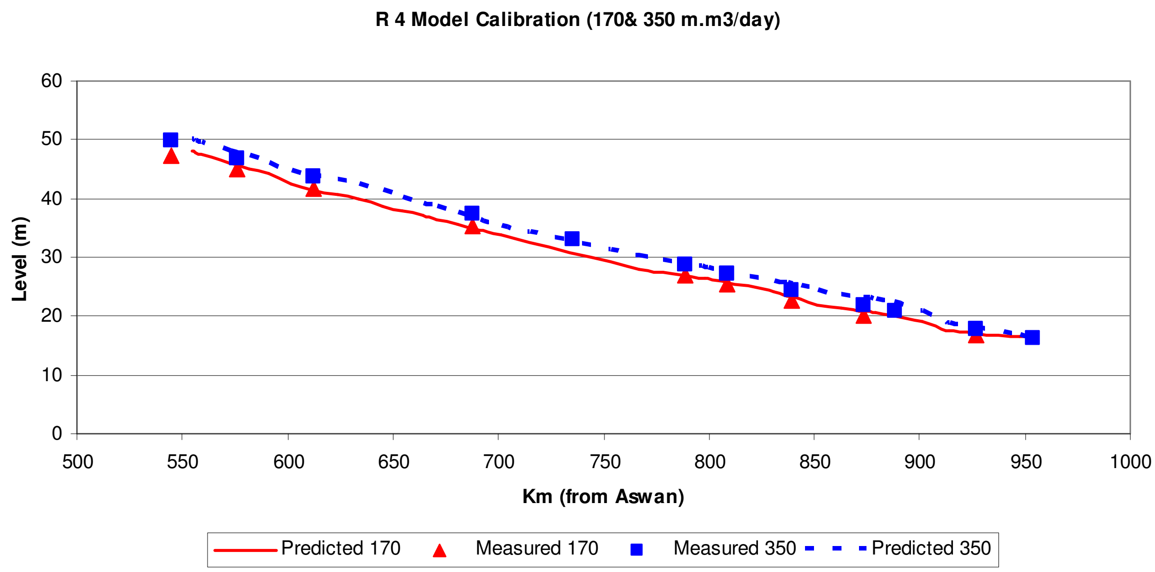

Figure 4. Calibration of Reach 4

MODEL RESULTS

Aswan Bridge

Table 1 shows the computation results for Aswan Bridge. These results are for the two discharges 270 and 350 million cubic meters per day. These results are computed based on contraction and pier scour for the bridge. It can be concluded from this table that the minimum expected local scour for the maximum occurred discharge (270 million cubic meters per day) is 4.89 m at pier number 6 (the one to the west). The eastern pier is out of the river channel. The maximum expected local scour for the maximum occurred discharge (270 million cubic meters per day) is 13.66 m at pier number 4. For the maximum probable future discharge (350 million cubic meters per day), the minimum expected local scour is 5.63 m at pier number 6 while the maximum expected local scour is 14.47 m at pier number 4.

Table 1. Local scour computation for Aswan Bridge

Pier No.	Local scour (m) for q = 270 m.m^3/day	Local scour (m) for q = 350 m.m^3/day
1	0	0
2	6.35	6.79
3	13.52	14.34
4	13.66	14.47
5	5.42	5.99
6	4.89	5.63

El-Minia Bridge

Table 2 shows the computation results for El-Minia Bridge. These results are for the two discharges 180 and 350 million cubic meters per day. These results are computed based on contraction and pier scour for the bridge. For the ordinary case that flow is normal to the bridge and tangent to the piers long side, it can be concluded that the minimum expected local scour for the maximum occurred discharge (180 million cubic meters per day) is 1.56 m at pier number 8 (from the west). The maximum expected local scour for the maximum occurred discharge (180 million cubic meters per day) is 1.81 m at pier number 7. For The maximum future discharge (350 million cubic meters per day), the local scour is 2.08 m for all piers. For this bridge, the bed topography is somewhat critical because of the deposition at the bridge location which may alter the flow attack angle to the bridge. This case is very sensitive for the local scour computations. A case of flow angle of 30 degrees with the normal to the bridge is tested. The same table shows the results for this case. It can be concluded that the minimum expected local scour for the maximum occurred discharge (180 million cubic meters per day) is 3.9 m at pier number 8 (from the west). The maximum expected local scour for the maximum occurred discharge (180 million cubic meters per day) is 4.53 m at pier number 7. For The maximum future discharge (350 million cubic meters per day), the local scour is 5.19 m for all piers.

Table 2. Local scour computation for EL-Minia Bridge

Pier No.	Local scour (m) for q = 180 m.m^3/day		Local scour (m) for q = 350 m.m^3/day	
	Flow normal to the bridge	Flow inclined with 30°	Flow normal to the bridge	Flow inclined with 30°
1	1.71	4.27	2.08	5.19
2	1.71	4.27	2.08	5.19
3	1.68	4.2	2.08	5.19
4	1.71	4.27	2.08	5.19
5	1.65	4.12	2.08	5.19
6	1.66	4.15	2.08	5.19
7	1.81	4.53	2.08	5.19
8	1.56	3.9	2.08	5.19

ACTUAL MEASURED LOCAL SCOUR

Aswan Bridge

The average river bed level at the bridge site, before the construction works, was varying between levels (77.00) and (78.00) above MSL. Figure 5 shows the bed level in 1982 (NRI, 1982). The minimum level at the bridge site was (75.50). After the bridge construction a hydrographic survey for the bridge site was performed in 2001 (NRI, 2007). This survey is shown in figure 6 and the local scour is shown on this figure. Form this figure, it can be shown that the minimum bed level at the bridge site was (70.00) m at the west side, which is related to a local scour of about 7.00 meters at the same location during three years. On the other hand, the eastern scour hole has reached a level of (67.50) which is related to a local scour of about 9.50 m. Figure 7 illustrates the bed topography surveyed in 2007 (NRI, 2007). The minimum bed level was 72.34 and the local scour is shown on this figure. It has to be mentioned here, that the rise in bed level in 2007 is due to bed protection. It has to be mentioned here that the maximum occurred local scour is about 9.50 m. The model predicted value of 13.66 meters for the flow of 270 million cubic meters per day has not occurred up till now. However, the predicted value is the ultimate predicted local scour value for this flow given sufficient flow period and other flow conditions. For the maximum future discharge this value increases to 14.47 m. It has to be mentioned here that the values of local scour exceeding 8.00 are exceeding the safe limit of local scour for the bridge (General Authority of Highway, Bridges and transport, 2006)**.** The value of 9.5 meters represents about 32% of actual embedded pile length and the most recent value in 2007 is about 16% of embedded pile length. This value is structurally safe but it has to be monitored and strategy has to appropriate mitigation be considered.

Figure 5. The location of Aswan Bridge (1982)

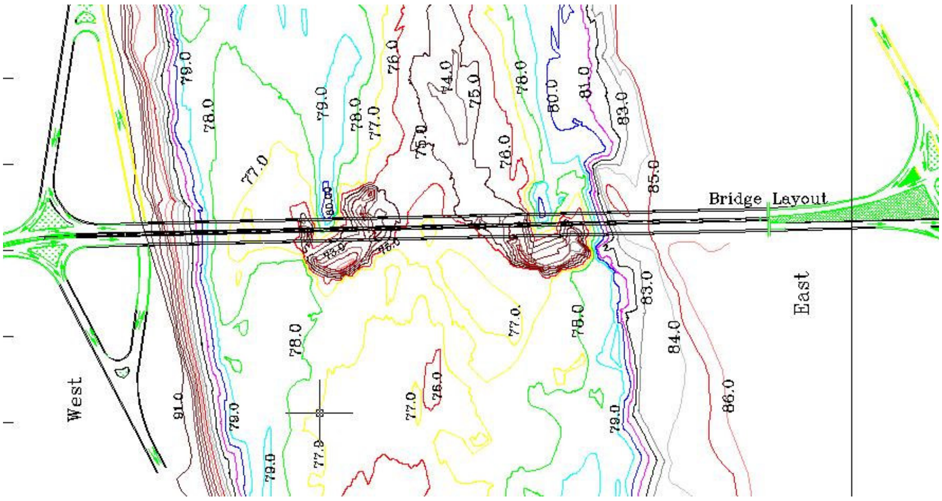

Figure 6. The location of Aswan Bridge (2001)

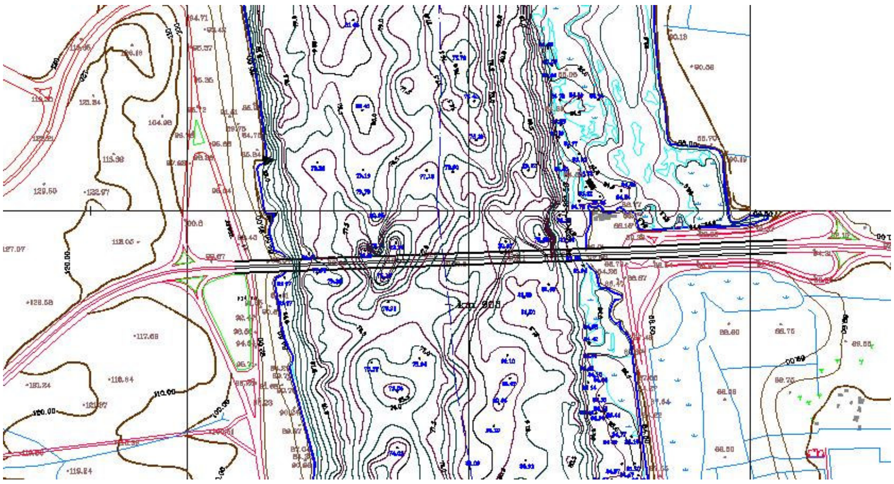

Figure 7. The location of Aswan Bridge (2007)

EL-Minia Bridge

The average river bed level at the bridge site, before the construction works, was varying between level (31.00) and level (32.00) above MSL. Figure 8 shows the bed level in 1982 (NRI, 1982). The minimum level at the bridge site was (28.50). Figure 9 shows the recent bed topography surveyed in 2004 (NRI, 2007). The minimum bed level was (27.00) and the local scour is shown on this figure. The measured local scour is ranging from about 1.5 m to 4.00 m at the eastern side and about 2.50 m at the western side. The model predicted value is 1.81 meters for the flow of 180 million cubic meters per day with flow normal to the bridge and the value of 4.53 m for the flow of 180 million cubic meters per day skewed 30 degree with the normal to the bridge.

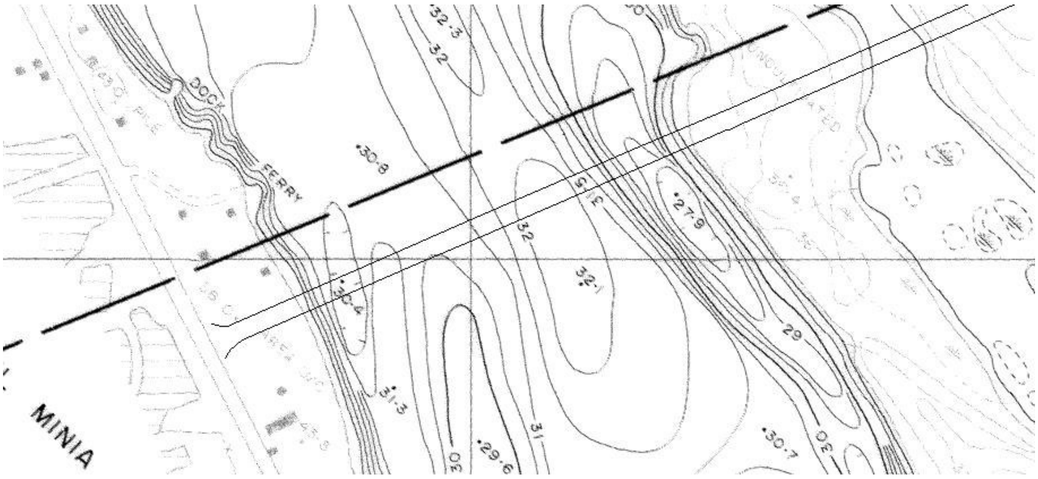

Figure 8. The location El Menia Bridge (1982)

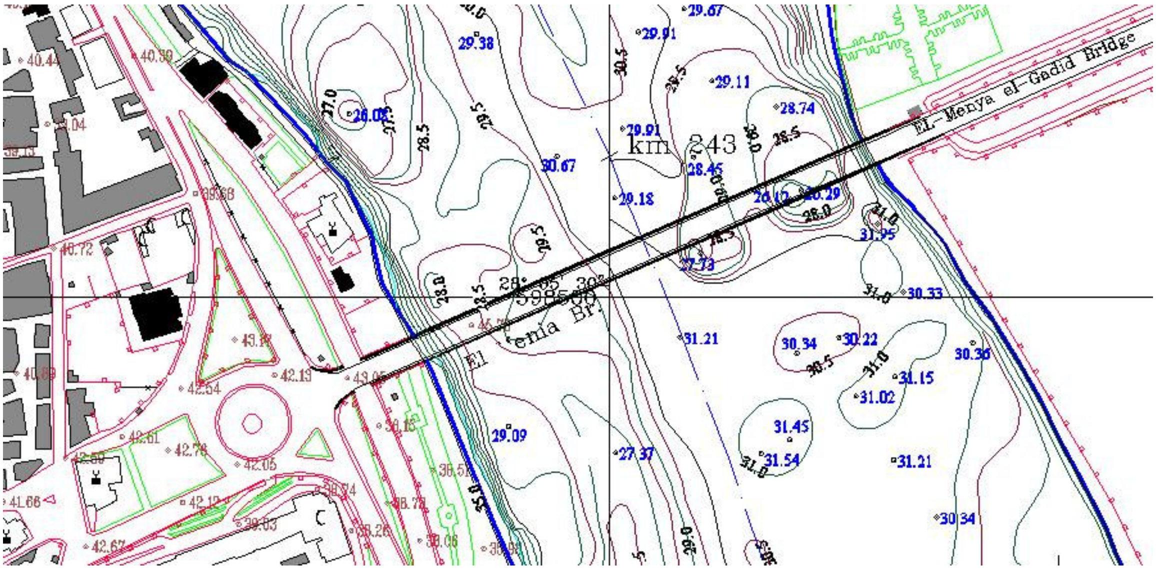

Figure 9. The location El Menia Bridge (2004)

This implies that the flow conditions were not exactly normal to the bridge due to bed topography. For the maximum future discharge the predicted local scour value goes up to 5.19 m for skewed 30 degree flow. It has to be mentioned here that the values of local scour are not exceeding 8.00 which is the safe limit of local scour for the bridge (General Authority of Highway, Bridges and transport, 2006). The value of 4.00 meters represents about 20% of actual embedded pile length and the most recent value in 2004. This value is structurally safe but it has to be monitored and appropriate mitigation should be used if needed.

PROPOSED MITIGATION

As explained in this research paper, River Nile bridges are suffering from local bed scour around piers. The proposed mitigation approach has two major steps; the first one is the continuous monitoring for all local scour around river bridge piers to be able to apply the suitable protection in the best suitable timing. The second step is to use, whenever needed, suitable protection at suitable time. This protection consists of an inverted layered filter. This filter is designed for each layer to prevent bed particles from moving and to allow water flow. The top filter layer consisted of crushed stones or filter sacks. The sacks can be used for all filter layers to be able to put them in the designated locations.

The following equation has to be fulfilled for the filter design:

1) For flow of water:

$$4 < \frac{D_{15}(\text{filter})}{D_{15}(\text{base})} < 40$$

2) For avoiding losing soil particles:

$$\frac{D_{15}(\text{filter})}{D_{85}(\text{base})} < 4$$

3) For homogeneity and to avoid particle segregation:

$$\frac{D_{50}(\text{filter})}{D_{50}(\text{base})} < 25$$

CONCLUSIONS

Local scour around River Nile bridge piers has been studied and evaluated.

Two bridges were considered as two study cases for bridges constructed along the River Nile; Aswan Bridge and EL Minia Bridge.

The two bridges are considered major bridges which their impacts should be studied and evaluated.

The impacts of the bridge construction are evaluated from the bed survey during different periods including the recent hydrographic survey for the River Nile.

Mathematical modeling was used to evaluate the expected local scour. The computer model HEC-RAS (developed by the US Army Corps of Engineers), was used during this analysis to evaluate local scour around the bridge piers.

For Aswan Bridge; the model predicted value of 13.66 meters for the flow of 270 million cubic meters per day, for the maximum future discharge this value goes up to 14.47 meters. The maximum occurred local scour is about 9.50 m up till now.

For El-Minia Bridge; the model predicted value of 1.81 to 4.53 meters for the flow of 180 million cubic meters per day, for the maximum future discharge this value goes up to 2.08 to 5.19 meters. The maximum occurred local scour is about 4.00 m up till now.

Structural safety has been addressed and even though the local scour is now within the allowed structural limit.

Proposed mitigation has been highlighted.

RECOMMENDATIONS

Continuous monitoring has to be performed for all River Nile bridges.
Appropriate mitigation should be used if needed at suitable timing.

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