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Evaluation of Bearing Capacity of Caissons Subject to Scour

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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. For many reasons, there exists a need to protect these assets by continuous monitoring and maintenance. For this research, 6^{th} October Bridge was considered as a case study for bridges constructed on caissons along the River Nile. A field data (contour maps for the bed of the River Nile at year 1982and 2008) and computer model FDOT (developed by Florida Department of Transportation), was used to evaluate the depth of scour at the caissons of 6^{th} October Bridge. Conclusions and recommendations were highlighted.

Keywords

Caissons; Scour; River Nile bridges; Bearing capacity

1. Introduction

Bridge scour is a removal of soil by erosion due to flowing water around bridge piers. It is depended on the following: bed material properties, bed configuration, flow properties, and the type of bridge foundation. The foundation type is the main factor to identify the possibility of scour.Deep foundations such as piles, piers or caissons are considered to have a high capacity to resist the scour damage. While shallow foundations such as isolated footings, raft or combined footings are considered to have a low capacity to resist the scour damage, so the shallow foundations are recommended to be considered high risk. As shown in figure (1) the total scour around bridge foundation comprises three components:

1. General scour and Long-term aggradations

2. Contraction scour

3. Local scour at bridge supports or abutments (FHWA, 2010).

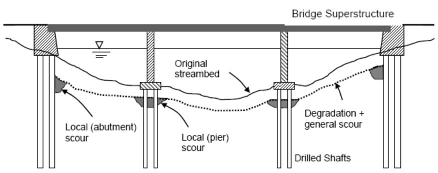

Figure 1. The scour around bridge supports (FHWA, 2010)

Structural and geotechnical engineers must take into account the effect of scour on bridge foundations especially friction piles. The effect of scour on bridge foundations may be summarised as follows:

1- Changes in soil stress around the bridge foundations,

2- Reduced embedment depth and therefore reduced in bearing capacity of foundations,

3- Possible changes in the structures response and the resulting foundation force effects (loading).

The coordination is required between hydraulic, geotechnical, and structural engineers to avoid the effect of scour on the bridge foundations.

As shown in figure (2) the state of effective stress corresponding to the scour conditions at any depth along the shaft can be estimated as follows. At the top of the embedded length of the shaft (Point C), the vertical stress is equal to zero. At a depth of embedment equal to 1.5 y_s or greater, assume the vertical stress is controlled by the streambed elevation B. Assume a linear variation in vertical stress over the depth 1.5 y_s. In other words, the effect of local scour on stress diminishes linearly over a depth equal to 1.5 times the scour hole depth, y_s. The change in effective stress and the embedded length of the deep foundation effects on the bearing capacity of the bridge foundations, so the effect of scour must be taken into consideration (AASHTO LRFD Bridge Design Specifications, 2007).

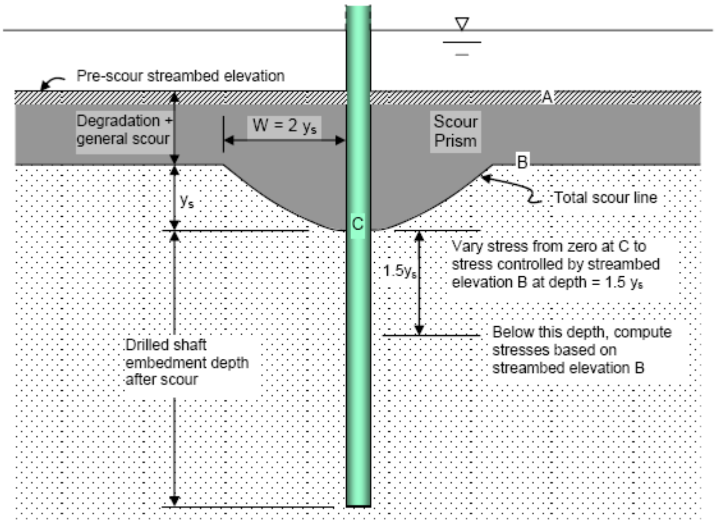

Figure 2. The effect of scour on bridge foundations (AASHTO LRFD Bridge DesignSpecifications, 2007).

Caissons are selected as the most practical method of founding long span bridges with heavy loads, in deep water environments. The caissons types are Open caissons, Box caissons, and pneumatic caissons. Open caisson is a watertight box made of steel or reinforced concrete and opened at both top and bottom. It can be constructed to depths of 20 m or more depending on the soil conditions. Box caisson is similar to open caisson but closed at the bottom and opened at the top. Pneumatic caissons have been installed to depths well in excess of 100 m in some projects.

The bearing capacity of caissons depending on the end resistance only, while the skin friction resistance is ignored in River bridges because the bed soil is liable to be scoured.

The designer must estimate the maximum depth of scour when applicable, which should be conservatively established from recognized analytical methods or from computer models. Figure (3) shows the failure of a bridge in South Africa constructed in the period from about 1930 until 1960, which were supported on caisson sunk to inadequate depths and founded in alluvial deposits well above bedrock (Frankipile, 2008).

Bridge foundations should be taken to a safe depth well below the anticipated scour level to protect it from any movement due to the force of the stream and other external forces. Figure (4) shows the components of bridge constructed on caissons.

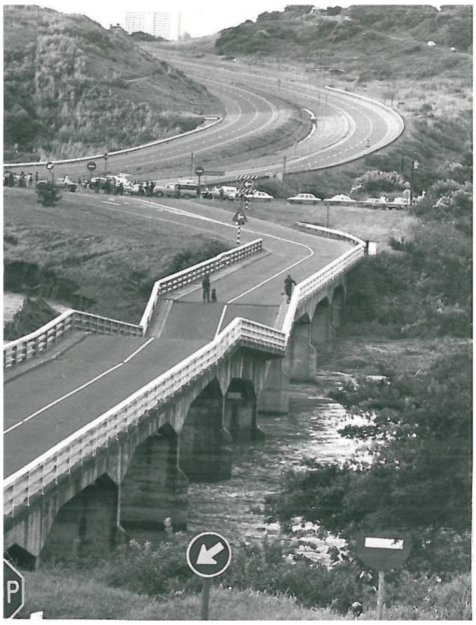

Figure 3. Caissons failure dueto bed erosion (Frankipile, 2008)

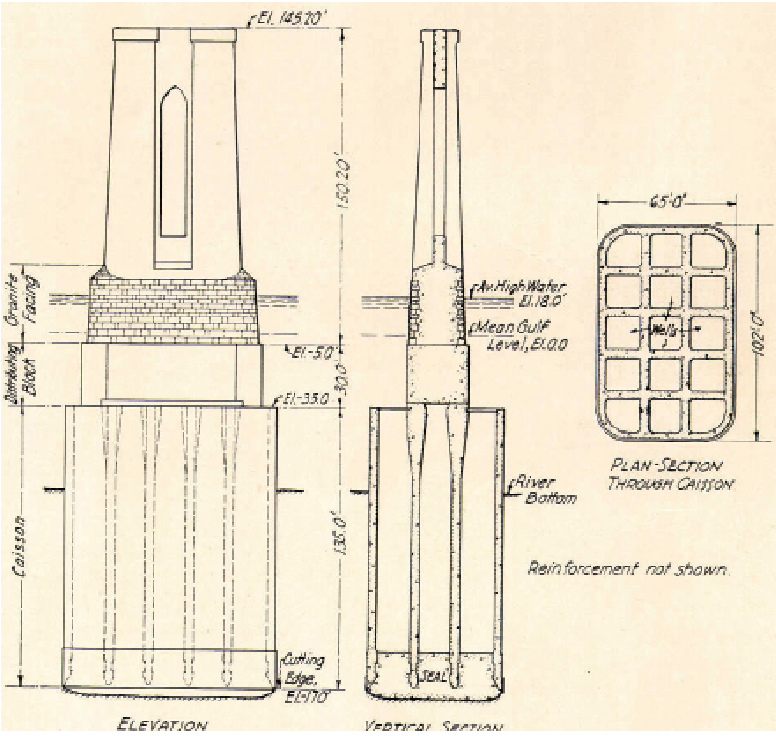

Figure 4. The various components of caissons

2. 6^{th} October Bridge

The 6^{th} October Bridge is an elevated highway in central Cairo, Egypt. With total length ramps, it is approximately 20 km. The bridge crosses the Nile River twice. It connects west bank suburbs, east through Gezira Island to Downtown Cairo, and on to connect the city to the Cairo International Airport to the east. The flyover was constructed in 10 main phases between 1969 and 2002**.** Bridge crossing the Nile in the east branch with width 34 m and ramps on Saraya El Gezira with width 8 m, the work in this in part started in January 1973 and finished in October 1976.It founded on four pneumatic caissons under the base of the Nile. Caissons were pulled on ship lift to the Nile then floated and pulled to its specified places to erect piers under the bottom of the Nile. The abutments are founded on 260 fibro piles. The bridge width is 26.5 m and capacity 70 ton as shown in figure (5) & (6).

The soil characteristic for the bed at the bridge is shown in table (1)

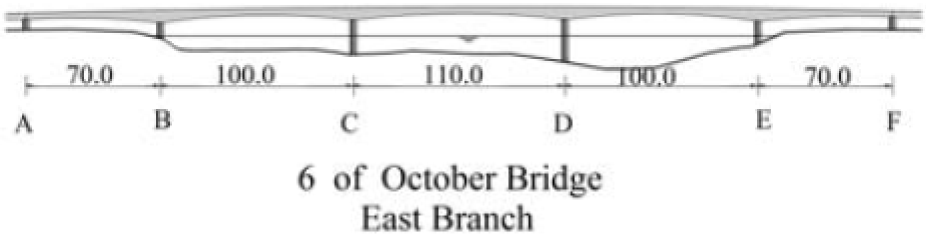

Figure 5. 6^{th}October Bridge east branch (Handbook of International Bridge Engineering, 2000)

Figure 6. Bridge crossing theNile

Table 1. The soilcharacterized to the bed at 6^{th} October Bridge

Location	D50 mm.	D Mean mm.	%Gravel	%Sand				%Silt	Soil type
				Coarse	Medium	Fine	Total		
East	0.14	0.13	0.00	0.00	13.19	80.36	100	0.00	Fine sand
Middle	0.14	0.13	0.00	0.00	11.93	79.92	100	0.00	Fine sand
West	0.14	0.12	0.00	0.00	8.76	82.93	100	0.00	Fine sand
Average	0.14	0.13	0.00	0.00	11.29	81.07	100	0.00	

3. Compute Scour Depth From Field Data

The field data used for this research are as follows.

3.1. Contour Maps of the River Nile Bed in Study Area at the Year 1982 and 2008

Contour maps with scale 1:5000 were produced by Kenting Earth sciences ltd. Ottawa, Canada, 1981-1982 from a hydrographic survey and aerial photography at 1978. These contain the river bed contour lines for the study area (6^{th} October Bridge) with interval 0.5m. And a set of maps produced at 2008 from a hydrographic survey and aerial photography. These contain the river bed contour lines for the study area (6^{th} October Bridge) with interval 0.5m as shown in figures (7) & (8).

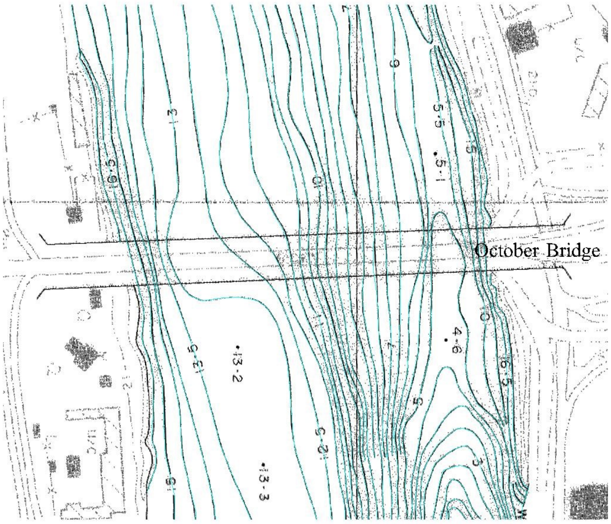

Figure 7. A contour map for River Nile bed at the year 1982

Figure 8. A contour map for River Nile bed at the year 2008

3.2. Data processing and analysis

Five sections every 50 m of River Nile in downstream of 6^{th} October Bridge (at years of 1982 and 2008) can be drawn using the contour maps. Figure (9) shows the places of the cross sections.

After drawing the sections of the River Nile using Auto Cad program, a comparison between the sections is doing to evaluate the changes in River Nile bed where the bridge was constructed as shown in figures from 10 to 14.

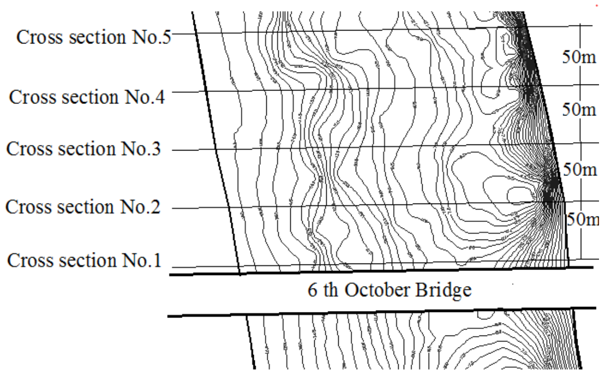

Figure 9. The places of the cross sections

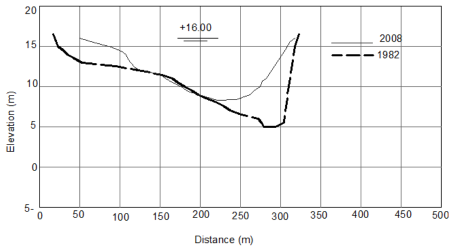

Figure 10. Cross section No.1

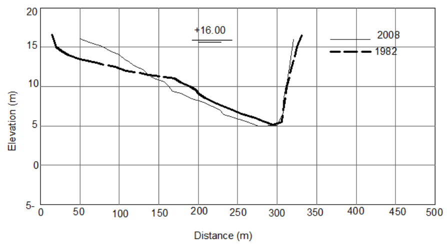

Figure 11. Cross section No.2

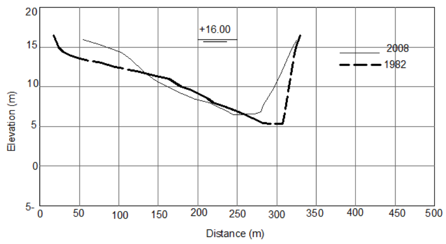

Figure 12. Cross section No.3

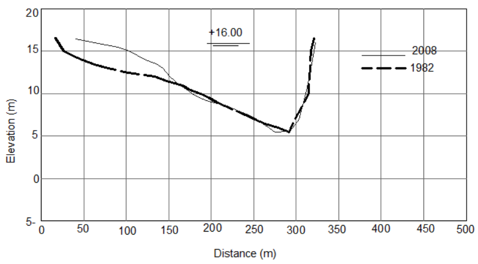

Figure 13. Cross section No.4

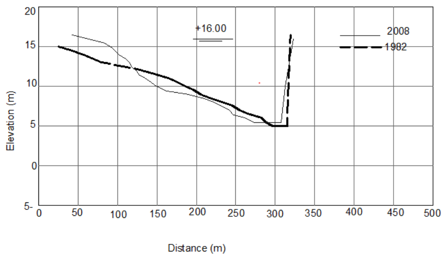

Figure 14. Cross section No.5

From the River Nile cross sections the data of the River Nile bed downstream 6^{th} October Bridge can be obtained as shown in table (2).

Table 2. The data of the River Nile cross sections down stream 6^{th} October Bridge

Cross Sections	Width of River Nile (1982)	Width of River Nile (2008)	Change in width	Max. scour depth(m)
1	320.25	282.7	-37.55	0.5
2	329.2	287.6	-41.6	1.7
3	321.9	290	-31.9	1.1
4	316	286	-30	0.5
5	311.25	284.33	-26.92	0.65

From the previous figures and table (2) the following can be observed:

1. Sedimentations were occurred especially on the western side of River Nile to distance 140 m and 2.5 m depths. It may be affected negatively on navigation.

2. The River Nile width was decreased to distance 38 m.

3. The elevation of the lowest point at 6^{th} October Bridge downstream is (+5.0).

4. No scour hole at the downstream of the bridge

5. The maximum scour depth is 1.7 m at the cross section No.2 (in the area situated between the two caissons), so a comparison between the River Nile bed at years 2004 and 2008 done to evaluate the changes of River Nile bed at this cross section, as shown in figure (15). The results were as follows:

Erosion was occurred on the western side of River Nile to distance 65.0 m and with depth ranging from 0.5 to 2.0 m.

At the middle of the River Nile cross section, the maximum depth of scour is 1.1 m (this scour occurred in four years only).

In the eastern side of the River, the scour depth between 1982 and 2004 was 0.4 m and it's become 1.2m in four years (between 2004 and 2008), so the slope of the east bank at cross section No.2 is less safe.

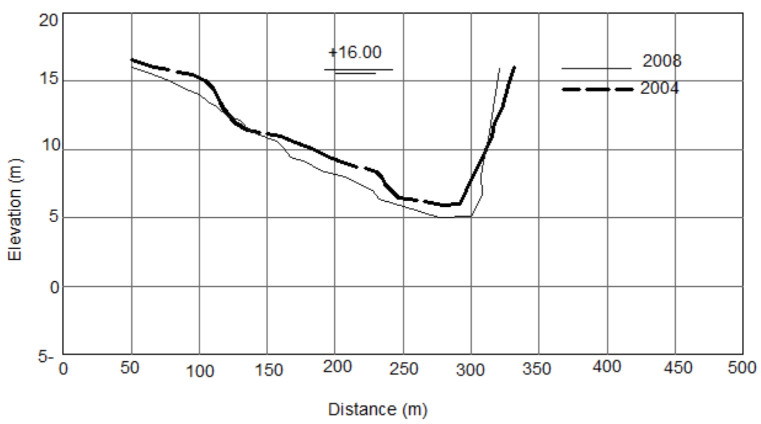

Figure 15. Cross section No.2 at years 2004 and 2008

6. Due to the sedimentations in the eastern side bank, the slope of the east bank becomes safer except the slope of the east bank at cross section No. 2.

to determine the risk of failure from scour. A team of engineers was assembled in each district of the Florida Department of Transportation to ensure proper evaluation. Experts in bridge hydraulics/hydrology, structures and geotechnical worked together to come to a consensus on potential bridge scour-related problems and possible corrective actions (Florida Department of Transportation, 2010). The computer program FDOT scour calculator was used during this analysis to evaluate local scour around 6^{th} October Bridge caissons.

4.1. INPUT DATA

The data that are provided to the program is as follows:

1. Bed material properties, Table (1).

2. The properties of flow in River Nile.

3. Bridge geometry which includes caisson dimensions and shape**.**

4.2. Computer Model Results

Figure (16) shows the input data and local scour depth occurred around 6^{th} October Bridge caissons**.** The maximum scour depth according to FDOT-scour calculator program is 2.87 m**.**

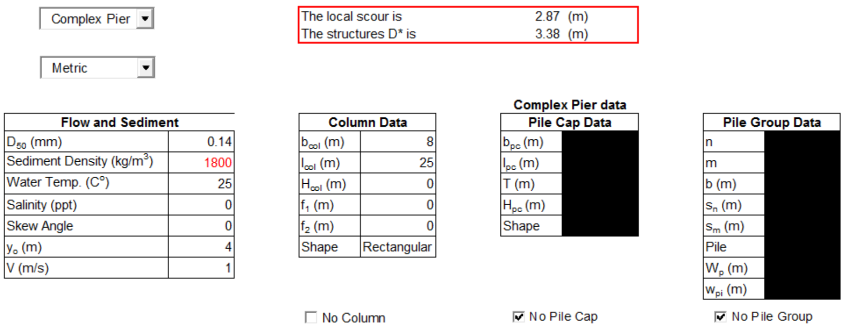

Figure 16. Scour depth calculation using FDOT program.

5. Conclusion and Recommendations

1. The field measurements from the contour maps show a scour depth of about 1.7 m since the bridge construction up till now.

2. The FDOT –scour calculator program results show a scour of a depth 2.87 m. that means the difference between the measured scour and calculated scour about 1.17 m.

3. Since the maximum scour depth was found 1.70 m the bridge foundations can tolerate this scour.

4. Caissons are most suitable foundations for the bridges constructed on River Nile since it affected by scour less than the piles due to the following:

The bearing capacity of caisson is not affected by scour due to the bearing capacity of caissons depending on the end resistance only, while the bearing capacity of piles decreased by scour especially friction piles

A bending moment due to current drag forces and wave action on the piles can be neglected in the case of a massive structure like caissons.

Caissons non-buckling in the case of scour. While piles are exposed to the buckling in the case of scour.

5. Periodic examination every two years must be done to avoid any damages that may occur.

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