Stability assessment of bridges impacted by scour

Etudes de stabilité des ouvrages d'art soumis aux affouillements

S. M. Sayed
GCI, Inc., Longwood, Florida

H. N. Sunna
Ayres Associates, Inc., Tampa, Florida

K. O. Amaning
GCI, Inc., Longwood, Florida

N. K. Jetha
Ayres Associates, Inc, Tampa, Florida (Currently The LPA Group, Tampa, Florida)

J. Garcia
Florida Department of Transportation, Tampa, Florida

ABSTRACT

This paper presents the approach used in the Bridge Scour Evaluation and Remediation (Maintenance) program throughout the State of Florida since 1993. The purpose of this program has been to evaluate state and local-owned government bridges over tidal and non-tidal waterways with scourable beds, to determine the risk of failure from scour. A multi-disciplined team of engineers was assembled to ensure proper evaluation. Experts in bridge hydraulics/hydrology, structures and geotechnology worked together to come to a consensus on potential bridge scour-related problems and possible corrective actions.

The approach presented in this paper focused on bridges supported on deep foundations with and without embedment data. Bridges with known foundation details are less troublesome compared to those with unknown foundations. The evaluation of the vulnerability of bridges with unknown foundations, mainly those founded on deep foundations, has been a major stumbling block in the implementation of the scour program. A methodical, multi-step approach to the scour evaluation of bridges on pile foundations of unknown embedments is presented. Case histories of major bridges with known/unknown foundations are presented to illustrate the usefulness of the proposed approach.

RÉSUMÉ

Ce document présente l'approche utilisée pour l'évaluation du phénomène d'affouillement des terrains de fondations d'ouvrages d'art, ainsi que le programme de protection et de maintenance de ces ouvrages, contre ce phénomène naturel, appliqué depuis 1993 à travers l'Etat de Floride. Ce programme a été mis au point pour l'évaluation de la stabilité des ouvrages de l'Etat et Gouvernements locaux, responsables de la gestion des structures implantées dans des lits de cours d'eau à régime régulier ou irrégulier et situé dans des terrains affouillables. Une équipe multidisciplinaire composée d'ingénieurs experts en ouvrages d'art, hydraulique, hydrologie, structures et géotechnique a travaillé en étroite collaboration afin d'aboutir à un consensus sur l'évaluation du risque et potentiel du phénomène d'affouillement et d'établir les solutions de protection voire de reprise en sous œuvre des ouvrages affectés.

L'approche présentée se focalise particulièrement sur les ouvrages d'art reposant sur des fondations profondes à ancrage non nécessairement connu. Les ouvrages aux fondations dont les caractéristiques sont bien définies présentent naturellement moins de difficultés dans leurs études et traitement, par rapport à ceux dont on dispose d'aucune information relative à leurs fondations. L'évaluation de la vulnérabilité des ouvrages dont les fondations sont méconnues, et principalement ceux reposant sur des fondations profondes, a été une des grandes complications dans l'élaboration et la mise en application de ce programme d'affouillement. Une approche méthodologique à plusieurs étapes, dans l'évaluation des affouillements des sols de fondations des ouvrages à ancrages non définis est présentée dans ce document. Des cas pathologiques d'ouvrages aux fondations diverses sont également présentés pour illustrer l'utilité et l'usage de cette approche.

Keywords: bridges, foundations, scour, stability, geotechnical engineering

1 INTRODUCTION

Scour is a complicated phenomenon that cannot be predicted by testing and calculations only. Therefore, a practical approach based on "Sound Engineering Judgment" in addressing the impact of scour on existing and new bridges over waterways is required. This approach must be based on the reasonableness of the predicted scour depth established jointly by the hydraulic, geotechnical and structural engineers (consultants and owner's staff) working on the project. Such approach seems to be extremely viable and a cost-saver for the stakeholders.

In the early 1990's, the Florida Department of Transportation (FDOT) implemented an extensive program to evaluate state and local-owned bridges over tidal and non-tidal waterways with scourable beds to determine the risk of failure from scour. It was recognized from the start that a multi-disciplined team of engineers would be required to properly perform the evaluation. The FDOT's scope of services called for experts in bridge hydraulics/hydrology, structures and geotechnology to come to a consensus on potential bridge scour associated problems and possible corrective actions.

2 APPROACH

The multi-phased process of the in-depth scour evaluation consists of four sequential phases:

- Phase I - Data Collection and Qualitative Analysis
- Phase II - Hydrologic/Hydraulic Assessment
- Phase III - Soil-Structural Assessment
- Phase IV - Recommended Plan of Action

The flow-chart in Figure 1 illustrates the various decision-making tasks in this sequential multi-phase evaluation.

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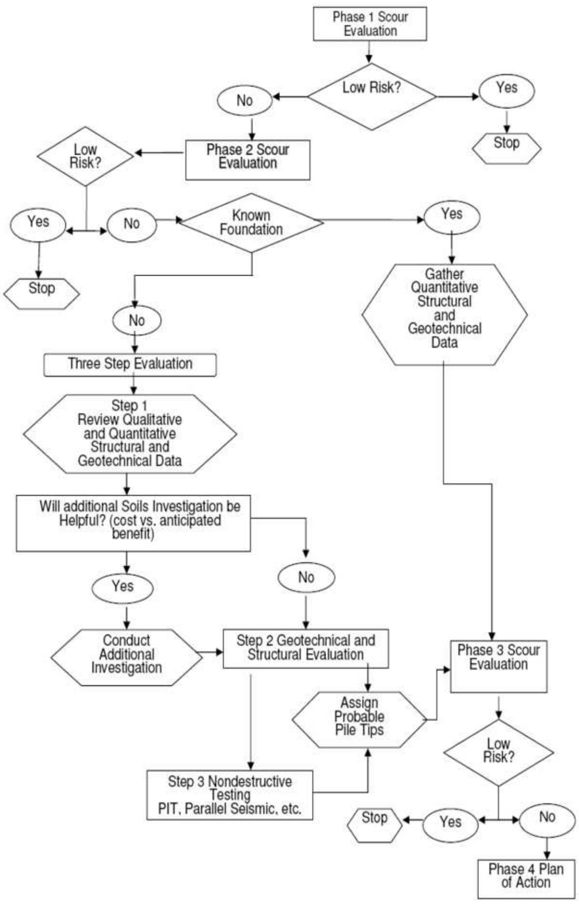

Figure 1. Evaluation of bridges impacted by scour

Once the hydrologic/hydraulic assessment (Phase II) classifies the bridges as "high risk", a Phase III study is carried out. In this phase, the potential scour depth and extent (considering the scourability of bed materials) is analyzed. A rigorous geotechnical and soil-structure interaction assessment using the computer programs FB-Deep and FB-Pier/FB-MultiPier (FDOT 1995) is subsequently performed. The FB-Deep computer program is a Windows-based program used to estimate the static axial capacity of drilled shafts and driven piles. The methodology is based on Federal Highway Administration (FHWA) and FDOT (Research Bulletin 121 (RB-121)) reports. FB-Deep guides the user through pile and shaft materials data, shape and dimensional inputs, soil properties, and boring log information. The program then computes drilled shaft or driven pile capacity in clays, sands, and intermediate geomaterials, provides settlement analyses (for drilled shafts), and load transfers. The FB-Pier/FB-MultiPier is a nonlinear finite element analysis program capable of analyzing single or multiple bridge pier structures interconnected by bridge spans. The full structure can be subjected to a full array of AASHTO load types in a static analysis or time varying load functions in a dynamic analysis. Each pier structure is composed of pier columns and cap supported on a pile cap and piles/shafts with nonlinear soil. This program couples nonlinear structural finite element analysis with nonlinear static soil models for axial, lateral, and torsional soil behavior to provide a robust system of analysis for coupled bridge pier structures and foundation systems. FB-Pier/FB-MultiPier generates the finite element model given the geometric definition of the structure and foundation system. The soil is characterized by user-defined parameters. Group effects are considered through P-Y multipliers that are assigned for each row within the pile group as well as axial group efficiency.

The paper focuses on the Geotechnical and Structural (i.e., Phase III) scour assessment of bridges supported on deep foundations. Case histories are presented in the following sections.

3 BRIDGE FOUNDATION STABLITY

3.1 *Bridges with known foundation*

3.1.1 *Bridge No. 010093 – US-17/SR-35 over Shell Creek, Charlotte County, Florida*

The bridge was constructed in 1986 and has undergone no repairs or rehabilitation (FDOT 1994-2005). It is approximately 132m (433 ft.) long, consisting of twelve (12) 11m (36 ft.-1 in.) spans. The superstructure is composed of 455mm (1 ft.-6 in.) thick prestressed slab units (1.22m (4 ft.) wide sections). Each intermediate pile bent has five (5), 455mm (18-in.) square prestressed concrete piles. According to the bridge plans, the design load for the intermediate bent piles was 534 kN (60 tons). All bents are normal to the centerline of the bridge. Seven (7), 455mm (18-in.) square prestressed concrete piles support each end bent. End bent protection consists of rubble riprap. Shell Creek has a tidal scour regime.

Pile cut-off and tip elevations were determined from the 1986 Pile Driving Records. The remaining pile embedments and unsupported lengths for the intermediate bents were determined from the existing conditions (as shown in the 2004 Bridge Inspection Report) as well as for the anticipated mudline conditions calculated for the 100-year scour event. Bent No. 7 was chosen for the analysis because its piles have the least amount of remaining embedment and the longest unsupported length.

3.1.2 *Geotechnical assessment*

The purpose of this evaluation was to gather information on the subsurface conditions used in evaluating the scourability of bed materials, pile foundation capacity, and stability considerations based on the scour depths calculated in Phase II. Provided in the Scour Evaluation Table 1 is a summary of pertinent information related to calculated scour and estimated remaining pile embedment for Bent No. 7.

Table 1. Scour Evaluation Data – Bridge No. 010093

Worst Case Pier No.	7
Approx. Channel Bottom Elevation (NGVD) [(1)]	-2.21m (-7.26 ft.)
Approx. Pile Cut-off Elevation (NGVD)	2.88m (9.45 ft.)
Approx. Pile Tip Elevation (NGVD)	-8.52m (-27.96 ft.)
Estimated Pile Embedment (1986)	6.31m (20.70 ft.)
Approx. Channel Bottom Elevation (NGVD) [(2)]	-2.94 (-9.66 ft.)
Estimated Pile Embedment (2004)	5.58m (18.30 ft.)
100-Year Scour Depth [(3)]	1.07m (3.50 ft.)
100-Year Scour Elevation (NGVD)	-4.01m (-13.16 ft.)
Estimated Pile Embedment after Scour	4.51m (14.80 ft.)
Pile Unsupported Length	6.89m (22.61 ft.)

[(1)] Obtained from the 1986 Pile Driving Records, State Project No. 01040-3508; [(2)] Obtained from 2004 Bridge Inspection Report; [(3)] Obtained from the Scour Evaluation Report, Phase II, 07/10/2000.

Scourability of bed materials. The materials encountered in the 1978 Boring B-3 (shown in Figure 2) consisted of a layer of brown to brown and gray fine sand overlying a mid-layer of gray to dark gray fine sand and a bottom layer of greenish-gray to gray fine sand. The Standard Penetration Test (SPT) had a blow count range between 18 and 100 blows per 0.3m (1.0 ft.) with the majority below the range of 60 blows per 0.3m (1.0 ft.). The material above the 100-year scour elevation is considered to be scourable based on FDOT criteria.

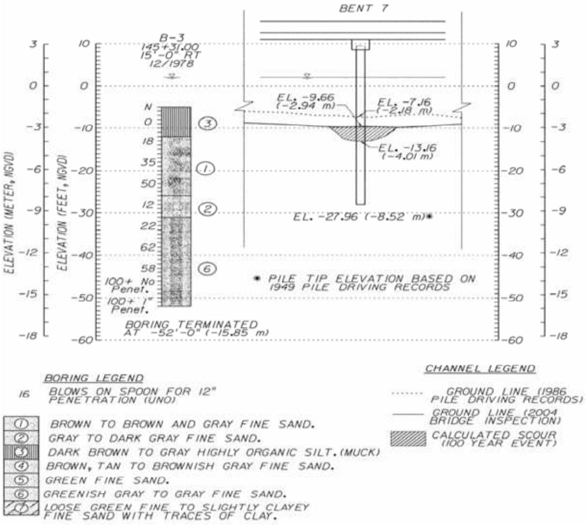

Figure 2. SPT Boring B-3 and Creek Profile

Pile Compression Capacity. An evaluation of the ultimate static compression capacity of a 455mm (18-in.) square concrete pile supporting Bent No. 7 was performed using FB-Deep and Boring B-3. Based on the scoured mudline elevation estimated for the 100-year storm event, the piles at Bent No. 7 would have approximately 4.5m (14.80 ft.) remaining embedment and can support an estimated ultimate (theoretical) axial compression load of approximately 1,531 kN (172 tons). If the ultimate compressive capacity is used as a basis for the evaluation, the piles have an estimated ultimate compressive capacity that exceeds the AASHTO Group I Axial Load of 635 kN (71.4 tons)/Pile.

3.1.3 *Structural assessment*

The foundation stability of Bent No. 7 at the 100-year scour elevation was evaluated in accordance with the Department's directives. The vertical and lateral loads were estimated in accordance with the 17th edition of the "Standard Specifications for Highway Bridges" (AASHTO). For the calculated loads at the 100-year scour elevation, the FB-Pier V3 analysis converged, indicating stability. The axial forces in all the piles were lower than the soil's ultimate (theoretical) compression capacity. Pile cap moments were also found to be less than the capacity of the cap.

3.1.4 *Findings and recommendations*

The stability analysis, using FB-Pier V3, showed Bent No. 7 to be stable for the modified Group I loads at the calculated 100-year scour elevation. Based on the results, the referenced bridge has been rated low risk and a Phase IV countermeasure plan is not recommended. However, the channel should be monitored during routine inspections and after major storm events to detect any signs of progressive scour.

3.2 *Bridges with unknown foundations*

3.2.1 *Bridge No. 100301 – SR-60 (Courtney Campbell Bridge) Over Old Tampa Bay, Hillsborough County, Florida*

Bridge number 100301 was constructed in 1974 and has undergone repairs and rehabilitation including rehabilitation of the bulkhead walls and spall and crack repairs (FDOT 1995–2008). The bridge is 992.4m (3,256 ft.) long and has forty-five (45) spans. The superstructure is composed of prestressed concrete beams with a 178mm (7-in.) concrete poured deck. Intermediate pile bents consist of eight (8), 610mm (24-in.) square prestressed concrete piles. Tower bents consist of ten (10), 610mm (24-in.) square prestressed concrete piles. The intermediate piers are 2-column piers that are supported by pile footings, with eight (8) or nine (9), 610mm (24-in.) square prestressed concrete piles per footing. The main span is a 3-column pier that is supported by pile footings, with thirty (30), HP 360x109 (HP 14x73) steel H-Piles per footing. According to the bridge plans, the design load for all piles was 668 kN (75 tons) per pile. All bents and piers are normal to the centerline of the bridge. End bent protection consists of rubble riprap, sand-cement riprap and bulkhead walls.

The pile driving records were not available and, hence, the pile cut-off and tip elevations were determined from the test pile lengths and soil borings for the test pile locations given in the plans. The remaining pile embedment and unsupported length of the intermediate bents were determined from the existing conditions shown in the 2007 Bridge Inspection Report as well as for the scoured mudline elevation computed for the 100-year scour event. Bent Nos. 23 & 24 (Pier Nos. 11 & 12) were chosen for the analysis based on the results of the Phase II Scour Evaluation. At the 100-year scour event, the piles at Bent Nos. 23 & 24 would respectively have approximately 10.64m (34.9 ft.) and 10.30m (33.8 ft.) of remaining embedment and 6.13m (20.1 ft.) and 6.46m (21.2 ft.) of unsupported length.

3.2.2 *Geotechnical assessment*

The purpose of this evaluation is described in Section 3.1.2. Provided in Table 2 is a summary of pertinent information related to calculated scour and estimated remaining pile embedment for Bent Nos. 23 & 24.

Table 2. Scour Evaluation Data – Bridge No. 100301

Worst Case Pier No.	Bent Nos. 23 & 24 (Pier Nos. 11 & 12)
Approx. Channel Bottom Elevation (NGVD) [(1)]	-3.26m (-10.7 ft.)
Approx. Pile Cut-off Elevation (NGVD) [(1)]	-5.18m (-17.0 ft.)
Approx. Pile Tip Elevation (NGVD)	-21.95m (-72.0 ft.)
Estimated Pile Embedment (1999)	18.69m (61.3 ft.)
Approx. Channel Bottom Elevation (NGVD) [(2)]	-3.96m (-13.0 ft.) & -4.30m (-14.1 ft.)
Estimated Pile Embedment (2007)	17.98m (59.0 ft.) & 17.65m (57.9 ft.)
100-Year Scour Depth [(3)]	7.35m (24.1 ft.)
100-Year Scour Elevation (NGVD)	-11.31m (-37.1 ft.) & -11.64m (-38.2 ft.)
Estimated Pile Embedment after Scour	10.64m (34.9 ft.) & 10.30m (33.8 ft.)
Pile Unsupported Length	6.132m (20.1 ft.) & 6.46m (21.2 ft.)

[(1)] Obtained from 1972 design plans, spreadsheets and SPT-97 data, SPN No. 10140-3509; [(2)] Obtained from 2007 Bridge Inspection Channel Profiles; [(3)] Obtained from the Phase II Scour Evaluation Report, 08/18/2003.

Scourability of bed materials. The materials encountered in the 1971 boring F-8 (shown in Figure 3) consisted of a layer of gray clayey sand overlying a black sandy clay layer followed by a light green sandy clay layer followed by a light brown clayey limerock layer and overlying a final layer consisting of a tan limerock/limestone formation. The SPT had a blow count values range between 7 and 100+ blows per 0.3m (1.0 ft.) with the majority below the range of 75 blows per 0.3m (1.0 ft.), which indicate scourable material above the 100-year scour elevation of -11.64m (-38.2 ft.).

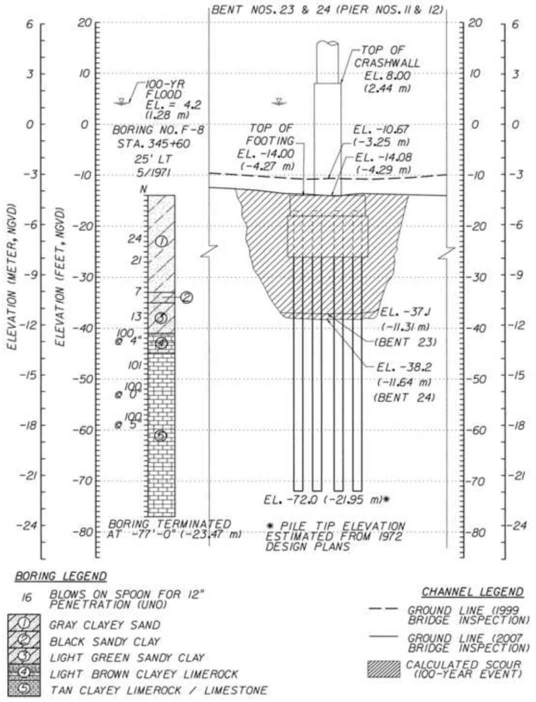

Figure 3. SPT Boring F-8 and Bay Profile

Pile Compression Capacity. An evaluation of the ultimate static compression capacity of a HP 360x109 (HP 14x73) H-pile supporting Bent Nos. 23 & 24 was performed using FB-Deep and the subsurface conditions encountered at Boring F-8 (shown in Figure 3). Based on the scoured mudline elevation estimated for the 100-year storm event, the piles at Bent Nos. 23 & 24 would have approximately 10.64m (34.92 ft.) and 10.30m (33.82 ft.) remaining embedment and can support an estimated ultimate (theoretical) axial compression load of approximately 2,252 kN (253 tons). If the ultimate compressive capacity is used as a basis for the evaluation, the piles have an estimated ultimate compressive capacity that exceeds the AASHTO Group I axial Load of 521 kN (58.5 tons)/Pile.

3.2.3 *Structural assessment*

The foundation stability of Bent Nos. 23 & 24 at the 100-year scour elevation of -11.6m (-38.2 ft.) was evaluated. A stability analysis, using FB-MultiPier, showed Bent Nos. 23 & 24 to Nos. 23 & 24 are considered low risk.

The vertical and lateral loads for Bent Nos. 23 & 24 (Pier Nos. 11 & 12) were estimated in accordance with the 17th edition of the "Standard Specifications for Highway Bridges" (AASHTO).

In addition, the original analysis for estimating the pile tip elevations was performed by taking 3m (10 ft.) off the test pile lengths and the study was further developed by moving pile tip elevations up until instability occurred. At elevation -15.54m (51.0 ft.), the structure became vertically unstable for the calculated vertical and lateral loads when a hypothetical pile length 9.45m (31.0 ft.) shorter than the test pile lengths was used. Although the pile length for Bent Nos. 23 & 24 (Pier Nos. 11 & 12) are technically unknown, the analysis indicates with the reasonably reduced estimated pile lengths from the original test pile lengths, the substructures are stable.

For Bent Nos. 23 & 24, the axial forces in all the piles were lower than the soil's ultimate (theoretical) compression capacity. The applied moments were insignificant. Pile cap moments were also found to be less than the capacity of the cap.

3.2.4 *Findings and recommendations*

The stability analysis showed Bent Nos. 23 & 24 to be stable for the modified Group I loads. Based on the results, Courtney Campbell Causeway bridge has been rated low risk and a Phase IV countermeasure plan is not recommended. However, the channel should be monitored during routine inspections and after major storm events to detect any signs of progressive scour.

4 CONCLUSIONS

A methodical three-step approach is combined with an evaluation of the hydraulic conditions, scourability of bed materials, engineering judgment, and a rigorous structural analysis of the bridge piers, to determine comparative vulnerability of bridges to scour. A thorough assessment of available bridge data is important in this three-step process in order to develop an optimum cost-effective program to accomplish the scour assessment task. Case histories of major bridges with and without foundation data are presented to illustrate the usefulness of the proposed approach.

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REFERENCES

Florida Department of Transportation (FDOT). 1995. *User's Manual for FB-Pier/FB-MultiPier Program.*

Florida Department of Transportation (FDOT) 1994 – 2005. Scour Evaluation Reports – Phase I through IV, Bridge No. 010093, US-17 Over Shell Creek, Charlotte County, Florida.

Florida Department of Transportation (FDOT) 1995 – 2008. Scour Evaluation Reports – Phase I through IV, Bridge No. 100301, SR-60 Over Tampa Bay, Hillsborough County, Florida.