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January 21, 2005

Via Electronic Mail

Patrick P. Hickox, P.E.
Southeastern Regional Office
Figg Bridge Engineers, Inc.
422 North Calhoun Street
Tallahassee, FL 32301

RE: Project No. 5782.GA
Addenda 1 & 2 Scour Analysis Summary
Proposed Indian River Inlet Bridge
Indian River Inlet, Sussex County, Delaware

Dear Mr. Hickox:

We have completed our report titled "Scour Analysis Evaluation, Proposed Indian River Inlet Bridge; Sussex County, Delaware." Enclosed are two bound copies. These services were performed in general accordance with Addenda 1 & 2 of an existing agreement between Duffield Associates, Inc. and Figg Bridge Engineers, Inc., (Figg) dated August 23, 2004 (revised September 7, 2004, October 11, 2004, and December 15, 2004).

We have appreciated this opportunity to be of continued service to you. If you have any questions or require further information, please do not hesitate to contact us.

Very truly yours,

DUFFIELD ASSOCIATES, INC.

Peter G. Kearney, P.E.
Project Manager

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Enclosure: Report (2 bound copies)

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SCOUR ANALYSIS EVALUATION

PROPOSED INDIAN RIVER INLET BRIDGE
SUSSEX COUNTY, DELAWARE

January 2005

Prepared for:

Figg Bridge Engineers, Inc.
422 North Calhoun Street
Tallahassee, Florida 32301

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Project No. 5782.GA

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I. INTRODUCTION

Duffield Associates, Inc. was retained by Figg Bridge Engineers, Inc. (Figg) to perform scour analyses for the proposed Indian River Inlet Bridge structural support element foundations, as well as the proposed Mechanically Stabilized Earth (MSE) walls. The analyses consisted of performance of local scour analyses for the proposed arch support foundations and expansion joint abutment foundations utilizing methods outlined in Chapter 6 of the FHWA Hydraulic Engineering Circular No. 18 (HEC-18) Manual, as requested by the Federal Highway Administration (FHWA) during a project meeting on August 19, 2004. Analysis of contraction scour utilizing the HEC-18 Manual and estimation of the potential scour at the proposed MSE walls were also requested. These services were performed in general accordance with Addenda 1 & 2 of an existing agreement between Duffield Associates, Inc. and Figg Bridge Engineers, Inc. (Figg), dated August 23, 2004 (revised September 7, 2004, October 11, 2004, and December 15, 2004).

It is understood that the project team evaluated the foundation options and the unsupported lengths that they can support concurrently with this scour evaluation. It is also understood that, depending upon the results of the foundation evaluation, methods of scour protection may or may not be included in the final design for individual bridge support elements.

Initially, "preliminary" or draft analyses of the potential scour were performed by Duffield Associates, which were subsequently summarized and forwarded to Figg and the FHWA for review and discussion prior to finalizing the results. The FHWA commented on the draft results and also provided several recommendations in a memorandum, dated December 21, 2004, which was forwarded to Duffield Associates by Figg on December 28, 2004. The following report summarizes the results of our analyses, and provides responses to comments and recommendations provided by the FHWA.

II. INFORMATION PROVIDED

To assist with the analyses, Figg provided copies of the proposed foundation layouts via electronic mail on October 19, 2004. The electronic mail contained a .pdf file of the three different foundation options for the proposed bridge. In addition, Dr. Kobayashi of the Center for Applied Research (CACR) at the University of Delaware provided a copy of a report titled, "Coastal Engineering Assessment of Storm-Induced Scour Problems for Proposed Indian River Inlet Bridge," dated April 2004. As indicated in the project proposal, the storm interval, overland flood depth, and current velocity from Dr. Kobayashi's report were utilized in the HEC-18 analyses as indicated in Table 1.

Table 1: Water Depths and Current Velocities

	STORM FREQUENCY		
	50-year	100-year	500-year
Overland Water Depth (ft)	3	5	7
Current Velocity (ft/s)	2.7	3.7	4.5

III. HEC-18 CONTRACTION SCOUR ANALYSIS

Chapter 5 of the FHWA HEC-18 Manual outlines several procedures for evaluating the potential scour due to contraction from a variety of bridge configurations. In order to simplify the analysis, it was assumed that the potential scour at the portion of flooded land between the Inlet channel and the expansion joint abutment is of primary importance when related to the total scour at each bridge support element.

The following general assumptions were made in order to perform the analysis:

- Live-bed contraction scour (Section 5.3) is anticipated at the Indian River Inlet because it is assumed that materials will be transported from the beaches and dune systems towards the proposed Bridge during a storm event;
- Overland areas on either side of the channel are analyzed separately disregarding the channel (i.e., scour of the existing channel is not of primary interest);
- Due to conservation of mass, the upstream flow (Q1) is equal to the flow in the contracted channel (Q2);
- The upstream channel width is assumed to equal the width of land between the channel and the expansion joint abutment (subtracting the width of the arch support), plus one-half the width of the approach roadway;
- The contracted width is assumed to equal the width of land between the channel and the expansion joint abutment (subtracting the width of the arch support); and
- The existing depth prior to scour is approximated by the overland water depth (y0 = y1).

The results of the live-bed contraction scour analysis for the various storm events are included in Table 2.

Table 2: Estimated Contraction Scour

	STORM FREQUENCY		
	50-year	100-year	500-year
Estimated Contraction Scour (ft)	2.6	4.4	6.2

IV. HEC-18 COMPLEX PIER ANALYSES

Chapter 6 and Section 6.4 of the HEC-18 Manual outline procedures for analyzing local scour for complex pier foundations, such as those proposed for the new Indian River Inlet Bridge. The analysis consists of estimating the scour due to each component of the bridge support structure and foundation, assuming that contraction scour has occurred first. For the purposes of these analyses, there were two bridge support structures evaluated: the arch support and the expansion joint abutment. The arch support consists of the arch support pier, the pile cap, and the pile group. The expansion joint abutment consists of the abutment, the pile cap, and the pile group. Because the arch support and expansion joint abutment are of different sizes, and require different numbers of piles, each case was analyzed separately.

The following general assumptions were made in order to perform the analyses:

- The original ground surface before scour is 5 feet above the top of the pile cap;
- The water depth is defined as the flood water depth plus the contraction scour;
- The direction of flow is perpendicular to the bridge structure (i.e., directly onshore);
- Soils conditions were assumed to be sandy with a D50 of 1 mm and a D85 of 3 mm; and
- For the expansion joint abutment, the evaluation disregards the presences of the approach roadway and assumes the abutment is a single element similar to the arch support.

V. TOTAL ESTIMATED SCOUR

According to the HEC-18 Manual, the total scour may be caused by any combination of the following contributors:

- Long-term degradation;

- Local scour due to the bridge support structures and foundations; and
- Contraction.

Because the arch support foundations and expansion joint abutment foundations are not proposed to be constructed in the Inlet (subaqueous environment), there should be no long-term degradation contribution to the total scour. However, the FHWA comments indicate that it would be appropriate to include the potential long-term affects of sea level rise to the evaluation of scour at the bridge foundations. Sea level rise may affect the estimated flood depths and velocities that were utilized to calculate the scour depth provided in Dr. Kobayashi's report. Inclusion of the sea level rise estimate provided in the FHWA memorandum increase the total scour estimate by less than 2%, which is assumed to lie within the margin of error anticipated for the given analysis. Therefore, for the purposes of our analysis, the total estimated scour is assumed to be a function of local scour and contraction scour only.

A. ARCH SUPPORTS

The maximum total estimated scour for the arch supports given each storm event is included in Table 3.

Table 3: Estimated Total Scour at the Arch Support

	STORM FREQUENCY		
	50-year	100-year	500-year
Estimated Total Scour (ft)	21.6	27.6	34.5

According to the FHWA memorandum, an additional analytical approach was utilized by the FHWA to evaluate the potential scour at the arch support foundation. The additional method utilized is indicated to be a new approach developed by the Florida Department of Transportation (FDOT) specifically for evaluating scour of piers in a coastal environment. While Duffield Associates has no technical basis for evaluating the FDOT method, the results presented in the FHWA memorandum appear to be consistent with those estimated utilizing the HEC-18 methods.

B. EXPANSION JOINT ABUTMENTS

The maximum total estimated scour for the expansion joint abutments given each storm event is included in Table 4.

Table 4: Estimated Total Scour at the Expansion Joint Abutment

	STORM FREQUENCY		
	50-year	100-year	500-year
Estimated Total Scour (ft)	27.2	33.8	39.3

The FHWA memorandum suggested that utilizing the methods outlined in Chapter 6 may provide results that are more conservative that methods specifically developed for abutments, which are included in Chapter 7. Based on this comment, the HIRE equation (Equation 7.2 from Chapter 7,) was utilized as a "check" of the results from the complex pier analysis of the abutment. The estimated scour depths from the HIRE equation were somewhat lower than the estimated utilizing the complex pier methods. However, the results from both methods of analysis are of the same order of magnitude.

VI. MSE WALL SCOUR

Because of the complex nature of the topography in the vicinity of the proposed bridge, which in turn may lead to complex flow patterns during flooded conditions, a rigorous analysis would be required to evaluate the potential scour at the MSE walls. However, for the purposes of this evaluation, methods for evaluating contraction scour in Chapter 5 of HEC-18 were assumed for the MSE walls in order to provide an order-of-magnitude estimate of potential scour. The estimates for the MSE wall scour are equal to the contraction scour estimates provided in Table 2 of this report.

VII. DISCUSSION

The foundation and support elements of the proposed Indian River Inlet Bridge are to be constructed in a coastal environment, which may be subject to short-duration storms (i.e., 24 to 48 hours) with forces due to tidal currents, non-breaking waves, and breaking waves as evaluated and discussed in Dr. Kobayashi's report. The estimates of scour calculated for this evaluation are based on estimated flood depths and current velocities provided in Dr. Kobayashi's report and equations in HEC-18 developed from empirical results for bridges typically constructed in riverine environments. The HEC-18 manual indicates that the methods utilized in the manual may provide conservative results in the absence of physical modeling or more extensive analysis. In addition, while the duration of a storm event may be shorter in a coastal environment, scour may occur rapidly and, as indicated in Dr. Kobayashi's report, may occur at a rate of up to 1 foot per hour. Based on the FHWA results from the FDOT analysis, it appears that the results from the HEC-18 analyses provide adequate estimates of scour for this project and for the more severe storm events (i.e., 100-year and 500-year) the potential scour depth is estimated to be closer to the upper limit of the estimated range presented in Dr. Kobayashi's report.

Based on the results of the analyses performed, several potential options exist to protect the proposed bridge in the event of severe storms. Such options include:

- Protection of the foundation and MSE wall elements utilizing an armor blanket, such as rip-rap, soil filled geotextile tubes, soil filled geotextile bags, in an attempt to prevent or prolong the removal of soil from around and beneath the bridge elements due to storm events;
- Design the bridge elements to be able to withstand the extreme storm and scour conditions estimated; or
- Some combination of the above options.

It is understood that structural analyses have been performed by the project team on the structural support elements for the bridge utilizing the total scour estimates provided during the course of the evaluation, which are summarized herein. It is also understood that, based on the results of the structural analyses, Figg has indicated that the foundation options (i.e., drilled shafts or driven piles) for both the arch support and the expansion joint abutment will be stable if the estimated scour occurs. Therefore, the project team is considering using scour protection limited to the expansion joint abutment foundations and the MSE walls. Scour protection for the expansion joint abutments will be installed to reduce the effects of scour at the foundation elements on the adjacent MSE walls. Recommendations for scour protection for these elements are provided in the following sections.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Based on the HEC-18 analyses performed as part of this evaluation, the following conclusions and recommendations are provided:

1. The results of total scour from the HEC-18 analyses fall within the limits of the total scour range of 2 to 50 feet estimated in Dr. Kobayashi's April 2004 report. The results also tend to indicate that for the more severe storm events (i.e., 100-year and 500-year) the potential scour depth is estimated to be closer to the upper limit of the estimated range.

2. The HEC-18 manual indicates that the methods utilized in the manual may provide conservative results in the absence of physical modeling or more extensive analysis. FHWA performed an additional method utilizing a new approach developed by the Florida Department of Transportation (FDOT) specifically for evaluating scour of piers in a coastal environment. Comparison of the results of both analyses indicates that they provide comparable results. Therefore, it is recommended that the values obtained from HEC-18, and included herein, be utilized for subsequent analyses by the project team.

3. Because of the complex nature of the topography in the vicinity of the proposed bridge, a rigorous analysis would be required to evaluate the potential scour at the MSE walls. For the purposes of this evaluation, methods for evaluating contraction scour in Chapter 5 of HEC-18 were assumed for the MSE walls in order to provide an order-of-magnitude estimate of potential scour. Based on the results of the contraction scour analysis, scour at the MSE walls was estimated to range between approximately 2.6 feet to 6.2 feet depending upon the frequency of the storm. However, portions of the MSE wall closer to the foundation elements of the expansion joint abutments may encounter additional scour due to the presence of the foundations. Therefore it is recommended that scour protection be provided for both the expansion joint abutment foundations and the MSE walls.

This report has been prepared according to generally accepted engineering standards, and is based on the based on the simplified analyses as outlined in the FHWA HEC-18 Manual and parameters provided in Dr. Kobayashi's April 2004 report. The results of the analyses are estimates of potential scour and do not indicate an in depth evaluation. Interpretation of this data should consider the requested scope of services and the conditions encountered at the site as a whole. In the event that changes in the presentation of this data are proposed, this report will not be considered valid unless the changes have been reviewed and the recommendations of this report modified and re-approved in writing by Duffield Associates, Inc.

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