HARRIS COUNTY TOLL ROAD AUTHORITY

March 10, 2020

Commissioners Court
Administration Building
Houston, Texas 77002

SUBJECT: Transmittal of the Independent Analysis, completed by COWI North America, Inc. in support of the Harris County Toll Road Authority's Ship Channel Bridge Program, for recommended acceptance, and possible discussion and action
Precinct 2

Dear Court Members:

Provided for your review, recommended acceptance, and possible discussion and action, is a transmittal of the independent analysis (report) recently completed by COWI North America, Inc. (COWI), in support of the Harris County Toll Road Authority's (HCTRA) Ship Channel Bridge Program. In 2019, COWI was contracted to Harris County, through HCTRA, to perform a fully independent analysis and structural check of the Sam Houston Ship Channel Bridge cable-stayed unit (under construction). To complete their fully independent analysis, COWI did not undertake any engineering to mitigate non-compliance with the project requirements, engineering which might justify acceptance of non-compliance of the design with project requirements or engineering which might justify design approaches alternative to those covered in the design standards specified for this Project.

COWI's independent analysis identifies twenty-one areas of significant concern, with additional concerns and details summarized in their report. Further, COWI's report provides a summary of recommendations arising from their review. COWI's recommendations include:

1) Making Plan revisions for components not yet constructed.
2) Undertaking corrective work for some components already constructed.
3) Undertaking additional investigations into whether the potential consequences of leaving certain already constructed components as-is would be acceptable even though this review has identified that they do not conform to the Project standards.
4) Requesting the Designer to validate the bridge design accounting for current information.

It is recommended that Commissioners Court accept this report and that COWI and HCTRA's Ship Channel Bridge design team (including Figg Bridge Engineers, Inc.) be authorized to work jointly with each other, while under contract to Harris County, to resolve the concerns identified in the COWI report. It is further recommended that, if necessary, HCTRA be authorized to prepare contract amendments or new contracts for Commissioners Court approval to effectuate resolution of the concerns identified in the COWI report.

We anticipate returning to Commissioners Court with an update on the Ship Channel Bridge Program's construction schedule and budget status once COWI and HCTRA's design team have begun their collaborative approach for resolution of the identified project concerns.

Sincerely,

Peter W. Key
Interim Executive Director

PWK:th
Attachment

cc: HCTRA Management Tisha Laws Agenda File

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FEBRUARY 2020
HARRIS COUNTY TOLL ROAD AUTHORITY

HOUSTON SHIP CHANNEL BRIDGE,

INDEPENDENT CHECK

FINAL REPORT

COWI

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FEBRUARY 2020
HARRIS COUNTY TOLL ROAD AUTHORITY

HOUSTON SHIP CHANNEL BRIDGE,

INDEPENDENT CHECK

FINAL REPORT

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PROJECT NO.	DOCUMENT NO.
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	2020 Feb 26		Brian Morgenstern	Don Bergman, PE	Don Bergman, PE

EXECUTIVE SUMMARY

Under terms of the Engineering Services Agreement (ESA) dated March 26, 2019 between COWI North America, Inc (COWI) and Harris County, acting for the Harris County Toll Road Authority (HCTRA), COWI has performed a fully independent analysis and structural check of the new Sam Houston Ship Channel Bridge Cable-Stayed Unit (HSC Bridge). The ESA has been amended by the First Amendment to Engineering Services Agreement (First Amendment to the ESA) dated 2019 August 13. The First Amendment to the ESA added, amongst other changes, checking of interim construction conditions to COWI's scope of services. Further references to the ESA refer to the ESA including modifications resulting from the First Amendment to the ESA.

COWI's check relates to the following structural conditions:

1 Completion of southbound (SB) structure, open to traffic.

2 Completion of full bridge, open to traffic.

3 Completion of full bridge, open to traffic and after time-dependent effects have occurred.

4 Temporary Construction Phases.

COWI's check is limited to comparison of the design, as depicted in the information supplied to us, to the Project requirements. COWI has not undertaken any engineering to mitigate non-compliance with the Project Requirements, engineering which might justify acceptance of non-compliance of the design with Project Requirements or engineering which might justify design approaches alternative to those covered in the design standards specified for this Project.

Highlights of COWI's check are summarized below:

<u>Information Basis for COWI's Check</u>

For performance of the check, COWI was provided with the Plans and Specifications, geotechnical reports produced for this project by Fugro USA Land, Inc (Fugro), wind reports produced by Boundary Layer Wind Tunnel Laboratory (BLWTL), a Vessel Impact Report produced

by FIGG, and other relevant information used for the design of the bridge. Under the terms of the ESA, COWI is entitled to rely on information provided by HCTRA, the Engineer of Record (EOR), and/or the Construction Engineer. Notwithstanding this provision COWI has generally reviewed the information provided for reasonableness. As a consequence, and in response to these high-level reviews by COWI, revised wind study information has been generated and provided for COWI's use. Additionally, COWI has independently developed some foundation information which supplements and/or replaces information provided by HCTRA. For both wind and geotechnical information, the new information generated during this study has been incorporated into this review as replacement and/or supplemental to the original information provided to COWI.

Design Standards for COWI's Check

Unless note otherwise in this Report, COWI's check is based on the design standards listed in the "Design Criteria and Notes" Plan sheets. We assume that HCTRA has agreed that these standards are suitable for this project. Detailed criteria used by COWI for this independent check are provided in Appendix F.

COWI's Structural Analysis Model(s)

COWI created an independent analysis model of the bridge, using different analysis software than used by the EOR (FIGG) and the Contractor's erection engineer (TY Lin). In accordance with the ESA, COWI's analysis model utilizes "joint coordinates and member connectivity that are consistent with the original design models", however all input data have been independently developed or verified by COWI. In addition, COWI has incorporated greater or differing modeling detail in some cases where it was judged necessary to accurately model the structure. Modeling for the foundations is an example where the COWI modelling differs from that of the Designer.

Construction sequences and scheduling that significantly affect the final forces in individual components of the structure have been captured by modeling relevant progressive construction stages in the analysis as detailed in the Contractor's erection analysis submission which has been accepted by HCTRA.

Foundation Behaviour Characteristics

Early in COWI's checking process we became concerned that the Designer's assumption that all piles in a group have an equal vertical load-displacement response was unconservative. This is a particular concern for the HSC Bridge because of the soil conditions at this site and the high loads, large size and unusual loading patterns on the pylon foundations.

Fugro's design stage PLAXIS model results, which were made available to COWI, indicated that the piles would not have an equal vertical load displacement response. With the assumption of equal response, a concentric vertical load on the pile group would result in equal loads in all the piles if the pile cap (footing) were rigid. As a result of discussions with Fugro and further investigations by COWI, HCTRA requested that COWI independently investigate the vertical load-

displacement response of piles, in particular the variation of this response depending on the pile location within the pile group.

In response to HCTRA's request, COWI first engaged a recognized expert in the field (Dr Bengt Fellenius) to apply an approximate method to estimate the expected distribution of pile forces in pylon foundation M3. The approximate method confirmed that pile loads would be concentrated to the corner and side piles. The load sharing estimated by Dr Fellenius results in significantly greater demands on the foundation components, particularly the pylon pile caps, than would result from the assumption of equal pile response as used for the design.

To check the reasonableness of Dr Fellenius' approximate method, comparison was made to reported measurements of pile load distribution in other large piled foundations. Documented measurements of 22 case histories show that the distribution of pile loads within a group is related to the pile spacing. For the average foundation M3 pile spacing, the pile load ratios estimated by the approximate method are within the range of the reported case history values, thus supporting the values estimated by Dr Fellenius for foundation M3 of the HSC Bridge.

To more confidently address the load sharing between piles in a group, HCTRA authorized COWI to undertake an independent assessment of the foundation pile-soil interaction characteristics using detailed 3-D PLAXIS modelling of the pile groups in the soil medium. PLAXIS analysis models were created for foundations M1, M3 and M4. The analyses confirmed the trend for pile loads to be concentrated in corner and side piles, and the results of the PLAXIS study have been incorporated into the evaluations contained in this Report.

Loading Criteria Used for COWI's Check

The loading criteria used for design have been adopted for COWI's design check, with some exceptions. Key exceptions are discussed below.

Wind Loading

Wind loadings for design were determined through a project specific wind study and wind tunnel tests conducted for FIGG by the Boundary Layer Wind Tunnel Laboratory (BLWTL). BLWTL provided recommended design wind speed return periods for stability and for strength under construction and completed structure configurations. The BLWTL report recommends design for a 100-year return period mean hourly wind speed for the completed bridge and a 10-year return period mean hourly wind speed during construction. The 10-year mean hourly wind speed corresponds to wind loads that are approximately 34% of the wind loads for the 100-year return period wind speed. Notwithstanding the BLWTL recommendation, COWI understands that the Designer checked certain components for a 25-year return period wind for construction stages following completion and opening of the SB structure. The 25-year wind forces are approximately 60% of the 100-year wind forces at this site, based on the return period wind information in the BLWTL report.

There is not a single generally accepted design return period wind for bridge construction. Generally, this is a judgement agreed with the project owner, designer and contractor based on

a project specific assessment of risk. Implications of this judgement decision are discussed in Section 6.4.1 of this Report. COWI assumes that these responsible parties have agreed that the wind criteria adopted for the construction period are suitable. COWI's design check has been conducted for 25-year return period wind during the construction period extending from start of construction until final completion of bridge construction.

The wind loads provided in BLWTL's report are in part based on structure dynamic properties which were provided to BLWTL by FIGG during the design. COWI's scope of services includes validation of the dynamic properties provided to BLWTL. COWI identified that the dynamic properties provided to BLWTL did not match the results of FIGG's analysis model which was provided to COWI, nor with the results of COWI's independent analysis model. As a result of this discrepancy FIGG generated new structure dynamic properties and provided those to BLWTL who in turn developed new wind loads. COWI used these revised wind loads for the in-service design checks described in COWI's Foundation Preliminary Report. These loads are different from the wind loads used to design the bridge.

While the new dynamic properties generated by FIGG for in-service conditions better matched with COWI's results, some differences remained which BLWTL stated were potentially significant. HCTRA then requested that COWI provide their structure dynamic properties to BLWTL, that BLWTL develop new wind loads using COWI's dynamic properties, and that COWI use those further revised wind loads for their design check. Concurrently, COWI identified an anomaly in the wind loads which BLWTL acknowledged to be an omission of some longitudinal components of the wind loading. After COWI provided their calculated structure dynamic properties, new in-service wind loads were generated by BLWTL based on COWI's dynamic properties and with corrections for the previous longitudinal wind load omission.

A similar sequence occurred for construction stage wind loads as for in-service wind loads. In response to COWI's observation about the dynamic properties that had been provided to BLWTL for development of wind loads, FIGG provided new construction stage dynamic properties to BLWTL and BLWTL calculated new construction stage wind loads. After receiving these new wind loads, COWI observed that the dynamic properties provided to BLWTL for calculating the wind loads did not match COWI's dynamic properties. In this case, the greatest differences arose because FIGG's analysis did not consider the presence of the temporary tower included in the construction process, did not account for the flexible elastomeric bearings which will be present on the NB structure at some stages of the construction, and did not recognize the significant difference in dynamic properties between the partially completed SB structure during Phase 1 construction and the combined system of the completed SB structure and the partially erected NB structure during Phase 2 construction. In addition, COWI and BLWTL agreed that the two construction conditions for which wind loads had been previously generated were insufficient for checking the critical construction stages. As a result of these considerations, BLWTL calculated new wind loads for the critical construction stages examined by COWI.

The Contractor's engineer, TY Lin, is using the wind loads from the original BLWTL study in the contractor's construction engineering. These wind loads have been superseded.

Traffic Loading During Construction of the NB Structure

Traffic on the SB structure contributes to demands on the partially erected NB structure due to interaction through the interconnected pylons during Phase 2 construction. COWI has considered the effects of traffic loading on the SB structure during construction of the NB structure but believes that the Contractor has not. The Contractor's erection analysis submission has been reviewed by the Designer and accepted by HCTRA. The effects of this load condition are significant and COWI concludes that consideration of this loading condition is necessary.

Foundation Settlement

As part of the pile-soil foundation study conducted by COWI, independent foundation settlement estimates were developed and have been incorporated into COWI's check analyses in place of the settlement estimates contained in the Fugro report. COWI's estimated settlements, and differential settlements, are significantly less than Fugro's. The differences in foundation settlement estimates affect the required construction geometry and potentially the stresses in the completed structure. The Fugro estimates are being used by the Contractor for determining required structure geometry adjustments. The Contractor's erection analysis submission provided to COWI does not include a contingency plan for dealing with settlements differing from their assumptions, if that should occur. COWI's analysis assumes that the Contractor will carefully monitor foundation settlements and adjust their construction geometry accordingly.

Structural Capacities

Component structural capacities were calculated in accordance with the project standards unless otherwise noted. Material properties have been taken as the contractually specified minimum values. For the pylon pile caps, consideration has also been given to greater concrete strength as indicated by test results for the as-constructed concrete. The basis for selection of the as-constructed concrete strengths is described in Appendix I.

The two common methods for evaluating bending and shear capacity of concrete elements are termed sectional analysis and strut-and-tie analysis (S-T). In COWI's opinion, the S-T method is the appropriate method for assessing the pylon pile caps, however the governing design standards for this Project do not specifically prohibit the use of sectional analysis. The S-T method applied in compliance with the Project specified standards (TxDOT BDM 2013 and AASHTO-LRFD 2012/13 standards) would demonstrate less pile cap capacity than the sectional analysis. The sectional analysis method has been used in developing the pile cap evaluation results presented in this Report.

Geotechnical Capacities

Geotechnical capacities used in COWI's check rely on Fugro's geotechnical report. According to Fugro's report, pile lengths were selected to provide pile geotechnical capacities with a factor of safety of at least 2 for sustained loads and transient loads on an individual pile basis and as a pile group. Fugro states that reduction of pile capacity for group effects is not required. Fugro does not specifically state the values of the pile capacities they determined, however based on

the preceding information, COWI infers that the capacities determined by Fugro are approximately (but not less than) two times the maximum service loads shown on Plan Sheet 454 which is sealed by both Fugro and FIGG. These inferred pile capacities have been adopted in the evaluations of geotechnical demand/capacity ratios presented in this Report.

Findings:

The following Table briefly summarizes the most significant concerns identified. Additional information can be found in the Report sections noted.

	Description	Report Reference
Design Parameters		
1	COWI considers the pile load-displacement relationship assumed for design inappropriate, significantly affecting the calculated loads in the piles and pile caps.	6.3.2
2	COWI's estimates for pylon foundation settlement and tilt are significantly less than used by the Contractor for construction analysis to develop the deck casting geometry and plan the erection process, including stay tensioning.	6.4.4,6.5.3,
Loading		
3	Multiple changes to the wind loading used for design of the in-service bridge have been found necessary as a result of COWI's review. COWI considers the wind loading used for design unreliable.	6.5.1.2
4	Multiple changes to the construction period wind loading have been found necessary as a result of COWI's review. HCTRA provided the original construction stage wind loading to the Contractor for use in their construction analysis. COWI considers the construction wind loading used for construction analysis unreliable.	6.5.1.3
5	Traffic load on the SB structure has not been considered in the Contractor's analysis for NB structure erection. COWI believes that such consideration is necessary.	6.6

Design Findings - Foundations		
6	Pile geotechnical capacities do not meet the Project requirements at any of the foundations.	7.1 to 7.4
7	Pylon pile cap structural capacities do not meet the Project requirements for strength.	7.3.2, 7.4.2
Design Findings - Substructure		
8	Pylon curved leg regions do not have the required capacity.	8.2.6.1
9	Pylon leg cross-tie arrangements do not satisfy AASHTO-LRFD requirements.	8.2.6.2
10	Pylon legs at deck level kinks require additional restraining reinforcing.	8.2.6.4
11	Reinforcing at the lower pylon leg access door openings does not have the required capacity.	8.2.6.7
12	Reinforcing in the pylon legs at transition zones from hollow to solid legs and adjacent to upper diaphragms does not meet the Project requirements.	8.2.6.3, 8.2.6.5
13	Reinforcing at the connection of the pylon leg tops does not have the required capacity or details.	8.2.6.6
Design Findings - Superstructure		
14	Shear reinforcing in edge beams of the superstructure does not meet the Project requirements.	9.3.3.1
15	COWI was informed that the stay segments are being re-designed to add capacity for transfer of stay loads into the segment webs. Consequently COWI did not complete a check for related aspects of the design.	9.3.3.1.2
Design Findings - Cables		
16	Slip resistance of stay cables in cradles in pylons does not meet the Project requirements in-service or during construction.	10.1.2, 10.2.2

Construction Related Findings		
17	Construction wind loads provided for use by the Contractor have been superseded.	6.5.1.3
18	Settlement data provided for use by Contractor may not be accurate. Contingency plans are recommended.	6.5.3
19	Cable slip checks provided by the Contractor are not in accordance with the Project Requirements.	10.1.2
20	Traffic load on the SB deck while the NB deck is being constructed needs to be considered in the Contractor's analysis.	9.2.1.2
21	Transverse local stress and strength checks under the segment lifter are required. Adjustments to the lifter support arrangement may be needed.	9.2.1.1.2

Additional concerns identified during COWI's review are summarized in Section 11.

Recommendations:

Section 12 of this Report provides a summary of recommendations arising from COWI's design review. The recommendations include making Plan revisions for components not yet constructed, undertaking corrective work for some components already constructed, and undertaking additional investigations into whether the potential consequences of leaving certain already constructed components as-is would be acceptable even though this review has identified that they do not conform to the Project standards.

The most critical recommendation is that HCTRA request the Designer to validate the bridge design accounting for current information including, but not limited to, the following design parameters identified as concerns during COWI's review. Additional information for the listed items can be found in the Report sections noted in brackets.

1 Wind loads calculated using updated structure dynamic properties which are not the same as those originally used for design. (6.5.1)

2 Wind loads which include the longitudinal components of wind which were previously missed. (6.5.1)

3 Wind loads which include dynamic wind on cables calculated in accordance with PTI 2012 recommendations rather than using the method recommended by BLWTL which is nonconservative. (6.5.1.5)

4 Wind loads in combination with traffic loads during construction which apply a wind load factor that, when combined with the reduced construction period wind speed, results in a wind speed in combination with traffic which is consistent with the wind speed that AASHTO-LRFD intends to be used in combination with traffic. (6.6)

5 Traffic loads applied on the SB structure during erection of the NB structure. (6.6)

6 Pile vertical load-displacement responses which reflect calculated (not assumed) behavior of each pile based on the pile's location within each of the HSC Bridge foundations, considering the soil conditions at the foundation under consideration. (6.3)

Designer Input to this Report:

A draft copy of this Report was provided to HCTRA on 2020 February 7. HCTRA in turn provided a copy to the Designer, FIGG. COWI was subsequently provided with comments from FIGG on the draft report. This final Report version has responded to several of those comments by providing additional information and explanations, and in some cases minor adjustments to the text. Many of the comments and questions received from FIGG were aimed at reconciling differences between the design and COWI's findings, which was not possible within the available time and which was outside COWI's scope of services for an Independent Check. In the event that HCTRA so wishes, COWI is prepared to review FIGG's design calculations to better understand the source of differences between the design and COWI's independent check and engage in discussions with FIGG to reconcile those differences.