1223 Michael Street, Suite 100, Ottawa, ON K1J 7T2
Tel: 613.738.4160 ● Fax: 613.739.7105
www.delcan.com

November 27th, 2013 Our Ref: BO2243BOB

City of Ottawa
Infrastructure Services Department
100 Constellation Crescent, 6th Floor West
Ottawa, ON, K2G 6J8

Attention: Carina Duclos P. Eng.
Manager - Infrastructure Services Special Projects

Dear Mrs. Duclos:

RE: Hunt Club Community Pathway Bridge over the Airport Parkway Report on Initial Investigation of Schemes to Complete the Bridge

1. INTRODUCTION

Observations by Delcan in June/July 2013 made in the context of a request to assist the City of Ottawa with discussions between the Contractor and Genivar about the connections of the pipe stays to the tower anchorages, led to our recommendation to the City of Ottawa ("the City") that a third party be brought in to review the design and construction of the main footbridge. Buckland & Taylor was subsequently retained by the City to undertake this review and their findings reflected our initial concerns.

Pursuant to the City's subsequent request, Delcan has now carried out a preliminary study for the City with a view to developing a methodology and recommended scheme for the completion of the Hunt Club Community Pathway Bridge over the Airport Parkway ("the Bridge"). This work has involved the development and consideration of a range of schemes, further development and evaluation of schemes judged to have particular merit, and finally the recommendation that a steel deck cable-stayed bridge scheme be carried forward to detailed design.

Delcan has carried out this work as quickly as possible and in conjunction with a series of meetings with the City and others, in order to assist in expediting the overall schedule of the project with a view to the earliest reasonable completion of the bridge. We have been assisted in this by our geotechnical engineering sub-consultant Golder Associates and our wind/vibration specialist sub-consultant RWDI.

2. SCOPE OF DELCAN'S DESIGN ASSIGNMENT

Once the options analysis has been completed and the recommendations for the preferred alternative has been accepted, the scope of the assignment involves the undertaking of a design to enable the completion of the bridge and does not involve other components of the project with the exception of the allowance in the design, for the completion of the lighting work and duct work on the bridge itself. We understand that the components of the overall project which have been completed prior to the commencement of this assignment have been completed in accordance with Genivar's designs, and they remain Genivar's responsibility as the original designer and certifier of those designs.

3. DESCRIPTION OF GENIVAR'S DESIGN

Certain elements of the Genivar bridge design have been completed on site, including the approach spans and their foundations, and the tower and its foundations, with the exception of the works required to complete the tip of the tower and to anchor the pipe stays to the tower.

A review by Buckland & Taylor has been carried out examining and reporting upon the Genivar bridge design, which included a number of comments with regard to the pipe-stayed bridge design.

Our appreciation of the pipe stays and our understanding of Buckland & Taylor's report suggested to us that it would be inappropriate to move forward with the completion of the bridge using the pipe stays, particularly since these fatigue-prone elements as configured in the Genivar Design, are fracture-critical members in that the failure of one of them would almost certainly result in the collapse of the bridge. Our recommendation was, therefore, that pipe stays be abandoned and replaced by conventional multi-strand cable stays.

A detailed review and assessment of Genivar's original bridge design is not included within Delcan's scope of work.

4. STATUS OF THE PROJECT ON SITE

Delcan's assignment commenced with a site visit and meetings on site on September 5, 2013. We visited the entire site but our focus was on the bridge as it is the bridge only that is within the scope of this assignment. The general status of the project at that time was as follows:

- The tower and its foundation were largely complete with the exception that the tip of the tower, where the stays connect, had not been completed and reinforcing steel projected from the top of concrete at that location. Concrete finishing works were being carried out on the tower concrete.

- Formwork and falsework were in place across the proposed main bridge spans.

- The approach spans, including deck, parapets, piers, abutments and associated foundations, were largely complete.

Essentially, what remained to be built was the main span deck and parapets, installation of the pipe stays, stay attachment at the tip of the tower, expansion joints, bearings, railings and incorporated lighting, as well as miscellaneous finishing works.

Background Information

Background information was made available to Delcan for consideration including the following:

- Tender documents, including Addenda 1 and 2;
- Tender drawings in CAD format;
- Artist's renderings of bridge;
- Design review report by Buckland & Taylor;
- Geotechnical Investigation Report by Houle Chevrier;
- Shop Drawings (incl. revisions) for deck, parapet, substructure and tower rebar; railings; stays and stay anchorages; and expansion joints;
- Concrete mix designs and material testing;
- Piling reports and PDA report;
- Technical specifications for concrete sealer and paint; and
- Site photos during construction.

5. OBSERVATIONS ON EXISTING BUILT COMPONENTS

Cracks in the Tower

A crack survey was carried out for existing bridge infrastructure and was recorded by Delcan personnel. The existence of cracks in the tower was noted, including the clear patterns associated with many of these which will be further investigated during design. Our initial analysis does not indicate that these are of serious concern, and they will be fully addressed in detailed design.

Cracks in the Approach Spans

Circular cracks in the top surface of the concrete deck were noted above each of the circular column capitals in the approach spans. These had already been subject to repair at time of inspection. It is understood that these have been characterized as shrinkage cracks by others, although the location and pattern would seem to indicate that these could be structural in nature.

Delcan's structural analysis of the approach spans suggests that the cracks observed around the column capitals on the bridge deck surfaces, are structural cracks caused in part by the low modulus of elasticity of the Glass Fiber Reinforced Polymer (GFRP) reinforcing used to reinforce the deck. The current layout of the deck reinforcing is causing excessive flexure of the deck in order to carry the parapet loads to the column below, thus resulting in inadequate crack control at the serviceability limit state. It is accordingly necessary to strengthen the bridge's approach spans at these locations. We have developed alternate schemes for doing this and suggest that the scheme to be selected and implemented should best accord with the architecture and aesthetics of the main spans. A thin wearing surface with waterproofing will also be added throughout the approach and main spans to further enhance the durability of the deck and prevent water infiltration within the existing cracks.

6. DESIGN SCHEMES TO COMPLETE BRIDGE CONSTRUCTION

Geometric Considerations

The original bridge design included a limited clearance between the underside of the structure and the roadway clearance envelope defined for the Airport Parkway. At the same time, the approach structures have been built, as has the tower, and this means that adjustments to the profile of the main spans cannot be more than very minimal, and indeed the profile should remain unchanged. This in turn means that structural alternatives for the main span which involve deep superstructure dimensions, such as deep steel girders or under-deck arches, cannot be considered for the main span of this bridge unless the approach spans and possibly the tower are fully rebuilt. Therefore, the primary bridge schemes which can be considered possible from the geometrical perspective are as follows:

1) The Genivar-designed reinforced concrete pipe stayed bridge.
2) Reinforced concrete decks supported by cable stays.
3) A concrete slab bridge with no cable stays and supported by additional piers.
4) A custom steel truss bridge though the tower with no cable stays.
5) Demolition of the tower and introduction of a custom steel truss bridge or any other completely new bridge
6) Steel decks supported by cable-stays.

Environmental Assessment Requirements

The Environmental Assessment carried out for the project of which this bridge is a part, includes two key requirements namely:

a) The bridge is to span the current and future roadways and ramps for the Airport Parkway with a clear span, and hence with no intermediate piers.

b) The bridge shall be an aesthetically pleasing structure over the Airport Parkway and is to be an appropriate 'gateway' to the National Capital Region.

Based on the approved Environmental Assessment Report, bridges with multiple piers (that is to say, a pier between the current and future Airport Parkway and a pier between the future Airport Parkway and the Hunt Club ramp, for example) do not conform to the requirements of the Environmental Assessment Report and adoption of any such scheme would require an amendment to the Environmental Assessment Report. This process could take about two months but it also opens the environmental assessment process up to a bump-up to the Ministry of the Environment as it does not conform to the approved criteria. This process could result in a delay of up to a year before the design can even be started.

7. EVALUATION OF BRIDGE DESIGN SCHEMES

1) Genivar-Designed Reinforced Concrete Pipe Stayed Bridge

As indicated in Section 3 of this report, the Genivar-designed reinforced concrete pipe stayed bridge received no further consideration during the evaluation process.

2) Reinforced Concrete Cable-Stayed Bridge

In developing the reinforced concrete cable-stayed bridge, further modifications to the Genivar design included:

- The original Genivar design used the concrete parapets as the main structural elements of the concrete deck. The new deck cross-section was therefore modified so that the deck itself (rather than the parapet walls) was directly supported by the cable stays. This was done to prevent the most exposed bridge elements from being fracture critical members. This feature also means that if the parapets deteriorate in the future (something which we consider is possible given that the parapets will be exposed to heavy salting) the parapets can be removed and replaced without the requirement that the entire bridge be externally supported.

- Introduction of more cable stays to provide redundancy in the event of a cable stay failure, which is a Post-Tensioning Institute (PTI) requirement from PTI DC45.1-12: Recommendations for Stay-Cable Design, Testing, and Installation. This will also permit future stay replacement without fully shoring the deck and thus simplify the future maintenance of the bridge.

Detailed structural analysis of the reinforced concrete cable-stayed bridge showed that the tower foundation at serviceability limit states and at ultimate limit states, would experience overstressing of the front piles and uplift of the back piles. This would cause permanent deformation of the tower foundation, which could lead to the overturning of the tower. A key reason for this was that the tower, although it appears to lean toward the back span (to the east), actually tends significantly to rotate toward the main span (to the west). The reasons for this are the unusual shape of the tower and the location of the pile foundation offset toward the east compared with the centre of gravity of the tower. This is an unusual situation and it poses difficulties for the bridge as even under the tower load alone with no superstructure and no live loads, the front piles are already heavily loaded.

In seeking to alleviate this overall situation somewhat, we requested of Golders that they assess the geotechnical and pile installation records in order to determine whether or not some additional capacity could reasonably be assigned to the piles in both tension and compression. Golder was able to do this; however the improvements were limited. These improvements were taken into account in assessing the pile foundations for all schemes.

Strengthening the Tower Foundation

One methodology for improving the performance of the tower foundation is to provide additional deep foundations such as piles, micropiles, or caissons. Some consideration was given to this possibility and a number of schemes were considered. Foundation strengthening schemes by their nature however involve disturbing the soil beneath the existing structure and therefore always have the potential for causing additional movements during construction. Even with the most sophisticated and careful methods, soil movements are unavoidable and some soil loss may be sustained, leading to tower movements. These risks are noteworthy here where the soils are generally poor and there is a relatively high water table.

Another risk that should be mentioned is the close proximity of a 1.2m diameter watermain to the west of the tower. Any foundation strengthening scheme would need to take this into careful consideration to ensure this large watermain is fully protected during the strengthening construction activities.

There are two types of schemes which could be considered in principle, namely:

- Schemes to augment the existing deep foundation capacity.
- Schemes to replace the existing deep foundation capacity.

Either scheme can be envisaged but both of them have the risks noted above. Foundation strengthening is typically a costly time-consuming activity which should only be adopted if there is no other alternative, given the risks associated with it compared with the risks of working above ground in some way (for example, by developing a lighter superstructure for the bridge).

All of this suggested to us that the risks involved in moving forward with a reinforced concrete cable-stayed bridge design were excessive. This scheme was therefore not pursued any further.

3) **Concrete Slab Bridge Supported by Additional Piers**

This multiple pier concrete slab bridge alternative would not require foundation reinforcement and would enable the tower to be retained. However, due to the introduction of piers between the current and future Airport Parkway and the Hunt Club ramp, this alternative would eliminate the clear span required under the Environmental Assessment. The requirement to undertake an Environmental Assessment amendment would increase the risk of a Part II Order (bump-up request) that could delay the project 8 to 12 months. In addition to the potential issue related to Environmental Assessment amendments, this alternative would create some roadway safety concerns with numerous piers in close proximity to the roadway, which would require some mitigation. This scheme was therefore not pursued any further.

4) **Custom Steel Truss Bridge with Tower**

A steel custom truss bridge was developed in concept which spanned the Airport Parkway and ramp roadways in a clear span and which, when integrated with the tower in a thoughtful manner taking due account of bridge architecture considerations, could be considered to be a gateway bridge. This was a custom truss bridge which was designed to be compatible with the delta opening in the reinforced concrete tower of the original cable-stayed bridge design, and the overall scheme has the ability to be supported either in whole, in part, or not at all, on the tower foundations. It, therefore, provided the maximum flexibility with regard to controlling loads on the tower and the foundations and offered the opportunity for minimal loading on these elements of the bridge.

This option did not provide significant benefits with regards to costs and construction time, as it was viewed as having a reasonably long fabrication time and one of the higher costs. Also, from an aesthetic or gateway perspective, it did not naturally fit the site as it had to marry to the existing tower, which was designed originally to be compatible with a stayed bridge. This scheme was therefore not pursued any further.

5) **Custom Steel Truss Bridge without Tower**

A variation of the previous scheme would be a simpler custom steel truss bridge without tower that would clear-span the roadway. This option would require the full removal of the existing tower, therefore fixing the compatibility issues and enhancing the aesthetics of this concept. This option however, did not provide significant benefits with regards to costs and construction time, as it was viewed as having a reasonably long fabrication time and one of the higher costs. This scheme was therefore not pursued any further.

6) **Steel Cable-Stayed Bridge**

The steel cable-stayed bridge design includes an orthotropic steel deck, steel framing and steel handrails, and is an all-steel construction supported by conventional cable-stays to the tower. The City noted that it would be possible and acceptable from their perspective to add an additional pier to the west of the Airport Parkway if it would simplify the analysis and design. Even without the extra pier, this concept significantly reduces the loads on the tower, as the steel bridge deck is significantly lighter than the concrete bridge deck. Other potentially even lighter bridges were considered in principle including aluminum and Fibre Reinforced Polymer (FRP) bridges, but these were not carried forward as they added potential unknown complications to an already very complicated situation where we are attempting to fit a new bridge to an existing bridge design which is partly built and where the foundations have raised significant questions.

Development of the steel deck cable-stayed bridge design showed that the piling loads under serviceability limit states and under ultimate limit states were acceptable and from that perspective this bridge scheme can be considered to work. Detailed investigation of the tower, footing and foundation remain to be carried out with the final design of the deck, railing, cable-stays and wearing surface; however the results are not expected to change significantly from the initial assumptions and there are some design modifications that are available to the designer to provide reduced loading on the tower, if required. The steel deck cable-stayed bridge was therefore selected as the preferred bridge scheme.

Orthotropic steel bridge decks are found across Canada and around the world, including the lift span of the Pretoria Vertical Lift Bridge in Ottawa. This deck type will be essentially no different than other bridge type when it comes to winter maintenance, as the bridge deck will be covered by a high quality waterproofing with wearing surface. Although the precise waterproofing and wearing surface are yet to be selected, there are specialist systems that will support the designed long service life of this crossing.

Although we are currently in the early stages of our design, the bridge deck and railings will be designed to fully accommodate winter maintenance. We will be meeting with the City of Ottawa operations staff to clearly understand the desired winter maintenance approach that will be used for this structure so that it can be accommodated within the design. All structural steel will be fully painted in accordance with MTO standards, including the railings, unless the stainless steel railing alternative is selected. The initial railing concept will be fairly open to retain its lightness but will meet all Canadian Highway Bridge Design Code (CHBDC) code requirements. It may include removable solid panels that may be installed over the winter months for zones over the Airport Parkway, or it may be detailed to incorporate such a feature all year round for the full length of the bridge, these details have yet to be confirmed. Based on there being a waterproofing membrane with wearing surface, this bridge is not expected to be noisier than any other concrete decks.

The deck's lightness will require some sophisticated analysis to ensure that it does not have any adverse wind, vibration or pedestrian comfort issues. To deal with these issues, we have secured the assistance of the specialists from RWDI, and at this point they are, we understand, fairly confident that these can be addressed with some relatively minor design adjustments and that wind tunnel testing should not be required. Wind tunnel testing remains an option should it be necessary.

8. DEALING WITH SEISMIC LOADING

Now that the preferred bridge scheme has been chosen, the seismic loading for this bridge remains to be resolved as part of detailed design. The CHBDC classifies all bridges into three seismic importance categories, based on the importance of the crossing within the transportation network, considering social/survival and security/defence requirements. These three seismic importance categories are: Lifeline Bridge, Emergency Route Bridges and Other Bridges. This bridge crossing has been classified by the City as an "other bridge". This means, that it is not required to meet the same seismic performance criteria as Lifeline Bridges or Emergency Route Bridges. The CHBDC does require however that bridges within the "other" category must resist collapse following a major earthquake, defined as a seismic event with a return period of 475 years.

To assess the seismic performance of bridges, the Bridge Code offers the following four analytical methods: uniform load method; single-modal spectral method; multi-modal spectral method; and time-history method. Each of these analytical methods gets progressively more sophisticated and complex than the previous one, but can offer a much reduced level of conservatism. Typically in Ottawa, which is a seismic performance zone 3, the multi-modal spectral method offers the best results for the level of effort. It is important to note however that this analytical method that is undertaken using design spectra established for all of Canada, is still very conservative, particularly for Eastern Canada.

Our initial seismic analysis, using the multimodal spectral method with the design seismic event (475 year return period) revealed that the bridge does not meet the Bridge Code's seismic design requirements regardless of the lightness of the proposed steel deck. The issue remains the limited capacity of the tower foundation, which would experience overstressing of the front piles and uplift of the back piles. This would cause permanent deformation of the tower foundation, which could lead to the overturning of the tower. It is important to note however, that the gap between achieving seismic code compliance and not, is much less with the steel deck than with the heavier concrete deck. With this smaller margin we believe that a significantly more refined time-history analysis may provide a favorable result. Should they be required, rock anchors could be utilized to help resist any possible remaining seismic capacity deficiency, which would be a reliable reserve solution.

The plan, therefore, is to resort to a more refined and less conservative site-specific time/history analyses with a view to developing confidence that the bridge will not collapse under the loads imposed by the design seismic event (475 year return period). This is highly complex work which takes significant time. Shear wave site investigation needs to be undertaken to precisely predict the wave propagation through the soil strata at the site. Then site specific seismic spectra and time histories need to be developed for this geological area to permit the refined and iterative seismic analysis.

Ideally one would develop the preliminary design of the bridge, carry out the full seismic analysis to its resolution, and then decide whether or not we should proceed with detailed design. However in this case, although it has yet to be fully proven, we believe that the steel cable-stayed bridge does hold a reasonable potential for resolving the seismic issues and as indicated there are other adjustments that could be utilized to help resist any possible remaining seismic capacity deficiency.

9. CONCLUSION

In conclusion, Delcan is proceeding with the detailed design of the steel cable-stayed bridge. Through the detailed design of the steel cable-stayed bridge, we will carefully consider the aerodynamic behavior of the bridge, the vibrations of the bridge, consideration of damping and, in particular, issues related to pedestrian comfort. In addition, issues such as the transition between the concrete parapets on the approach spans and the steel railings envisaged for the steel cable-stayed bridge will be addressed. Similarly issues related to ducts found within those parapets, as well as the lighting and existing railings which have been designed for the original pipe-stayed bridge, will be resolved.

In summary, we are proceeding with the design of a steel cable-stayed bridge superstructure to complete the Hunt Club Community Pathway Bridge over the Airport Parkway.

W. Victor Anderson, ing., P.Eng.
Executive Vice President

Sylvain Montminy, ing., P.Eng.
Structures Division Manager, Vice President