Attachment 3

Memorandum

AECOM
ConnectEd Transit Partnership
10403 172 Street, Suite 220, Edmonton, AB, Canada T5S 1K9

To	Jeff Ward (COE)	Page	1
CC	Nat Alampi (COE), Art Washuta (CTP), Mark Perry (CTP),		
Subject	Recommendation for LRT Bridge over the North Saskatchewan River		
From	Scott Alexander (CTP)		
Date	October 15, 2012	Project Number	60222337

This memo is an addendum to the report entitled “North Saskatchewan River Bridge – Bridge Options Report” prepared by the ConnectEd Transit Partnership and dated September 2012. The September report describes the various alternative bridge designs considered for the Southeast LRT crossing of the North Saskatchewan River and recommends that further work be done on three of those alternatives, namely a variable-depth concrete box-girder bridge, an extradosed box-girder bridge, and a cable-stayed bridge. This purpose of this memo is to update the evaluation of the options and provide the results of an independent review of the three options as well as estimated costs of construction and outstanding risks.

Description of Alternatives

All three alternatives feature a shared use pathway (SUP) on essentially the same alignment as the existing Cloverdale Pedestrian Bridge. The SUP is suspended from the superstructure above. As shown in the September report, the SUP is approximately 9 meters wide with a central corridor between hanger supports for pedestrians and cyclists. The central corridor is flanked on either side by continuous viewing corridors. As an alternative, the pedestrian pathway could be reduced in width with viewing platforms constructed at the piers.

The existing pedestrian bridge has three piers in the river and provides a 70 meter wide navigation channel between the north and middle piers. For permitting purposes, the proposed LRT bridge will have to respect the existing navigation channel.

For any proposed LRT bridge type requiring a pier on the north side of the river, that pier is constrained to the same location as the existing pier of the river bridge. Moving it to the north could affect the stability of the north bank while moving it to the south will impinge on the existing navigation channel. With respect to the proposed LRT bridge, the north pier is located approximately 100 meters from the bridge abutment on the north bank.

<u>Variable depth concrete box-girder</u>: a three span bridge with spans of 60 m – 90 m – 60 m. The reduced midspan depth is intended to match that of the approach spans on either end. The north pier is at the same location as the north pier of the existing Cloverdale Pedestrian Bridge while the south

pier is located in the shallows on the south side of the river approximately 30 m from the south river bank.

This alternative has two piers in the river. The north pier is at the same location as the north pier of the existing pedestrian bridge. The middle span provides a navigation channel that is 90 meters wide. This is more than the minimum of 70 meters established by the existing bridge but it is considered better proportions for this type of bridge on this site.

Extradosed box-girder: two cable-reinforced spans of 100 m. The reduced girder section is intended to match that of the conventional approach spans. The north pier is located at the same location as the north pier of the existing Cloverdale Pedestrian Bridge while the south pier is located in the shallows on the south side of the river approximately 20 m from the south river bank. The main tower rises approximately 18 m above the deck.

The north span of 100 meters clears the least stable ground conditions. The south span of 100 meters balances the north span and provides a more-than-adequate navigation channel.

Cable stayed: a two span bridge with spans of 170 m – 90 m. The pier tower is located on the south side of the existing navigation channel, approximately 50 m from the south river bank, as far north as possible without encroaching on the channel. The north span of 170 meters clears the existing navigation channel (70 meters) plus the remaining distance to the abutment (100 meters). The pier tower rises approximately 68 m above the LRT deck level.

Evaluation of Bridge Options

The three bridge options noted above are subjectively evaluated based on five Engineering and three Sustainable Urban Integration (SUI) criteria. The bridge options are ranked within each criterion with the higher score indicating superior performance. The criteria are equally weighted, resulting in an aggregate score that is 62.5% Engineering and 37.5% SUI, a balance that is considered appropriate.

This section describes the criteria that were used to evaluate the three bridge options as well as the pros and cons of each bridge option relative to each criterion.

Geometrical Accommodation of Pedestrian Bridge

The LRT bridge options need to be able to geometrically accommodate the required width of the pedestrian bridge as well as of any required features such as lookouts. They also need to be able to accommodate geometrically the vertical and horizontal clearances required for the pedestrian bridge as well as the required vertical navigational clearance required beneath the pedestrian bridge.

The variable depth girder bridge option requires a total structural depth (including SUP) of 9.0 m while the extradosed and cable stayed bridge options require total structural depths (including SUP) between 7.0 m and 6.0 m. The shallower total structural depths allow for more flexibility in setting the LRT gradeline, i.e. a straight gradeline rather than one with a hogging vertical curve, while meeting the vertical navigational clearance requirements.

The proposed 4.5 m width of the box-girder required for the girder and extradosed bridge options may restrict the placement of hanger supports for the pedestrian bridge.

Based on this evaluation criterion the cable stayed bridge option is ranked the highest followed by the extradosed bridge option and the constant depth box-girder bridge option.

Geotechnical Considerations

The north river bank at the proposed bridge site has a history of geotechnical instability. Long term slope movements are possible despite slope stabilization measures planned as part of the project.

Bridge options are evaluated based on their ability to accommodate or span over the potential north river bank movements.

The cable stayed and extradosed bridge options span over the unstable portion of the north river bank, while the box-girder bridge option has end spans on pile-supported piers onthe north river bank.

Based on this evaluation criterion the variable-depth box-girder option is ranked lowest. With respect to the cable stayed and the extradosed options, the extradosed is considered superior although the differences are slight.

Design Considerations

As the SE-W LRT project is currently in the preliminary engineering phase there is a possibility that the quantities and costs assumed for each bridge option could increase during detailed design. This risk is considered to be greater for bridge options that have less accumulated design experience for their design basis. Also restrictions need to be placed on the allowable magnitude of pedestrian bridge accelerations in order to maintain pedestrian comfort levels. Traditionally LRT bridges have been restricted to having a minimum natural frequency in the range of 2.5 to 3.0 Hz to minimize bridge accelerations due to interaction between the bridge and LRT trains. However this is generally not possible for longer span bridges and as a result maximum acceleration limits can be harder to control. As a result there is an increased risk in longer span bridges that additional quantities and costs will be required to meet maximum acceleration limits.

Bridge options are evaluated based on the risk that design criteria will not be able to be met without an increase in assumed bridge material quantities and costs.

The cable stayed bridge option has the greatest structural flexibility. The box-girder bridge option has greater structural stiffness and considerable accumulated experience for their design and construction. The extradosed bridge option has a structural stiffness comparable to that of the box-girder option; however, it is a relatively new style of bridge with less accumulated experience than either the box-girder or cable stayed options.

Based on this evaluation criterion the cable stayed bridge option is ranked the lowest, the box-girder bridge option the highest, and the extradosed bridge option in between.

Environmental Considerations

Construction of the LRT bridge options as well as dismantling of the existing Cloverdale Pedestrian Bridge will require in-stream work in the North Saskatchewan River. The amount of environmental disturbance created will depend on the extent and duration of the in-stream work.

Bridge options are evaluated based on the extent and duration of the in-stream work required for construction. A minimum base level of in-stream work is required for all of the bridge options due to the need to dismantle the existing Cloverdale Pedestrian Bridge.

The cable stayed bridge option is expected to require the greatest amount of additional in-stream work. It is estimated that construction of the inclined tower alone will take 1 year. The remaining two bridge options each require 2 piers in the river.

The extradosed and box-girder bridge options can both be built using balanced cantilever, concrete segmental construction, meaning that access will need to be maintained to the in-stream piers during construction of the bridge superstructure. The extradosed bridge option could also be built using a steel girder, which may provide cost or schedule advantages. The asymmetry of the cable stayed bridge option makes balanced cantilever construction impractical. This will lengthen the period of construction.

Based on this evaluation criterion the cable stayed bridge option is ranked the lowest. Because it has the added possibility of using a steel girder, the extradosed bridge option is considered somewhat superior to the variable depth box-girder bridge option.

Operations and Maintenance

Operations and maintenance requirements need to be considered in the evaluation of the bridge options. These considerations include the accessibility provided to maintenance items such as utilities, catenaries, and track as well as consideration of the separation of the main bridge load carrying members from the LRT tracks. Increased separation reduces the potential for damage to the main load carrying members from an LRT train derailment and also allows maintenance/rehabilitation work to occur on the main load carrying members without directly affecting LRT traffic.

Bridge options are evaluated based on the accessibility they provide to items requiring maintenance as well as on the effect that required bridge maintenance/rehabilitation would have on LRT traffic.

The extradosed and cable stayed bridge options are expected to have additional maintenance requirements associated with cable maintenance and possible replacement. Any future cable replacements would be expected to affect LRT operations both because the bridge capacity would be affected and also because the work would need to take place adjacent to the LRT tracks. In the case of the extradosed bridge option, cable maintenance would require LRT traffic to be diverted to the opposite side of the bridge. Operationally, this is essentially the same as what is routinely done for track maintenance. For the cable stayed bridge option, the extreme height of the work area relative to the deck of the bridge will require new operations procedures. The box-girder bridge option has an advantage in that its main load carrying members are below the deck. Less maintenance is expected and, when it is required, that maintenance will have less effect on LRT operations.

Based on this evaluation criterion the box-girder bridge option is ranked the highest followed by the extradosed bridge option and finally the cable stayed bridge option.

Context and Architecture

The proposed LRT river bridge is located in a prominent location in the river valley and will be highly visible to the public. Viewpoints include views from downtown, from adjacent parks and from adjacent residences. Based on the Public Involvement (PI) process there appears to be a desire to create a structure that is a piece of public art yet compliments and does not detract from the river valley.

Bridge options are evaluated based on their aesthetics as well as on how well they complement their river valley setting, both components of SUI.

The cable stayed and single tower extradosed bridges are considered to be elegant bridge options in their own right. However the cable stayed bridge option would give a greater opportunity to create a unique “postcard” structure that could become a symbol of Edmonton. This must be balanced against the imposing nature of the cable-stayed tower, a structure extending approximately 68 m above the bridge deck. Of the three options, the variable depth box-girder bridge is considered the more utilitarian.

Based on this evaluation criterion the single tower extradosed bridge option was ranked the highest followed by the cable stayed and variable depth box-girder bridge options.

River Valley Impact

The river valley is considered to be the jewel in the heart of Edmonton and is highly used. It is considered desirable that the selected bridge option be integrated with the existing grades, trails and landscape and not detract from the river valley experience. Bridge features that could detract from the experience of river valley users include the locations of piers and overhead superstructures that crowd in on the river valley trail network, the dominance of the bridge from the perspective of a user of the river valley trails and the visual continuity provided between the river bridge and its approaches. Note that the approach spans to the main river bridge are expected to be concrete spans that are approximately 2.5 m deep.

Bridge options are evaluated based on how well they will enhance the experience of users of the river valley.

On the south river bank bridge the superstructure depths and span arrangements are similar for all three bridge options. On the north river bank all of the bridge options have similar superstructure depths and span arrangements. Because the cable stayed and single tower extradosed bridge options clear span over the north river bank, they avoid the inconvenience of a pier in this somewhat restricted area.

Based on this evaluation criterion the box-girder bridge option is ranked lowest. Between the cable stayed and extradosed bridge options, the extradosed bridge option is considered superior. The height of the main tower for the cable stayed bridge option would make it a dominating feature of the river valley. This tower would roughly match the height of a 25 story building, something that seems inappropriate in the context of the river valley.

User Experience

The pedestrian bridge is intended to enhance the experience of river valley users not only in allowing them access from one side of the river to the other but also in providing them with a positive experience as they cross the bridge. Bridge features that could make the experience of pedestrian bridge users more positive include the views from the bridge, opportunities for overlooks and seating areas and views of the LRT bridge from the pedestrian bridge.

Bridge options are evaluated based on how well they will enhance the experience of users of the pedestrian bridge.

The extradosed and box-girder bridge options use box-girders that provide a smooth concrete soffit above the pedestrian bridge as opposed to a steel or concrete floor system with cable trays to support utilities. At pier supports, the greater structural depth of the variable depth box-girder option may lead to a feeling of confinement for pedestrians.

The cable stayed bridge option has the lightest deck structure of the three alternatives and may be susceptible to LRT-induced accelerations that pedestrians could find unsettling.

Based on this criterion the single tower extradosed bridge was ranked the highest followed by the cable stayed and variable depth box-girder bridge options.

Review of Alternatives

The long-span specialist bridge team of AECOM provided an informal review of the three options. The team was asked to comment on the geometric proportioning of the alternatives, the expected suitability of the dynamic responses for pedestrian traffic, as well as any anticipated construction or maintenance issues. Their comments are summarized below.

Geometry

The general layout of the variable-depth box-girder bridge is considered appropriate. It is felt that the 50-meter sidespans might be a little long for full balanced cantilever construction throughout; however, the cost of supporting formwork on falsework in the shallows or on shore is not punitive.

The proportions of the extradosed box-girder bridge are considered to be consistent with similar bridge installations. While the box itself is usually concrete, it would be possible to substitute a structural steel box. It was commented that the height of the tower is a little greater in proportion to the span than would ordinarily be expected for an extradosed bridge, but it is felt that the change improved the aesthetic proportions of the bridge without any significant impact to economy. It is suggested that economy of the bridge could be improved by reducing the number of stay cables to 5 from the 9 currently shown. The splay of the tines of the tower and the widening of the bridge at the north end introduce splitting forces in the tower. These may require a tie element between the tines.

The cable stayed bridge is judged to be well-proportioned. Additional stays will be needed up to the pier supports at both the north and south ends, including an anchor stay at the south end. The south pier will likely have to be designed for permanent tension, a significant cost element. As is the case for the extradosed tower, the tines of the tower pier may also require a transverse tie to resist splitting forces.

Dynamic Response

Based on the known satisfactory performance of similar structures, the team anticipates that meeting the required acceleration limit for pedestrian use (0. 5 m/s^2) is reasonable for both the variable depth box and extradosed options.

The team is not as confident with regard to the dynamic response of the cable stayed bridge. In this case the dynamic response will depend strongly on the interaction between the bridge and the LRT. With a light superstructure, the moving mass of the LRT becomes significant compared to that of the bridge. While it is generally felt that the acceleration limits for LRT passengers can be met, the more stringent limits for pedestrian traffic may not be easily achieved.

The extradosed bridge option can be viewed as a hybrid between a variable depth box-girder and a cable stayed bridge. As is the case for a variable depth box-girder bridge, the extradosed bridge features a stiff girder with significant mass. The moving mass of the LRT is not significant compared to the mass of the girder. Increasing the tower height of an extradosed bridge shifts the proportions of the bridge toward those of a cable stayed bridge. At this stage of design it is not known whether this will lead to a problem satisfying acceleration limits for pedestrians.

Construction

The estimated time for construction of both the variable depth box and extradosed options is 2 years. The actual time for construction will depend on a number of variables that are not known at this time. The contractor may or may not choose to work through winter; scheduling of other elements of the Southeast LRT segment may take precedence over bridge construction.

Regardless of bridge type, demolition of the existing pedestrian bridge will have to be completed prior to construction of the new bridge. The first step will be for a contractor to construct either berms or work bridges to access the structure. This requires in-stream work and will likely have a restricted window in mid to late summer. These berms or work bridges would serve both demolition of the existing bridge and construction of the new bridge. It is likely that the contractor would complete demolition over the course of the fall, winter, and early spring in time for the following construction season.

Both the variable depth box and the extradosed box are compatible with form travellers and balanced cantilever construction. Having made the investment in form travellers, there may be a cost benefit to the contractor in maximizing their use by employing the same construction technique throughout the approach spans. The spacing of piers for the approach spans would likely need to be adjusted for consistency with any change in girder cross section.

Assuming the average same level of effort over time, construction of the cable stayed bridge will require approximately 3 years. The inclined tower pier itself will take roughly 1 year to construct. Balanced cantilever construction is impractical because of the unequal spacing of stays. Instead, it is expected that the back span will be constructed using forms supported on falsework. The main span would be built by the cantilever method.

Maintenance
As a rule, girder structures have lower maintenance costs than through structures. It follows that, of the three alternatives, the variable depth box will likely have the lowest maintenance cost; however, the difference is slight. The extradosed and cable stayed options both have significant superstructure above the bridge deck, but the typical design life for modern cable stays is 75 years. Maintenance of cables is not likely to be a significant cost over the design life of the bridge.

Another possible maintenance item will be adjustments to cope with geotechnical movements on the north bank. These movements are expected to be gradual. In the case of the variable depth box, provision will have to be made to adjust bearings over the piers on the north shore. This type of coping strategy has been used in the Peace region where bank instability is common. Both cable supported options avoid this maintenance problem by spanning over the region most likely to move.

Cost of Construction

The ConnectEd Transit Partnership team considered input from a number of different sources to develop estimated ranges of construction costs. These estimates for the bridge report are comparative estimates for a transit bridge in present day, 2012, dollars; prepared to provide an indication of the differing costs of bridge designs under consideration. It is assumed that the bridge would be constructed as part of an overall design build contract to deliver the complete transit system; and may be procured as a P3 project, the details for which are under review.

The estimates exclude the following:

1. Inflation between the date of this report and construction, anticipated to be around the years 2015 and 2016
2. Design and engineering costs
3. Owner’s project and construction management
4. Financing interest during construction, and any other financing thereafter
5. Environmental studies and issues
6. Any premium costs related to work to the north river bank, such as stabilization and access; these costs are covered separately as part of the site preparation elements of the estimate and are independent of bridge type.
7. Design enhancements to any of the options, for example sloping columns or special lighting
8. Transit systems (rail, catenary, etc.) on the bridges.
9. Landscaping and trail design in the river valley.
10. Property costs
11. Contingencies
12. GST

Estimated costs are $34.5 million for the variable depth box-girder bridge, $43.0 million for the extradosed box-girder bridge, and $54.5 million for the cable-stayed bridge. These costs are estimated on the basis of precedent structures of comparable scale built across North America. The level of design has not been advanced to the point where cost estimates can be based on a quantity survey of the design. As a result, an additional margin of roughly 40% for cost uncertainty is considered appropriate at this time.

Outstanding Risks

There are risks with the scale of the bridge and types of proposed structure. All three bridge alternatives use structural systems that are uncommon in the local market although the variable depth concrete box-girder bridge is the most conventional. Because the proposed LRT bridge is part of a much larger project, it is expected to tap into the global construction community, making local expertise less a factor.

The risk associated with the lack of detailed analysis is most significant for the cable stayed bridge alternative. The response of this bridge, and in particular the suitability of the dynamic response for pedestrian traffic, cannot be predicted reliably without a significant analysis effort. While it is possible that the proposed cable stayed bridge would prove to be satisfactory, it is not assured.

Summary

The following table summarizes the main considerations and risks of the three alternatives. In addition, the evaluation matrix presented in the September report has been updated to address the three remaining bridge alternatives. The revised matrix is presented in Appendix A. The results are provided in parentheses in the summary below.

Alternative (evaluation)	Considerations	Risks	Construction Cost (millions)
Variable-depth box (13)	• More common form of construction. • No bridge structure above deck. • 2-year construction. • Easily meets design requirements for pedestrians. • Two river piers.	• Potential maintenance associated with possible north bank movement.	$35 – $50
Extradosed box (21)	• Tower 18 m above bridge deck. • Less common form of construction. • 2-year construction. • Easily meets design requirements for pedestrians. • Two river piers. • Steel or concrete box is possible.	• Smallest pool of design and construction experience.	$45 – $65
Cable-stayed (14)	• Tower 68 m above bridge deck. • 3-year construction period. • One river pier.	• Potential problem in meeting pedestrian design criteria.	$55 – $80

Recommendation

The ConnetEd transit Partnership recommends that the City move forward with either the Extradosed box-girder bridge or the Variable depth box-girder bridge. The cable stayed bridge is not recommended. It is inappropriate in the context of the river valley, has potential design risks that are not present in the other alternatives, has the longest construction period and the greatest estimated cost.

Appendix A

Bridge Type Selection Matrix (draft) October 15, 2012

Table 1 - Summary

CRITERIA		BRIDGE TYPE		
		Variable Depth Concrete Girder Bridge	Cable Stay Bridge	Single Tower Extradosed bridge
Summary	Engineering	10	8	12
	SUI Criteria	3	6	9
	Total Score	13	14	21

Appendix A

Bridge Type Selection Matrix (draft)

October 15, 2012

Table 2 - Screening Based on Engineering Criteria

	CRITERIA Rating: 1 to 3 with 3 as the highest rating	BRIDGE TYPE Variable Depth Concrete Girder Bridge	 Cable Stay Bridge	 Single Tower Extradosed bridge
Engineering Criteria	**a Geometrical Accomodation of Pedestrian Bridge** • How well does bridge option geometrically accommodate required pedestrian bridge width, clearances and features, e.g. lookouts? • Can structural depth of bridge option allow gradeline to be optimized while still meeting navigational requirements?	1	3	2
	b Geotechnical Considerations • Is bridge option susceptible to geotechnical instabilities at the north riverbank? • Does construction of bridge option present a risk to the stability of the north riverbank?	1	2	3
	c Design Considerations • Does flexibility of bridge option present risk that additional costs will be incurred to meet acceleration limits required for LRT user and pedestrian comfort? • How much historical design experience has been accumulated for each bridge option to extablish its design basis? • How forgiving is the design or each bridge option to accomodate unforseen changes?	3	1	2
	d Environmental Considerations •What is the extent and duration of in-stream construction required for the bridge option?	2	1	3
	e Operations and Maintenance • Does bridge option have its main bridge load carrying members seperated from the LRT tracks to minimize the possibility of damage to the main members and to make their maintenance easier? • How well does the bridge option accommodate utilities and their accessibility for inspection and maintenance?	3	1	2
Total Score		10	8	12

Table 3 - Sustainable Urban Integration

CRITERIA Rating: 1 to 3 with 3 as the highest rating			BRIDGE TYPE		
			Variable Depth Concrete Girder Bridge	Cable Stay Bridge	Single Tower Extradosed bridge
Sustainable Urban Integra	f	**Context & Architecture** • View of the structure from adjacent park users • View of the structure from adjacent land uses-residents (both sides of river) • View of the structure from downtown and adjacent roadways • Does the structure type enhance the city context?	1	2	3
	g	**River Valley Impact** • Do the approaches to the structure require retaining walls? • Integration of the approach slabs, abutments and piers into existing grade and landscape • Is the approach for ped/bike access intuitive and meet ADA grades? • Interruption to park improvements • Environmental impact and issues	1	2	3
	h	**User Experience** • View from LRT • View from pedestrians and bicyclists on approach paths • View from underhung path and lookouts • Integration of two levels within pier design • Quality of experience under superstructure: clearance, structure type, bird roosting, graffiti deterrent, CPTED • Opportunities for overlook/seating areas • Path width: does the structure provide ample width within bridge envelope for clearance of path modes (bike and	1	2	3
Total Score			**3**	**6**	**9**