Niagara Region

PARSONS

Transportation Infrastructure Means Protection

Concept Design Report

The Regional Municipality of Niagara
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1.0 INTRODUCTION

1.1 EXISTING BRIDGE

The Burgoyne Bridge is located in the City of St. Catharines and carries Regional Road 81 (St. Paul Street West) over Twelve Mile Creek and Highway 406. The new 333-meter-long structure was completed in September 2017 and replaced the original Burgoyne Bridge which was constructed in 1915. The bridge serves as an important link between downtown St. Catharines and the western portion of the city and is oriented in the north-south direction. The span arrangement consists of seven spans of 30m, 42m, 42m, 44m, 125m, 30m, and 20m from south to north, with the 125m main span being supported by a centrally mounted steel tri-chord arch. The bridge is supported on reinforced concrete abutments and piers sitting on reinforced concrete caisson foundations. Figure 1.1 shows the general plan and elevation arrangement of the new Burgoyne Bridge. Appendix A includes the full general arrangement drawing for the Burgoyne Bridge.

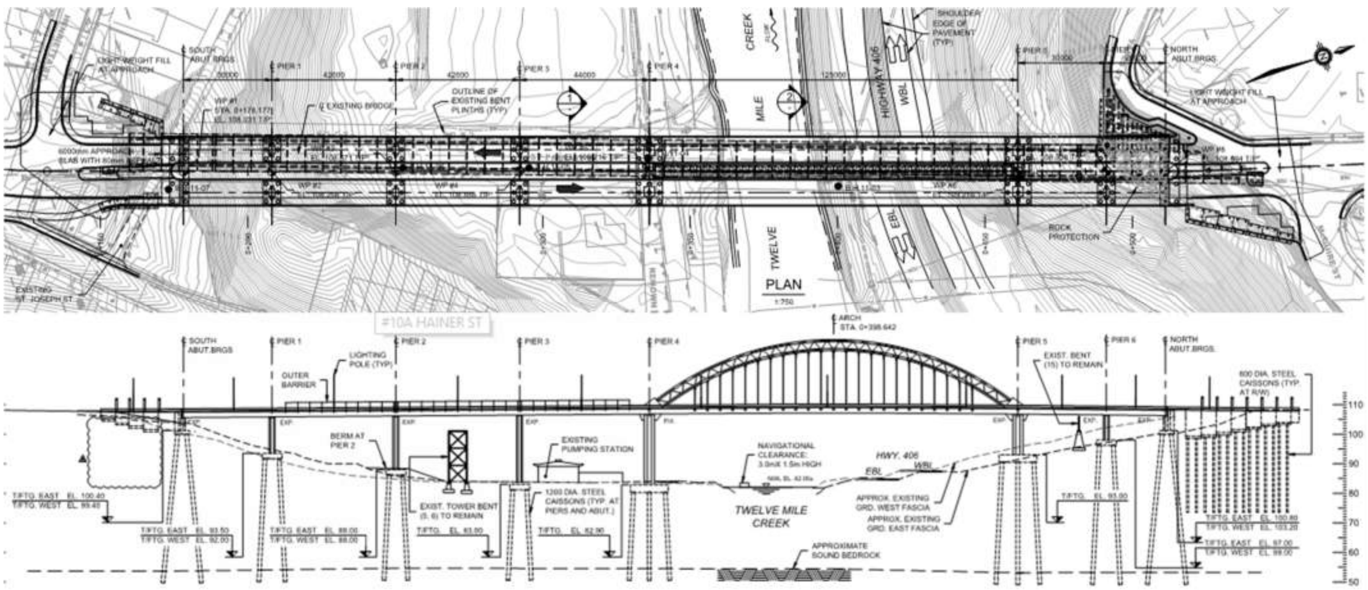

Figure 1.1 – Burgoyne Bridge Plan and Elevation

The cross section of the Burgoyne Bridge is in the form of a twin-deck structure making use of 2 parallel continuous composite trapezoidal box girders running the full length of the bridge. Each deck consists of 0.3m wide parapet walls, a 2.4m wide sidewalk, a 1.6m bike lane, a 3.5m traffic lane, and a 0.9m wide shoulder. The northbound and southbound decks are separated by a 5.5m gap over the entire bridge length. A series of floor beams and inclined hanger cables are utilized over the main span to transfer loads from the decks to the arch system. In addition, the main span has both lateral and longitudinal prestressed cables to increase the stiffness of the span and support the arch system. Figure 1.2 outlines a typical cross section for both the arch span and non-arch spans. Appendix A includes the full general arrangement drawing for the Burgoyne Bridge.

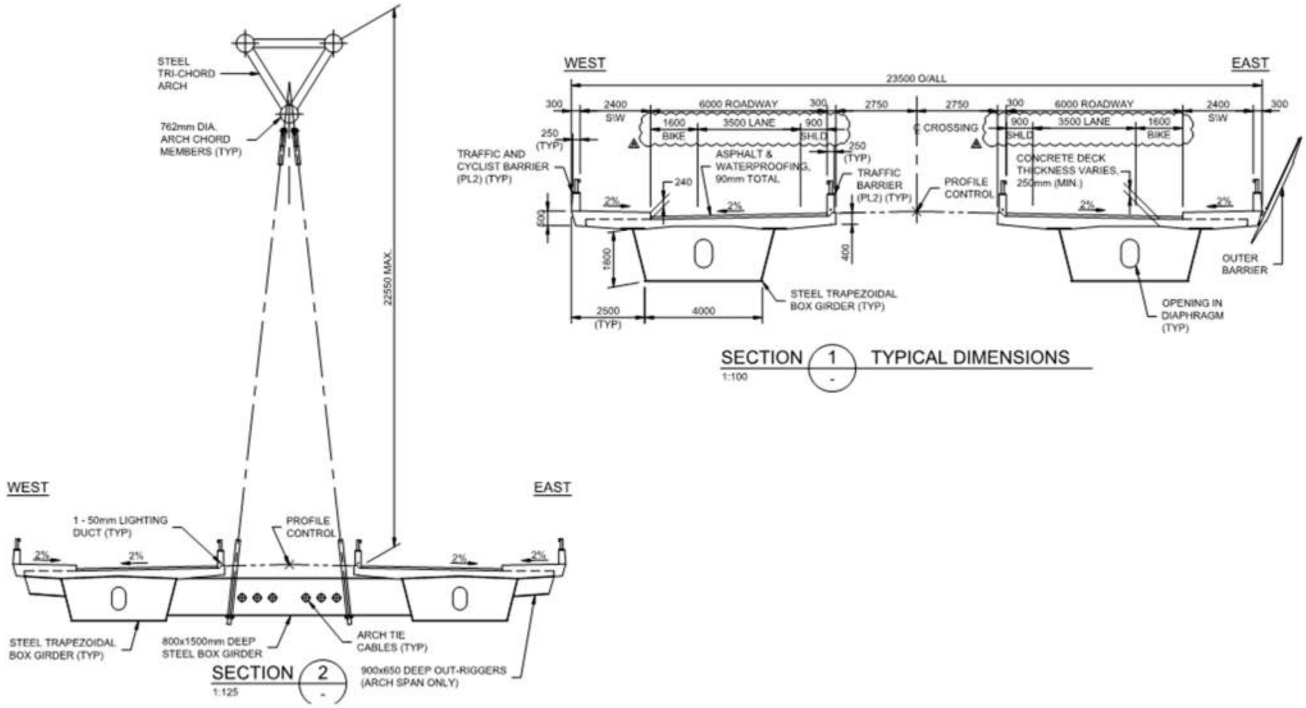

Figure 1.2 – Burgoyne Bridge Cross Sections

1.2 MEANS PREVENTION

Parsons has been contracted by the Regional Municipality of Niagara (the "Region") Public Works Department to investigate possible means prevention measures following several deaths by suicide and similar attempts from the Burgoyne Bridge. Means prevention refers to the action of preventing or blocking the ability of a person to die by suicide through various direct and indirect methods. Examples of means prevention include barriers, nets, and the complete removal of pedestrian access. Such measures vary between encouraging a person contemplating suicide to seek help, to physically removing the ability for such a person to die by suicide. Deaths by suicide from a bridge is a world-wide concern, with fatalities occurring at many landmark structures, which become known as suicide "magnets". This means that once a structure becomes known as a magnet, suicide contagion may result in an increasing number of deaths from the bridge. It is crucial that a system be put in place to prevent such notoriety and to remove the attraction of the bridge to persons contemplating suicide (Toronto Public Health, 2018).

Generally, physical barriers are considered the most effective means of preventing deaths by suicide as they restrict one's ability to make an attempt as well as provide a sense of imperviousness which may help to reduce the "ease" of dying by suicide (Draper, 2017). This report will focus on comparing different types of barrier solutions for the Burgoyne Bridge and make recommend an effective solution. It should also be noted that the Region may add supplementary measures to the bridge in the form of signage, help phones, or security cameras. These methods have only shown weak statistical evidence of effectiveness in reducing the rate of suicides, particularly if implemented on their own. However, they may be useful to supplement a barrier system as a means to encourage a suicidal person to seek help (Toronto Public Health, 2018).

When discussing deaths by suicide from bridges, it is important also to consider the concepts of displacement and substitution. Suicide displacement is the idea that a person contemplating suicide who is blocked from dying at a certain bridge may look for other, nearby structures instead. Suicide substitution is similar in concept, wherein a person may seek another method of dying by suicide. Adding means prevention barriers may reduce or eliminate the rate of deaths by suicide at a specific bridge, but that does not guarantee that the overall deaths from falling from a height (or any other means) will be reduced. Research has shown that at some locations there has been a partial counterbalancing at nearby bridges immediately following a barrier installation in which the deaths by suicide increases at these bridges. This temporary displacement is then followed by a long-term stabilization and reduction in the overall death by suicide rate in the area. Comparatively, research has indicated that at other locations there have been no signs of displacement or substitution after a means prevention barrier was installed, therefore reducing the overall deaths by suicide (Draper, 2017). However, the most important takeaway is that there is no guarantee that all deaths by suicide from the Burgoyne Bridge, nearby bridges, or by any other means will be completely prevented after the implementation of a means prevention barrier.

1.3 BARRIERS ON THE BURGOYNE BRIDGE

It is understood the Region is proposing a barrier system on the Burgoyne Bridge as a means to prevent deaths by suicide from the structure. On the exterior sides of the bridge decks the Region has expressed an interest in a barrier that will match the profile and appearance of the existing debris fence located on the south east edge of the east bridge deck as pictured in Figure 1.3. Additionally, the inner gap between the two bridge decks will also need to be blocked. There are two possible methods to provide means prevention between the decks. Firstly, to provide a barrier which is similar to the exterior means prevention barrier, and secondly, through the addition of a horizontal steel mesh system on the interior edges of the bridge decks, spanning the existing gap between them, as shown in Figure 1.4.

Figure 1.3 – Existing Debris Barrier

Figure 1.4 – Existing Gap Between Bridge Decks

It is understood that the optimal solution will be one that minimizes the visual impacts to the structure while simultaneously simplifying construction through the incorporation of the existing bridge features. Due to the unique design and complexity of the existing traffic, pedestrian, and bicycle railing systems on the Burgoyne Bridge, it is preferable to minimize impact to their design and functionality wherever possible.

This report will investigate the advantages and disadvantages of similar systems installed at other bridge locations and will apply the knowledge gained from these case studies to develop alternatives for both the interior and exterior means prevention barriers on the Burgoyne Bridge. The primary goal is to identify feasible solutions which will help to reduce deaths by suicide from the bridge while also minimizing the aesthetic impacts and not impede the current ease of access for vehicles, pedestrians, and cyclists. It is very important to understand that there is no solution which will fully remove the risk of deaths by suicide from the Burgoyne Bridge. Even the most comprehensive and expensive systems installed at other bridges have had reported deaths since the implementation of a means prevention barrier. It is crucial that the Region and the Public are aware that there is still a chance of deaths by suicide from the Burgoyne Bridge, even after a barrier is installed.

2.0 STATE OF PRACTICE

In recent years, much focus has been put on researching and understanding mental health issues and the reasons why a person would choose to fall from a tall structure. Combined with a push in refurbishing existing structures with means prevention systems and also incorporating such measures into the design of new bridges, many different means prevention applications can be found. Specifically, means prevention in the form of barriers has been shown to be the preferred method of preventing deaths by suicide, both in Canada and throughout the world. Few examples of netting systems exist and are typically only implemented when there are large concerns from the Public regarding the aesthetic impacts of a traditional deck-mounted barrier. Many of these examples also have signs, security cameras, and help phones installed in addition to barriers. It is inconclusive whether or not these steps reduce the rate of suicide attempts at a site and are mostly regarded as optional, supplementary measures that may be considered. These items may be added to the structure with relative ease if the Region would find it beneficial, however an analysis of such measures is excluded from this report as they do not address the immediate issue of means restriction.

This section will discuss the different types of barriers installed at various bridges and the advantages and disadvantages with each unique system. The information gained from analyzing the barriers on other structures is critical in identifying what design aspects should and should not be included in the proposed Burgoyne Bridge means prevention barrier alternatives.

2.1 BURRARD STREET BRIDGE, VANCOUVER

Located in Vancouver, British Columbia, the Burrard Street Bridge is an 836m long steel truss bridge built in 1932. The area is known for having a high rate of deaths by suicides, with many deaths occurring from the bridge and others nearby. To address this issue, the City of Vancouver elected to retrofit the bridge with a means prevention barrier as shown in Figure 2.1. The barrier is a vertical steel rod fence mounted on top of the existing concrete parapet wall. The barrier was reported to cost $3.5 million and was constructed as part of a larger rehabilitation operation (Brown, 2016). A Public consultation was held to narrow down the options and find a solution that worked for both the City and the Public. Netting, glass, and mesh fencing were all considered, but were deemed to be too costly or too detrimental to the appearance of the bridge. The selected design was decided to be optimal for visibility, construction, and maintenance (Toronto, 2018).

Figure 2.1 – Burrard Street Bridge Barrier (City of Vancouver, 2017)

Advantages

The simple picket design minimizes view obstructions while mimicking the architectural features of the heritage structure. The design also incorporates concrete elements into the barrier system to enforce the image of consistency with the rest of the bridge. Horizontal members near the top of the fence provide an upper connection point for the pickets. This allows a thinner steel rod to be used, saving cost and weight while minimizing impacts to the view. Additionally, the staggered picket detail at the top has the dual purpose of matching the style of the existing bridge while also making it difficult for a person to climb over top of the fence. This design is easy to construct and minimizes construction and schedule costs by utilizing the existing bridge parapets.

Disadvantages

As a result of the decision to incorporate the existing parapet walls into the barrier design, a person has the ability to stand on top of the concrete parapets and light pole pedestals due to the fence being thinner than the concrete components it sits on. Additionally, gaps in the pickets at the concrete light pedestals may provide an opportunity to bypass the spike feature at the top of the pickets. Also, the horizontal member near the top of the fence may be too near to the top of the barrier to prevent someone from lifting themselves over the cantilevered bars. Similarly, the flat tops of the barrier support posts may provide a handhold to bypass the pickets. Combined with the ability to stand on top of the parapets, these hand holds may reduce the ability of the fence to stop climbers. Finally, due to the minimalist design and thinness of the vertical pickets, this barrier system does not give the same illusion of imperviousness that other options may provide.

2.2 IRONWORKERS MEMORIAL BRIDGE, SURREY

Located near the Burrard Street Bridge in Vancouver, British Columbia, the Ironworkers Memorial Bridge is a 1292m long steel truss cantilever bridge built in 1957, which carries 6 lanes of traffic over the Burrard Inlet. Similar to the Burrard Bridge, a high number of deaths by suicide from the Ironworkers Bridge necessitated that a means prevention barrier be installed. The $10 million project (Saltman, 2017) consists of a vertical galvanized cantilevered pipe barrier acting as both a means prevention barrier and a pedestrian and cyclist guardrail. Refer to Figures 2.2 and 2.3 for details.

Figure 2.2 – Ironworkers Memorial Bridge Barrier (Saltman, 2017)

Figure 2.3 – Ironworkers Memorial Bridge Barrier (Ironworkers, 2018)

Advantages

The Ironworkers Memorial Bridge barrier primarily consists of vertical cantilevered steel pipes. By designing the vertical members to be cantilevered, no horizontal components are required near the top of the barrier which may otherwise provide a handhold for anyone attempting to climb it. The larger member size is also very resistant to any bending, and the size and height of the barrier gives a good sense of imperviousness to detract anyone from attempting to climb. The sidewalks were extended as part of a rehabilitation project, so there were no requirements to tie into the existing parapet walls. This reduces the number of footholds and allows the barrier to be continuous from top to bottom along the entire bridge. Additionally, the tops of the cantilevered pipes are cut at an angle away from the deck to prevent them from becoming a handhold. No deaths have been reported since the barrier was constructed.

Disadvantages

The largest concern for the Ironworkers Memorial Bridge barrier is the larger view obstruction when compared to a picket style barrier. To allow for the cantilevered design, larger vertical components must be used which will further block the view, particularly at steep angles (refer to Figure 2.2 above). Consequently, no design considerations appear to have been put into the barrier to maintain the architectural style of the existing bridge. As such, the barrier is very obvious and intrusive when viewing the structure. Additionally, a cantilevered pipe design may prove to be heavier and potentially more expensive than a lighter picket design such as the one used on the Burrard Bridge. Finally, the pedestrian and cyclist railings mounted to the inside face of the barrier may allow a spot for a person to stand. However, it would be extremely difficult to lift oneself over top of the barrier from this position due to the lack of handholds and the pointed tops of the pipes.

2.3 GOLDEN GATE BRIDGE, SAN FRANCISCO

The Golden Gate Bridge in San Francisco is infamous for having the highest rate of deaths by suicide of any bridge in North America. The bridge has seen more than 1700 deaths since its opening in 1937. Discussions of installing a barrier have been occurring for decades but all attempts have been held back by preservation groups who were opposed to “tarnishing” the historic design. The Public also had many concerns that individuals contemplating suicide would seek another site nearby and that a barrier would not solve the underlying problem (Swan, 2018). It was finally decided that the best way to minimize the impact to the appearance and visibility from the structure was a netting system that is to be installed 20 feet below the edges of the deck, projecting 20 feet outwards. The net is currently being built and will reportedly cost approximately US$211 million by the time construction is complete in 2021 (Toronto, 2018). The net itself is made of a horizontal steel mesh supported by cantilevered steel brackets connected to the bridge superstructure. Figure 2.4 below shows a rendering of the proposed net system.

Figure 2.4 – Golden Gate Bridge Net - Render (Swan, 2018)

Advantages

The proposed Golden Gate Bridge netting system caters to the psychological concept that individuals contemplating suicide only wish to take their lives, so as such they may avoid situations that would cause harm but not death. A steel mesh 20 feet below the deck could cause substantial harm to a person who has jumped onto it, but it is not likely to result in death. This also ties into the concept of remorse after an attempt to die by suicide. Many survivors of an intentional fall from a height have stated they regret the decision immediately after the attempt. A net can provide this “second chance” that a desperate person may need (Draper, 2017). A netting solution is also optimal when it comes to minimizing visual impacts to the structure, particularly from the deck level. Such a system would have no influence on the view from the bridge deck and would partially blend in to the rest of the bridge superstructure when viewed from the sides. Consequently, a below-deck net is also optimal from an architectural preservation perspective, whereby the image of the bridge is not substantially altered.

Disadvantages

There are several consequences from a structural standpoint when adding such a heavy system onto a comparatively lightweight and slender bridge. In the case of the Golden Gate Bridge, motion dampers are being installed to counteract the additional wind load induced by the significant netting area (Toronto, 2018). Depending on the condition and design characteristics of a particular structure, such a system may require significant stiffening and additional brackets and support members to support such a net, if the bridge is even structurally capable of supporting it at all. As seen in the Golden Gate Bridge example, such a system and the associated structural improvements can be extremely expensive and take a significant amount of time to design and construct.

One could also make the argument that a net is not a true means prevention system in that it does not physically prevent a person contemplating suicide from attempting to fall from the bridge. A net will only provide the threat of injury or will catch individuals who do have an intentional fall and will then need to be rescued at the risk of first responders. A similar concern is that if an individual sees the net when contemplating death, they may decide to climb down to the net and then fall from this lower position.

2.4 PRINCE EDWARD VIADUCT, TORONTO

The Prince Edward Viaduct, also known as the Bloor Street Viaduct, had the 2nd highest rate of deaths by suicide of any bridge in North America, behind only the Golden Gate Bridge (Toronto, 2018). Located in Toronto, Ontario, the 494m length bridge experiences substantial pedestrian traffic and crosses over one of the busiest highways in the city. To address rising concerns over the high number of deaths from the bridge, the City of Toronto installed a complex vertical barrier system in 2003. The barrier uses a series of 5m tall vertical rods connected to an inclined structure supported off the side of the bridge. To maintain structural integrity, the barrier uses a system of cables to support the structure and reduce the impacts of additional wind loads. The barrier is considered to be architecturally significant and has been given the name ‘Luminous Veil’. Refer to Figure 2.5 below for a deck view of the barrier.

Figure 2.5 – Prince Edward Viaduct Barrier (McQuigge, 2017)

Advantages

The Prince Edward Viaduct barrier showcases the most extensive version of a means prevention barrier. Reaching over 5m tall, it is regarded as one of the most effective systems of its kind. Since its construction in 2003, only a single death by suicide has occurred when there had previously been an average of 9 per year (McQuigge, 2017). One of the key design features of this barrier is the focus put on creating a system that was very effective, but also architectural pleasing. The design received approval from the local heritage groups who were previously opposed to a barrier (Toronto, 2018). The height and slenderness of the vertical rods prevent climbers from scaling the barrier while minimizing the impacts to the view from the bridge. Help phones and signage were also installed on the bridge as supplementary measures.

Disadvantages

While the Prince Edward Viaduct barrier is regarded as one of the most effective means prevention barriers, it is also one of the most complex. Significant architectural and structural design would have been required, and the tremendous size of the barrier would incur high material and construction costs. A barrier of this size also presents maintenance issues as specialized equipment would be needed to clear the barrier to access the outer portions of the bridge. Additionally, it was recorded that deaths by suicide on nearby structures increased immediately after the barrier was constructed, indicating that suicide displacement was occurring. However, the rate of deaths on these nearby bridges has since stabilized to the levels prior to the Luminous Veil's construction, meaning a long-term reduction in deaths by suicide from bridges has occurred (Toronto, 2018). This corresponds to research conducted at other high-profile suicide-magnet bridges around the world (McQuigge, 2017). It should be noted however that it is impossible to say that other factors, such as increased public awareness and new assistance programs, have not skewed these results positively in the long-term.

2.5 HIGH LEVEL BRIDGE, EDMONTON

To address rising concerns of deaths by suicide from the High Level Bridge in Edmonton, Alberta, a horizontal steel cable barrier was constructed on each side of the 777m long structure. The system makes use of a series of horizontal cables suspended between steel posts which are mounted directly to the sidewalk, as shown in Figure 2.6 below. The tops of the posts are inclined towards the sidewalks to deter individuals from climbing over the barrier. The system was reported to cost $3 million (Toronto, 2018).

Figure 2.6 – High Level Bridge Barrier (Suicide, 2017)

Advantages

Research indicates that the overall rate of deaths by suicide in the area has decreased since the barrier has been installed (McQuigge, 2017). The design was considered the most cost-effective solution for the long length of the bridge. The barriers were bolted directly to the sidewalks and required no other structural connections or modifications. The barrier was also installed in front of the existing bridge railing, simplifying construction accessibility and negating any interference with existing bridge components. Consequently, this system is fairly light weight, easy to construct, and uses a minimum amount of material. It is also preferable in that it minimizes the impacts to the view from the bridge. The design of the painted black steel components also fits in with the architecture of the existing bridge.

Disadvantages

The High Level Bridge barrier is an example of a non-optimal barrier design being installed due to cost concerns. Since the implementation of the barrier, there has only been a reported 50% reduction in deaths by suicide from the structure. Individuals are still able to climb over the barrier due to the horizontal cables acting as a ladder (Suicide, 2017). For comparison, the proposed optimal design was to use vertical stainless-steel bars, but this option was rejected due to a higher estimated cost of $7.5 million (Toronto, 2018). In addition to acting as a ladder, the horizontal cables have been susceptible to vandalism, with several examples reported of people cutting the cables. This allows a gap of any size to be created, essentially bypassing the barrier completely. Finally, cyclists and Pedestrians have made complaints regarding the tapered barrier impeding on the sidewalk headroom.

2.6 OTHER BARRIER EXAMPLES

In addition to the case studies described above, there exist many other examples of means prevention barriers installed on many different types of bridges throughout the world. Table 1 below summarizes several of these other bridges and indicates which barrier type is installed. Most of these examples follow similar designs to the examples previously outlined in this section. If further samples of bridge barriers are needed, several pictures and articles exist for each of the listed structures. Note that many of these bridges also have supplementary measures installed, such as help phones and signage, which may also be reviewed for information if needed.

Table 1 – Means Prevention Barrier Examples

Bridge Name	Location	Barrier Type
Golden Ears Bridge	Vancouver, British Columbia	Cantilevered steel pipe barrier (similar to Ironworkers Memorial Bridge).
Jacques Cartier Bridge	Montreal, Quebec	Picket fence barrier mounted to sidewalk with horizontal member near top. Tops of pickets are curved towards the sidewalk.
Angus L. MacDonald Bridge	Halifax, Nova Scotia	Cantilevered steel pipe barrier (similar to Ironworkers Memorial Bridge).
Aurora Bridge	Seattle, Washington	Picket fence barrier mounted to edge of deck with horizontal member near top. Barrier is outside of the existing parapet and mounted to deck overhang.
Bourne Bridge Sagamore Bridge	Bourne, Massachusetts	Picket fence barriers mounted to sidewalk with horizontal member near top. Tops of pickets are curved towards the sidewalk.
Ithaca Gorge Bridges	Ithaca, New York	Net system installed below deck (Similar to Golden Gate Bridge). Reports exist of suicides still occurring at the bridge. A temporary vertical barrier has since been installed at deck level.
All-America Bridge	Akron, Ohio	Vertical mesh fence barrier. Uses a fine steel mesh supported between adjacent vertical posts.
Memorial Bridge	Augusta, Maine	Vertical mesh fence barrier. Uses a standard steel mesh supported between adjacent vertical posts. Top of fence is inclined towards the sidewalks.
Duke Ellington Bridge	Washington, DC	Picket fence barrier mounted to edge of deck with horizontal member near top (similar to Burrard Street Bridge). Pickets curved towards sidewalk. Barrier is outside of existing parapet mounted to deck overhang.
Cold Spring Canyon Arch Bridge	Santa Barbara, California	Vertical mesh fence barrier. Uses a standard steel mesh supported between adjacent vertical posts. Fence is inclined towards the sidewalks.
Grafton Bridge	Auckland, New Zealand	Curved clear polycarbonate barrier mounted on top of parapets. Forms a canopy above the sidewalks.
Sydney Harbour Bridge	Sydney, Australia	Vertical mesh fence barrier. Top of fence is curved towards the sidewalks with barbed wire at the top. Fence is on both sides of both sidewalks, creating a “cage” that fully encloses the sidewalks.

3.0 BARRIER ALTERNATIVES

3.1 DESIGN CONSIDERATIONS

Using the recommendations and design traits of other successful means prevention barriers, Parsons is proposing the following criteria for the successful implementation of a barrier on the exterior edges of the Burgoyne Bridge. This list is also compiled based on the results from analyzing the case studies in Section 2 of this report.

1. A height greater than 2.5m above the sidewalk to prevent individuals from reaching up and easily pulling themselves over. The taller the barrier, the more effective it will be to prevent climbers.
2. Gaps between components should be 150mm or less to prevent an entire body from passing through any openings.
3. No foot or hand holds, particularly near the top of the barrier which would allow someone to lift or push themselves over. Likewise, any flat surfaces near the top of the barrier should be avoided.
4. The barrier should be composed of smooth vertical components that are hard to grab onto and provide no grip for a foot or hand to push against.
5. The components at the top of the barrier (pickets, posts, pipes, etc.) should be angled or pointed to prevent them from becoming a hand hold. If any horizontal members are located near the top of the barrier, the vertical components should be extended beyond to prevent someone from using the horizontal section to pull themselves up and over the barrier.
6. A barrier should provide the impression of imperviousness. The more difficult a barrier looks to overcome, the lower the chances that someone will attempt to climb it. This can be done by increasing the height of the barrier, using solid and stiff components, and minimizing any hand and foot holds.
7. Structural and aerodynamic stability: any barrier system should not compromise the structural capacity of the bridge and should be sound under all operating conditions. Special consideration should be put into the wind and snow/ice effects of the barrier and the impacts to the entire bridge.
8. Accessibility should not be impacted by the barrier for vehicles, cyclists, or pedestrians. This may be an issue on barriers which have a taper or incline towards the sidewalk or bike lane.

Similar considerations exist for the design of the horizontal net system that is proposed for the interior gap between the bridge decks. The net system must be structurally sound, free of any openings that would allow someone to pass through and should give the impression of imperviousness. In the case of the Burgoyne Bridge, the small number of netting examples and lack of any inclined barrier case studies will require barrier designs not seen on any other bridges. However, there are key concepts and design considerations that can be taken from the case studies outlined in Section 2 and applied to the special requirements of the Burgoyne Bridge. This section will describe and compare the alternatives proposed by Parsons for both the interior and exterior means prevention barriers.

3.2 EXTERIOR BARRIER

As previously discussed, it is understood that the Region is requesting an exterior barrier which will match the profile of the existing debris fence on the south east edge of the east bridge deck. Additionally, it has been noted that all barrier alternatives should minimize impacts to the existing bridge railing systems. As such, Parsons is recommending two alternatives for the exterior barrier. Both barrier options will have the same profile but will have different options for the design of the vertical members which will act as the primary means prevention components. It should be noted that a system identical to the exiting debris barrier (which uses a mesh fence) is not recommended for the purposes of a means prevention barrier as such a fence is easily scalable, regardless of height.

Additionally, per the Region’s request, the proposed barrier alternatives will have the capacity to be constructed with either galvanized steel or aluminum materials. However, due to the structural differences with regards to material properties between the two metals, member sizes will be different between the two metal types to achieve the same deflection performance. The impacts of each metal type for the proposed barrier will be discussed in the following sections. It should also be noted that stainless steel was omitted from consideration due to the much higher material costs as compared to galvanized steel and aluminum, with costs reaching upwards of 10-15 times more than these metals.

3.2.1 ALTERNATIVE 1: INCLINED BARRIER WITH CANTILEVERED PIPES

The first proposed alternative for the exterior means prevention barrier on the Burgoyne Bridge is an inclined cantilevered pipe barrier. Similar to the Ironworkers Memorial Bridge barrier outlined in Section 2.2, this barrier type utilizes larger diameter members to eliminate the need for any horizontal elements at the top of the barrier which could be used to climb over. Refer to Figure 3.1 below for a concept drawing for this barrier alternative. Refer to Appendix B for the full drawing. The pipes will in turn be mounted to a series of I-section posts. The posts will be connected to the bridge at every other existing railing post with a plate and bracket and will be anchored to the exterior face of the deck overhang. The tops of the pipes will be cut at an angle to prevent someone from using them to pull themselves over the top of the barrier. This option also has the capacity for an architectural shape at the top of the barrier, such as a scalloped or stepped top.

The estimated galvanized steel pipe outer dimeter for this option is 48mm, with aluminum being 60mm. This is due to the reduced stiffness of the aluminum creating deflection concerns if an individual were to attempt to force the members apart as compared to steel. In order to account for the decreased stiffness and reduce deflections to an acceptable limit, the aluminum components would need to be larger than their steel counterparts.

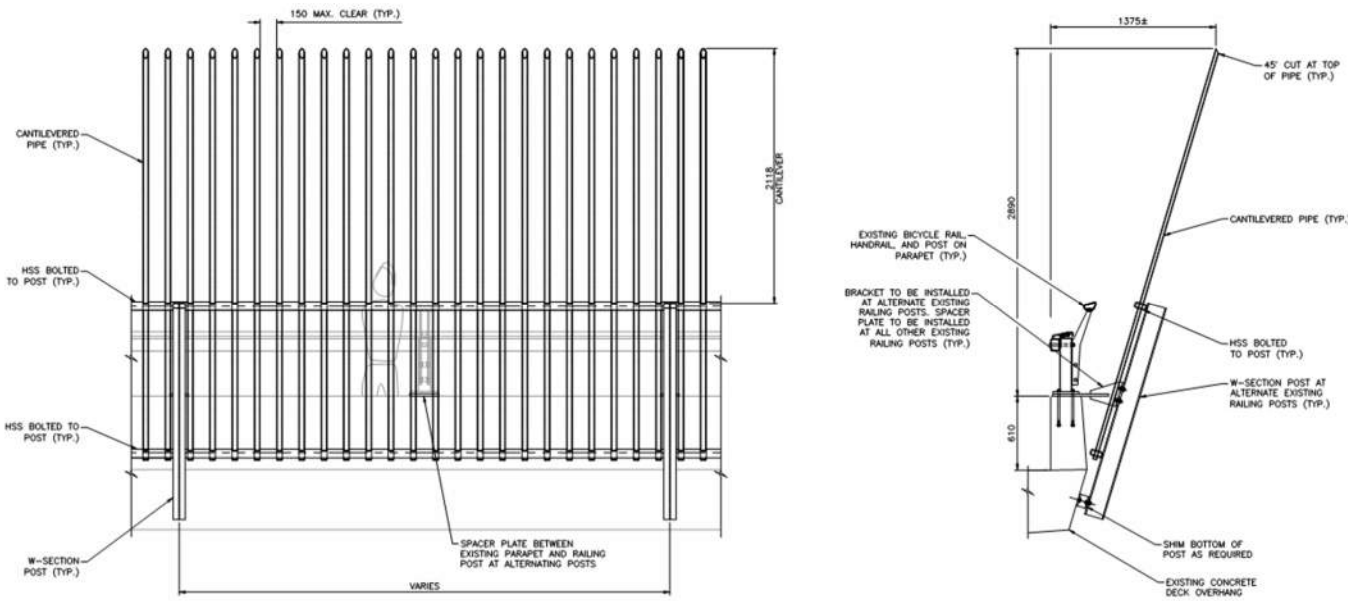

Figure 3.1 – Exterior Barrier Alternative 1

Advantages

This barrier type imposes a good sense of impassability and is the best option for means prevention effectiveness. The cantilevered pipe design limits the number of available handholds by not requiring an upper horizontal member for support. Likewise, the smooth surfaces of the pipes will prevent anyone from getting a solid grip and scaling the barrier. The angled cut at the top of the pipes would make it difficult for anyone to grab the top of the pipes and pull themselves up and over the barrier. Many existing barriers of the same design can be found on several landmark structures around North America, giving evidence of the effectiveness and efficiency of this type of barrier. Mock-ups have also shown that this barrier type gives a strong impression of imperviousness due to its height, member sizes, and lack of handholds. Finally, the ability to add architectural shaping to the top of the barrier will help to incorporate the system into the existing bridge design as much as possible.

Disadvantages

Alternative 1 may prove to be heavier than option 2 due to the increased member sizes required for the cantilever construction. However, this weight would be reduced if considering the aluminum option, even though the members will need to be larger. Additionally, the larger diameter pipes will reduce the view from the bridge and will be clearly visible when observing the bridge from the sides. This view obstruction is compounded when considering the larger diameter pipe required for the aluminum option. Consequently, increasing the diameter of the pipes for aluminum construction will result in an increased size for the HSS supports at the lower end of the barrier.

Damping of the cantilevered pipes will be required to reduce the effects of vibration for both the steel and aluminum options as a result of wind, rain, snow, and ice loading. More extensive damping will be required for the aluminum pipes due to the reduced stiffness when compared to steel. Aluminum is much more susceptible to induced vibrations than steel, with vibrations starting at lower applied loads and lasting for longer durations. This observed phenomenon can be easily explained from a material properties standpoint, with aluminum having a much lower stiffness than a comparable steel member, which results in a higher vibration frequency and time period before self-damping occurs. If the aluminum material option is selected for this barrier, special consideration will need to be given to the dynamic and fatigue design of the members to ensure there are no long-term performance concerns.

3.2.2 ALTERNATIVE 2: INCLINED BARRIER WITH SUPPORTED PICKETS

The second proposed alternative for the exterior means prevention barrier is an inclined supported picket barrier. Similar to the Burrard Street Bridge outlined in Section 2.1, this barrier type utilizes round steel pickets supported with horizontal members. The horizontal supports near the top of the barrier combined with full-height I-section posts will allow this alternative to use thinner, solid metal rods as the primary fencing system. Refer to Figure 3.2 below for a concept drawing for this barrier alternative. Refer to Appendix B for the full drawing. The remainder of the system will be identical to Alternative 1 due to the constraints of matching the profile to the existing debris barrier and minimizing impacts to the railing system.

The approximate diameter for the picket rods would be 21mm for galvanized steel and 25mm for aluminum. The upper HSS support alleviates many of the concerns found with using aluminum for Alternative 1 in that this system will be less susceptible to vibrations and induced deflections if a person attempts to pull the bars apart.

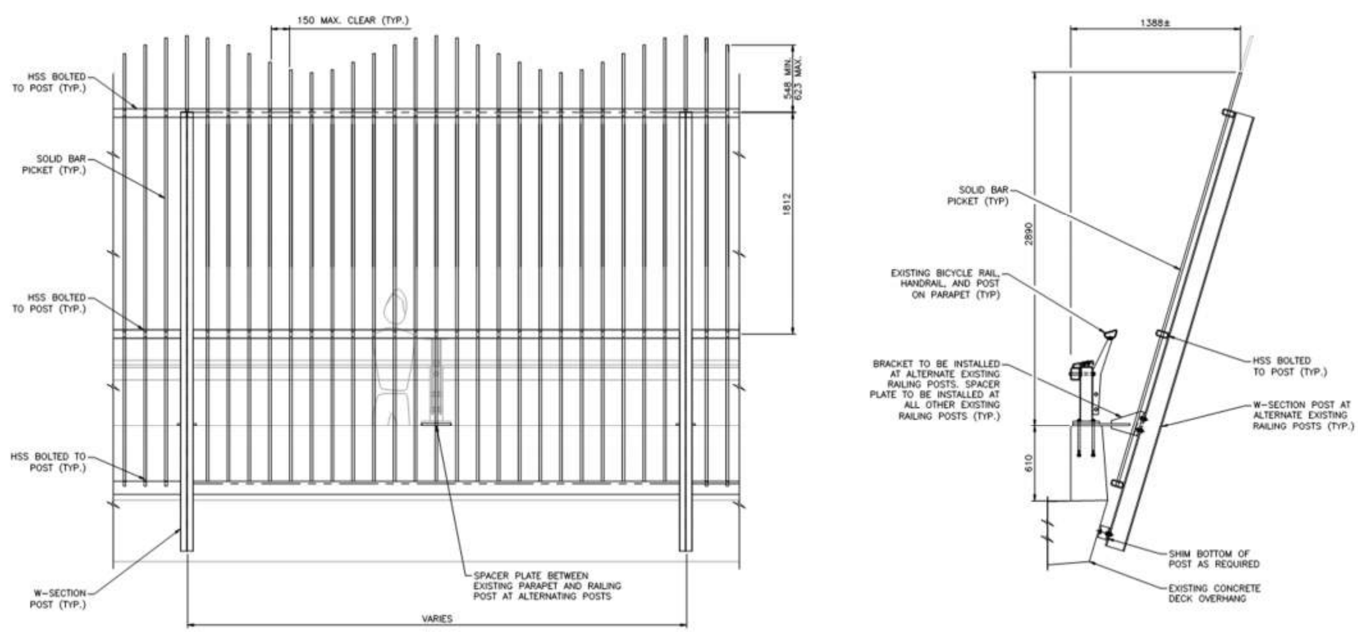

Figure 3.2 – Exterior Barrier Alternative 2

Advantages

Alternative 2 for the exterior barrier benefits from a lighter assembly due to the thinner pickets. By providing full-height posts and horizontal support members, the pickets do not need to be as large as they would be if they were cantilevered. The thinner vertical bars are also optimal from a viewing perspective as they will result in less obstruction to the view from the bridge. As with Alternative 1, this option allows for architectural features in the design. As shown in Figure 3.2 above, the proposed alternative 2 has a scalloped design, but other styles can easily be accommodated. The thin nature of the pickets also results in a built-in safety feature in that the small diameter tops would make it difficult for someone to pull themselves onto and over the barrier. As with Alternative 1, the top of the pickets can be clipped to deter them from being used as a handhold. As a result of the extra horizontal support, there will be less concerns over the barrier members vibrating when exposed to wind and snow loading. Finally, the steel and aluminum options will have generally the same construction, with the aluminum components only slightly larger than their steel counterparts to accommodate the lower stiffness of the aluminum.

Disadvantages

The primary drawback of the supported picket style barrier is the inclusion of the horizontal member near the top of the barrier which may present a handhold and potentially increase the risks of an individual being able to scale the barrier. However, by extending the pickets above this member, the ability for someone to use it as a handhold is reduced. Another drawback of this design is that the I-section posts would need to extend the full height of the barrier in order to support the upper picket connection member. This will add bulk to the barrier resulting in a discontinuous appearance to the overall system. Finally, Alternative 2 may not be as physically imposing as Alternative 1 due to thinner components comprising the majority of the barrier, which reduces the impression of impassability that is crucial to a successful means prevention barrier.

3.3 INTERIOR BARRIER

As previously discussed, it is understood that the Region is requesting an interior means prevention barrier system which will be in the form of a steel net spanning between the bridge decks over the full length of the Burgoyne Bridge. As with the exterior barrier, it has been noted that all barrier alternatives should minimize impacts to the existing bridge railing systems and other bridge components. An additional constraint on the arch span is that the net cannot impact the performance of the arch hanger system. As with the exterior barrier, Parsons is recommending two alternatives for the interior barrier. Both systems will be identical in design but will be positioned at different heights on the exterior side of the parapet walls. It is recommended that both alternatives use a very large mesh opening to discourage anyone from walking or climbing on top of the net. This will also reduce the visual and weight impacts of the system to the bridge. The proposed netting options on the Burgoyne Bridge also alleviates the major concerns with other netting systems (such as the Golden Gate Bridge) in that there will be no option to bypass the net as it will completely fill the gap between the bridges.

The proposed net system for both alternatives will be a stainless-steel cable net which will be supported by longitudinal cables adjacent to the parapet walls and transverse cables at intervals along the entire bridge length. The system will be supported by stainless steel connectors and brackets which will be either bolted to the parapet walls or utilize the existing railing anchorages. The net system will be highly durable, weather resistant, and customizable to be able to fit the complex geometry of the Burgoyne Bridge. Various options exist to allow for the replacement of the light poles on the bridge, as well as maintenance of the arch stay pipes and cables. Such a system has been used in various applications for pedestrian safety on buildings and bridges, particularly in Europe.

3.3.1 ALTERNATIVE A: HORIZONTAL MESH AT TOP OF PARAPETS

Interior barrier Alternative A consists of a horizontal steel mesh system spanning between the bridge decks which utilizes the existing railing anchorages for support brackets. The benefit of this arrangement is that there will be no drop onto the net if someone attempts to climb onto it. The net will act purely as a fence system to block anyone from falling from the bridge, as opposed to a method of catching someone during a fall. This option will be visible from the bridge deck to vehicles and pedestrians, which may have the unintended result of promoting people to climb on the net. There is also the potential of vandalism occurring to the net, an issue that will be compounded if the system is easily accessible from the deck level. However, construction and maintenance of the net system will be easier as the components will be accessible from deck level. Additionally, having the net located at the railings allows for the existing railing anchor bolts to be used, avoiding the need to anchor new brackets into the parapet walls. Coincidentally, mounting the net at the top of the parapets avoids interfering with the light pole pedestals and the access panels for the arch thrust blocks. Refer to Figure 3.3 for a concept sketch for Alternative A. The full drawing can be found in Appendix B as well as a separate drawing which includes the proposed provisions for protrusions in the net for the stay cables and light poles.

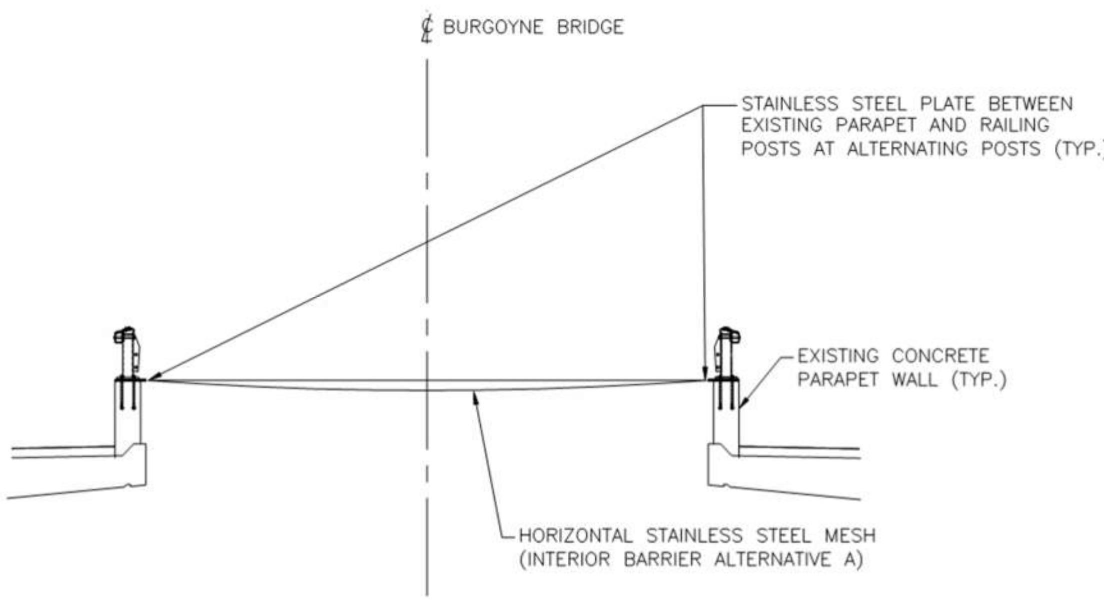

Figure 3.3 – Interior Barrier Alternative A

3.3.2 ALTERNATIVE B: HORIZONTAL MESH AT BOTTOM OF PARAPETS

Interior barrier Alternative B consists of a horizontal steel mesh system spanning between the bridge decks which is anchored to the deck overhang faces at the bottom of the parapet walls. This arrangement may allow someone to scale over the railing and parapet wall and climb on the net. Since the net is partially hidden by the parapet, it may be difficult to identify if a person is on the net and if they may need help. Similarly, a person would have the opportunity to jump onto the net from the top of the parapet wall due to the height difference, which may result in injury. Consequently, retrieving a person who is on the net may be more difficult for rescue personnel due to the restriction from the parapet and railing. Otherwise, having the net system below the level of the parapets will help to reduce the visual impact on the structure as it will be more difficult to see from the deck level. This option will also help to reduce the possibility of vandalism as the net will be more difficult to access from the deck. However, installation and maintenance of this system will also be reduced as the connections will be more difficult to access. Additionally, conflicts with the light pole pedestals and the arch thrust block access panels would require additional detailing of the net and may limit the required access during service. Finally, anchoring the support brackets to the existing concrete parapet walls may be difficult and time consuming due to the possibility of striking reinforcement within the wall. Refer to Figure 3.4 below for a concept sketch for Alternative B. The full drawing can be found in Appendix B.

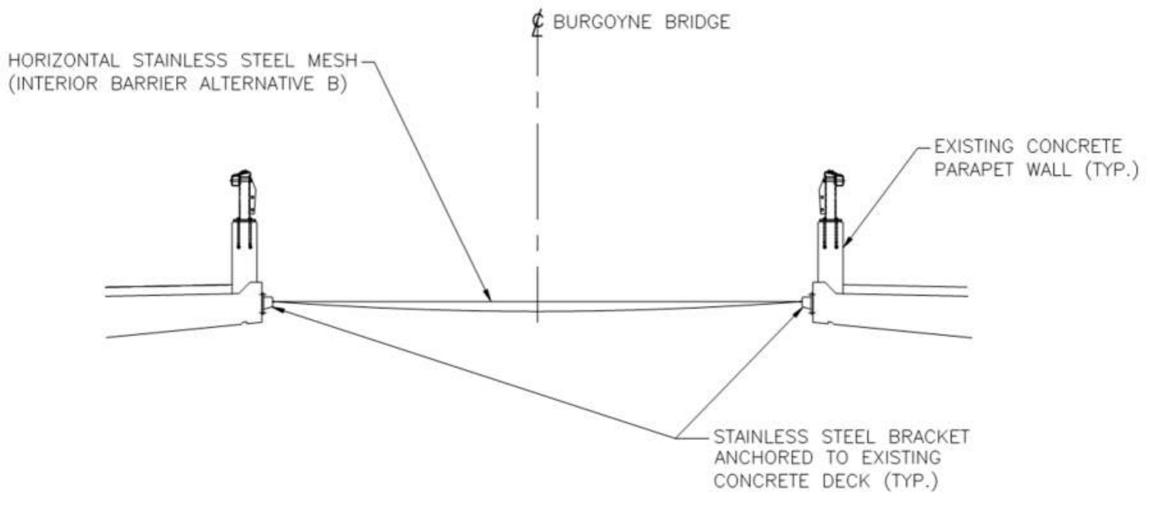

Figure 3.4 – Interior Barrier Alternative B

3.3 RECOMMENDED BARRIERS

Exterior Barrier

Parsons is recommending that Alternative 1 be selected for the exterior barrier. This inclined cantilevered pipe barrier was determined to be the best option with regards to means prevention. This barrier type provides a greater sense of impassibility and imperviousness, while the cantilevered design reduces the number of handholds, making it very difficult to scale the barrier. The smooth, larger diameter pipes would be challenging to hold on to or use as a foothold, and the angle cut into the top of the pipes further limits the ability for an individual to attempt to climb over the barrier. Most importantly, there are numerous successful precedents that can be observed on several bridges throughout the world where the same barrier type has been constructed.

Per the Region's request, Parsons has allowed for this barrier type to be constructed with either galvanized steel or aluminum components. As previously discussed, the lower stiffness of aluminum as compared to steel results in larger structural members for an aluminum option (60mm outer diameter) vs. the steel (48mm outer diameter) to limit the deflections of the pipe components. In an effort to understand the view differences between the two material options for the proposed exterior barrier system, Parsons has created a model comparing the two materials, as shown in Figure 3.5 below.

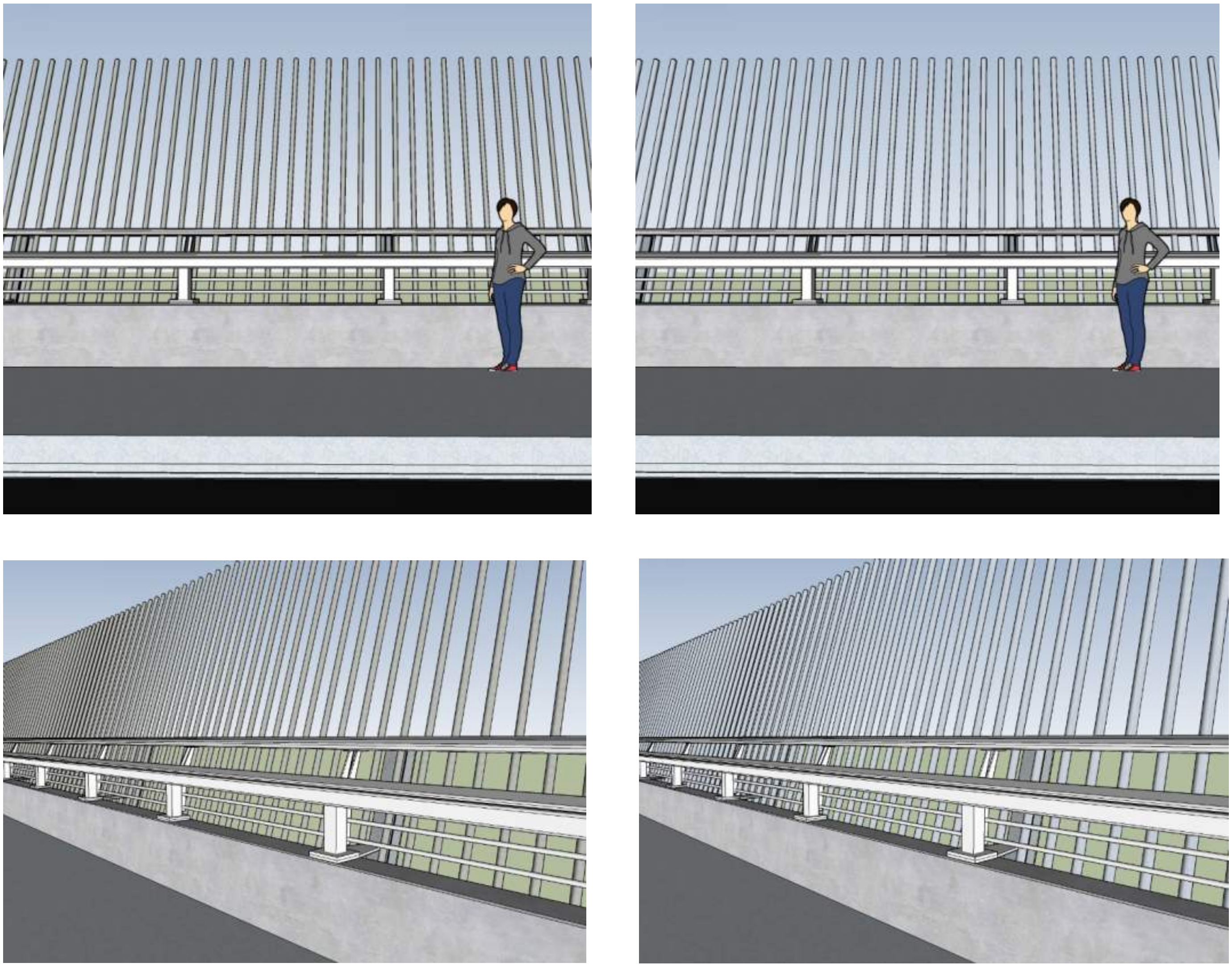

Figure 3.5 – Exterior Barrier Proposed Alternative – Galvanized Steel (Left) vs. Aluminum (Right)

The recommended interior and exterior barriers will be further discussed in the following sections and the preferred material type will be determined for the exterior barrier.

Interior Barrier

Parsons is recommending that Alternative A, a horizontal steel mesh mounted at the top of the parapet walls, be utilized for the interior barrier. This interior barrier configuration would allow for easier installation and maintenance of the net as compared to the other option due to the easier access from the bridge decks. By utilizing the existing railing anchor bolt assemblies for attaching the support brackets, construction of the net would minimize impacts to the bridge and avoid time consuming concrete anchoring. Additionally, no drop onto the net from the parapet wall and railing could potentially reduce the ability for a person to become trapped on the net and limits the efforts required for emergency personnel to rescue someone from the net if help is needed. Finally, by mounting the net at the top of the parapets, the light pole pedestals and arch thrust block access panels are avoided, thereby limiting complicated mounting techniques and impacts to the bridge and barrier during service.

4.0 DYNAMIC ANALYSIS

Parsons has retained RWDI to conduct dynamic analysis and wind tunnel testing of the proposed Burgoyne means prevention barriers. RWDI is in the process of building a sectional model of the bridge deck that replicates the bridge's main span geometry and mass distribution. The sectional model will be mounted on a spring suspension system and tested in the wind tunnel for the wind speed range that is expected at the project site. The model will be mounted in such a way that it can move both vertically and torsionally about the longitudinal axis. The deck will be tested with and without the means prevention barrier to assess the barrier's impact on the overall aerodynamic stability of the bridge deck. Tests will also be carried out to measure aerodynamic force and moment coefficients, with and without the barrier, that will be used for derivation of wind loads acting on the bridge. The sectional model tests are planned to take place in the coming weeks.

After completion of the tests, numerical methods will be used to combine the design wind speeds, turbulence levels at the site, static force and moment coefficients, and modes of vibration in order to determine wind loads acting on the bridge. Having recorded aerodynamic coefficients with and without the barrier allows for direct derivation and comparison of the wind loads between the two configurations evaluated. This information will be used during the detailed design phase of the barrier to ensure appropriate dynamic performance of the barrier.

In addition to determining the wind loads and confirming the dynamic performance of the bridge as a whole, dynamic analysis of the exterior barrier pipes will be required during the detailed design phase. It is likely that the pipes will require mass dampers to reduce vibrations caused by wind loading and potential vortex shedding around the exterior barrier pickets. Other successful precedents have been shown to use mass dampers within steel cantilevered pipes to limit vibrations under wind loading. These dampers have been shown to use minimal material and installation effort on similar barriers on other bridges. Without further analysis it is uncertain what extent of damping would be required for an aluminum barrier option. However, due to the reduced stiffness of aluminum as compared to steel, it could be argued that the level of damping will need to be more extensive than a steel option and may prove to be prohibitive from a cost or constructability standpoint or may simply be unfeasible for the member sizes and lengths proposed for this barrier. If aluminum is deemed to be the preferred material for the exterior barrier, more in-depth dynamic and material analysis will be required to confirm the extent of damping and that the final system will still conform to the mandatory means prevention requirements. Due to the lack of precedents on other bridges, the performance of an aluminum option is uncertain, and the level of damping poses a risk if this material is required.

5.0 CONSTRUCTION CONSIDERATIONS

Exterior Barrier

The exterior barrier will be designed in such a way that construction can be accommodated via lifting equipment situated on the bridge deck. The barrier brackets and posts will be installed as a single piece by locally lifting the existing railing and installing a plate onto the anchor bolts holding the railing to the parapet. The lower portion of the posts will be anchored to the concrete deck fascia with provisions to alter the anchor location if conflicts with reinforcement are encountered during anchor installation. Once the posts are installed, the vertical and horizontal barrier members will be installed in panels and bolted to the posts. This will allow for quicker construction, maintenance, and replacement. Depending on the size of lifting equipment selected, traffic can either be maintained on both bridge decks with traffic protection to delineate traffic from the workers and equipment (which would be located on the sidewalk side of the deck), or a closure of one of the decks during construction activities as with the interior barrier. If required, a bridge master unit can be used to scale over top of the outer barrier for construction of the barrier or maintenance and inspection during service. Several bridge master models from various suppliers are capable of passing over top of the proposed exterior barrier. As depicted in Appendix C, it is estimated that the installation of the exterior barrier will require approximately 33 working days. A more thorough staging plan can be developed during the detailed design of the barrier.

Interior Barrier

The interior mesh net can be primarily installed from the deck level. Brackets can be installed between the parapet walls and railing posts by utilizing the existing post anchor bolts by locally unbolting and lifting the railing. Once the brackets are installed the longitudinal and transverse support cables can be connected. The mesh net can then be attached to these support cables. An under-deck platform will be required spanning between the decks for a portion of the interior barrier where the transverse net cables are installed to allow for the net to be threaded onto these cables. It is expected the platform can be relocated at each applicable location as required. The installation of this barrier will also require a closure of one of the bridge decks when installing the barrier components as the net will need to be put into place from the deck level. Temporary traffic signals or flagging could be utilized to maintain two-way traffic during construction. As depicted in Appendix C, it is estimated that the installation of the interior barrier will require approximately 27 working days. A more thorough staging plan can be developed during the detailed design of the barrier.

6.0 COST ESTIMATES

6.1 CONSTRUCTION COST ESTIMATES

Estimated material, fabrication, delivery, and installation costs for the interior barrier and both galvanized steel and aluminum options for the exterior barrier are included in Appendix C. This cost estimate includes all expected works for the Burgoyne means prevention barriers. These cost estimates include a 40% contingency due to the custom fabrication and installation work which is difficult to quantify due to the lack of similar projects in Ontario for reference. Table 2 below includes a summary of the total material and fabrication costs, delivery costs, and installation costs for both barriers.

Table 2 – Construction Cost Estimates

Item	Material and Fabrication	Delivery	Installation	Contingency (40%)	Total Cost
Interior Barrier	$ 178,000	$ 4,000	$ 430,000	$ 245,000	$ 857,000
Exterior Barrier – Galvanized Steel	$ 694,000	$ 32,000	$ 511,000	$ 495,000	$ 1,732,000
Exterior Barrier - Aluminum	$ 657,000	$ 32,000	$ 511,000	$480,000	$1,680,000

As depicted in the table above, the aluminum exterior barrier is marginally less expensive than the steel exterior. This difference in estimated cost can largely be accounted for in the galvanizing process required for the steel components. If anodizing is selected for the aluminum option, it is expected the costs may become very similar for the two material options. As previously discussed, the extent of damping required for the aluminum option may also have unexpected costs associated with the analysis, design, fabrication, and installation of mass dampers.

6.2 LIFE CYCLE COST ANALYSIS

In order to evaluate and compare the life cycle cost performance of the steel and aluminum exterior barrier options, as well as the interior barrier, a life cycle cost analysis was performed, which can be found in Appendix D. The life cycle analysis considers a life cycle of 125 years to match the design life of the Burgoyne Bridge itself. Due to the life span differences between the galvanized steel, aluminum, and stainless steel, different material life spans and replacement years were selected based on an expected service life of the respective material. The cost analysis also considers periodic replacement of a certain percentage of the barrier components to account for damage, vandalism, or localized excessive corrosion. Table 3 below summarizes the 125-year net present value costs associated with each barrier type.

Table 3 – Life Cycle Cost Analysis

Item	Life Cycle Cost: Net Present Value (NPV) at End of 125-year Life Cycle
Interior Barrier	$ 892,000
Exterior Barrier – Galvanized Steel	$ 2,465,000
Exterior Barrier - Aluminum	$ 1,984,000

Table 3 indicates that the aluminum exterior barrier option will have a lower 125-year NPV life cycle cost as compared to an equivalent steel barrier. This is largely due to the longer material life of aluminum which is expected to remain in service condition for a longer period than galvanized steel. Comparatively, the stainless-steel interior barrier has a much longer material life meaning that the increase in life cycle cost over the capital cost is negligible over the life cycle of the barrier.

7.0 SUMMARY AND RECOMMENDATIONS

Parsons has been contracted by the Regional Municipality of Niagara Public Works Department to investigate possible means prevention measures following several deaths by suicide and suicide attempts from the Burgoyne Bridge. Along with the Region's feedback, Parsons has selected two barrier types for use as means prevention on the Burgoyne Bridge based on case studies and feasibility analysis. It is understood that means prevention effectiveness is of utmost importance in the selection of appropriate barriers for use on the bridge.

Parsons is proposing two barriers for the bridge: an interior stainless-steel mesh net barrier which is mounted at the top of the parapet walls spanning horizontally between the two bridge decks, and an exterior cantilevered pipe barrier mounted on the exterior edges of the bridge. The interior barrier was selected as it completely removes the ability for a person to fall from the bridge, while minimizing impacts to the appearance and functionality of the structure. Stainless steel components ensure a long service life and utilizing the existing bridge railing anchor bolts minimizes the construction difficulty and schedule. The exterior barrier was selected primarily due to its effectiveness at providing means protection. By utilizing cantilevered vertical members, the ability of a person to use hand holds to scale the barrier is removed. This barrier option is optimal for providing a sense of imperviousness which will help deter individuals from attempting to climb the barrier.

Parsons also investigated the use of both galvanized steel and aluminum materials for the construction of the exterior barrier. While life cycle costs are higher than an equivalent aluminum barrier (with similar initial construction costs), many precedents of steel pipe barriers indicate that other designers and owners have determined galvanized steel to be the most effective and efficient material for constructing such a barrier. While aluminum has been used in bridge railing systems, there have been no identified cantilevered pipe means prevention barriers constructed with this material. If aluminum is determined to be the selected material for this barrier, additional effort will be required. While both materials are expected to be feasible for the proposed exterior barrier, further analysis will be required during detailed design.

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Senior Structural Engineer, Bridges

Report Reviewed by:

Sardar A. Nabi, M.S., P.E., P.Eng.

Program Director, Bridges

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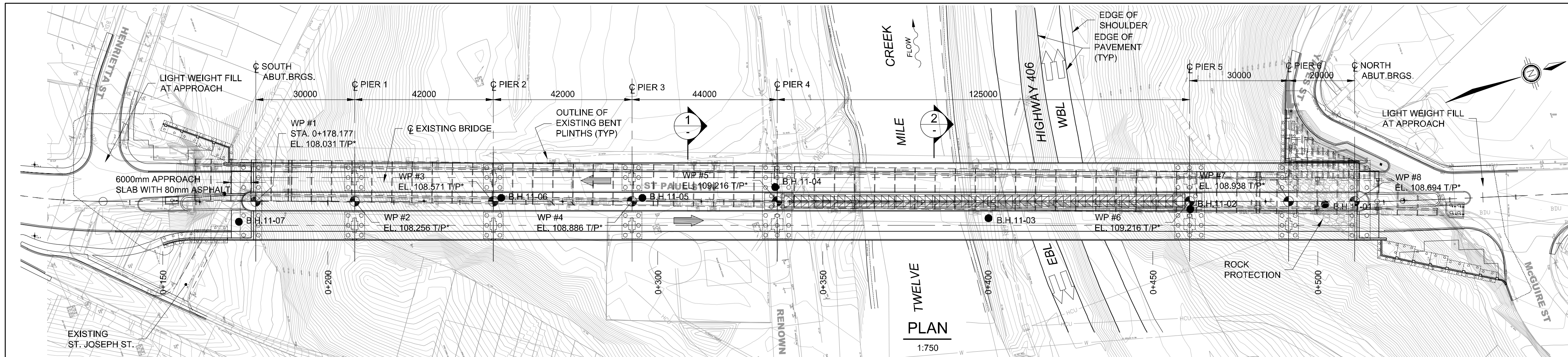
APPENDIX A

BURGOYNE BRIDGE GENERAL ARRANGEMENT



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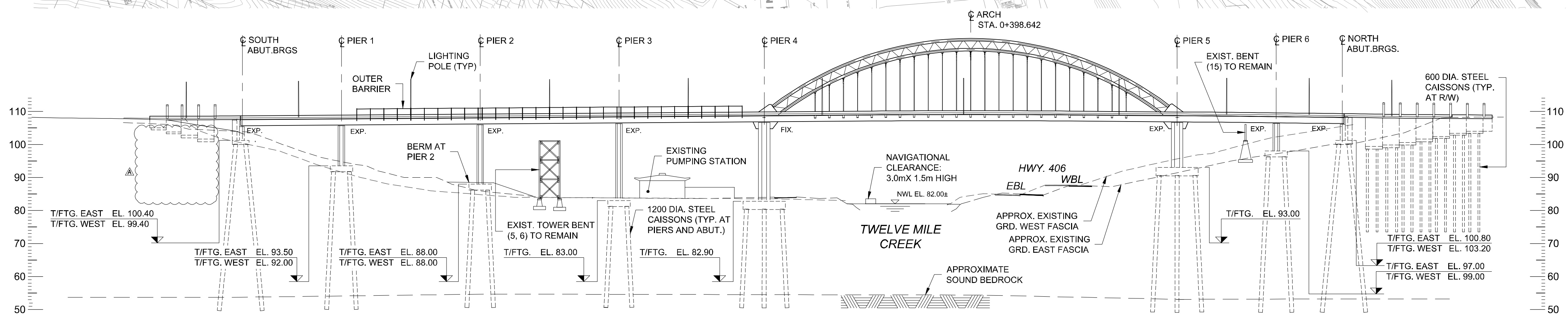

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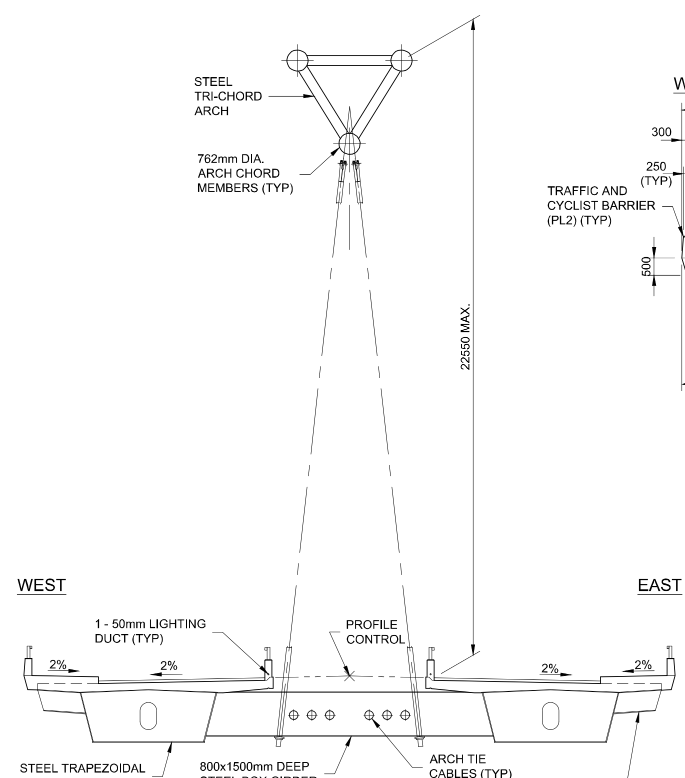

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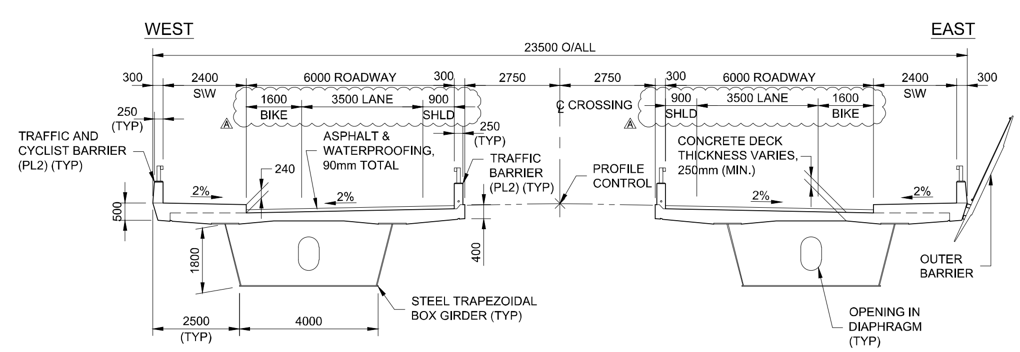

SECTION 1 TYPICAL DIMENSIONS
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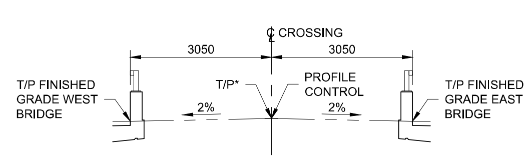
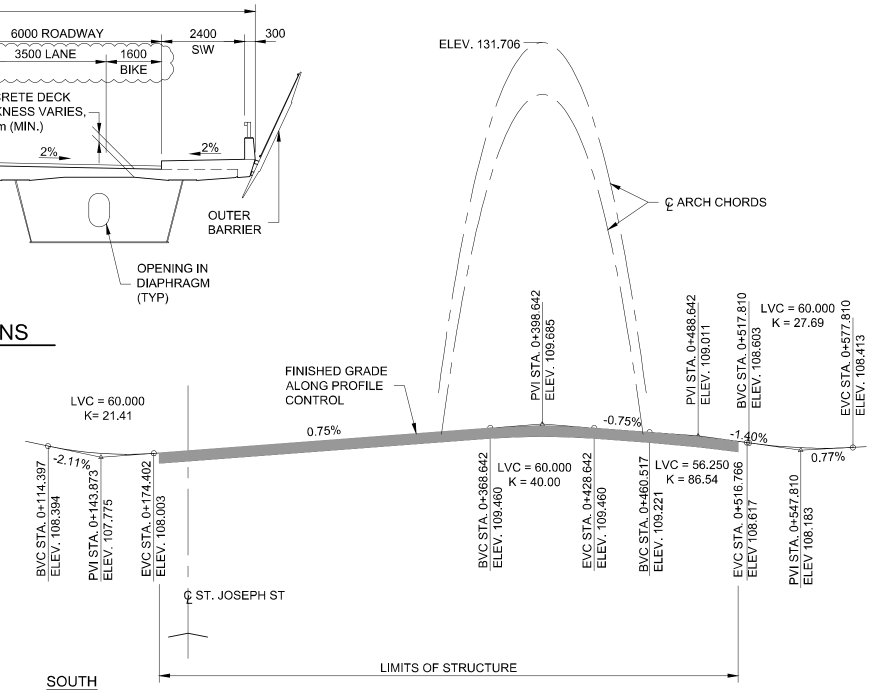


DETAIL A
1:75



PROFILE-REGIONAL RD. 81/ST. PAUL ST. W.
NTS

GENERAL NOTES:

DESIGN LOADS

BRIDGE:
- CL-625-ONT TRUCK LOAD, CL-625-ONT LANE LOAD.

SIDEWALK:
- PEDESTRIAN LOADS AND MAINTENANCE VEHICLE OF CHBDC S6-06.

CLASS OF CONCRETE

THRUST BLOCKS .... 40 MPa
FOOTINGS, CAISSONS AND TOPPING SLABS .... 30 MPa
REMAINDER (UNLESS OTHERWISE NOTED) .... 35 MPa
- THE MAXIMUM NOMINAL SIZE OF AGGREGATE IN SIDEWALK SHALL NOT EXCEED 13.0mm.

CLEAR COVER TO REINFORCING STEEL

FOOTINGS & CAISSONS .... 100 ± 20mm
DECK & SIDEWALK:
TOP & SIDES (STAINLESS STEEL REINFORCING) .... 60 ± 10mm
BOTTOM (BLACK STEEL REINFORCING) .... 50 ± 10mm
REMAINDER .... 70 ± 20mm
UNLESS OTHERWISE SPECIFIED

REINFORCING STEEL

1. REINFORCING SHALL BE GRADE 400W UNLESS OTHERWISE SPECIFIED.
2. STAINLESS REINFORCING STEEL SHALL BE TYPE 316LN OR DUPLEX 2205 AND HAVE A MINIMUM YIELD STRENGTH OF 500MPa, UNLESS OTHERWISE SPECIFIED
3. BARS MARKED WITH PREFIX "S" DENOTE STAINLESS STEEL BARS.
4. UNLESS SHOWN OTHERWISE, TENSION LAP SPLICES SHALL BE CLASS B.
5. BAR HOOKS SHALL HAVE STANDARD HOOK DIMENSIONS USING MINIMUM BEND DIAMETERS, WHILE STIRRUPS AND TIES SHALL HAVE MINIMUM HOOK DIMENSIONS. ALL HOOKS SHALL BE IN ACCORDANCE WITH THE MTO STRUCTURAL STANDARD DRAWING SS12-1, UNLESS INDICATED OTHERWISE.

CONSTRUCTION NOTES

1. ALL DIMENSIONS ARE IN MILLIMETERS UNLESS NOTED OTHERWISE. CHAINAGES AND ELEVATIONS ARE IN METRES,
2. MAINTAIN FULL NAVIGATIONAL CLEARANCE THROUGHOUT CONSTRUCTION.
3. THE CONTRACTOR SHALL ESTABLISH THE BEARING SEAT ELEVATIONS BY DEDUCTING THE ACTUAL BEARING THICKNESSES FROM THE TOP OF BEARING ELEVATIONS. IF THE ACTUAL THICKNESSES ARE DIFFERENT FROM THOSE GIVEN WITH THE BEARING DESIGN DATA, THE CONTRACTOR SHALL ADJUST THE REINFORCING STEEL TO SUIT.

LEGEND:

WP	DENOTES WORKING POINT
T/P*	DENOTES THEORETICAL TOP OF PAVEMENT AT PROFILE CONTROL (SEE DETAIL "A")
U/S	DENOTES UNDERSIDE
S/W	DENOTES SIDEWALK
R/W	DENOTES RETAINING WALL
T/FTG	DENOTES TOP OF FOOTING

REFERENCE DRAWINGS

DRAWINGS OF THE EXISTING BRIDGE MAY BE VIEWED FOR INFORMATION PURPOSES AT THE OFFICES OF THE CITY OF ST. CATHERINES. ALL DIMENSIONS SHOWN ON REFERENCE DRAWINGS SHALL BE CONSIDERED APPROXIMATE.

THE PREFIX RR81-ST SHALL BE APPLIED TO ALL DRAWING NUMBER REFERENCES.

BENCHMARK

ELEVATION: 111.886
STATION: 00163U3519
N:4,778,711.270 E:642,154.302

APPLICABLE STANDARD DRAWINGS:

OPSD-3329.100	DECK, REINFORCEMENT SUPPORTS FOR REINFORCING STEEL FOR SLABS DEPTHS 300mm OR LESS
OPSD-3349.100	DECK, DRAINS DRAINAGE OF NEW DECK BELOW ASPHALT WEARING SURFACE
OPSD-3941.200	FIGURES IN CONCRETE, SITE NUMBER AND DATE LAYOUT
OPSD-3950.100	JOINTS, CONCRETE EXPANSION AND CONSTRUCTION ON STRUCTURE

NO.	REVISION	DATE	INIT.
A	AS-BUILT	2018-08-31	BIA

NOTES/LEGEND

1 THE POSITION OF POLE LINES, CONDUITS, WATERMAINS, SEWER AND OTHER UNDERGROUND AND OVERGROUND UTILITIES AND STRUCTURES IS NOT NECESSARILY SHOWN ON THE CONTRACT DRAWINGS AND, WHERE SHOWN, THE ACCURACY OF THE POSITION OF SUCH UTILITIES AND STRUCTURES IS NOT GUARANTEED. BEFORE STARTING WORK, THE CONTRACTOR SHALL INFORM HIMSELF OF THE EXACT LOCATION OF ALL SUCH UTILITIES AND STRUCTURES AND SHALL ASSUME ALL LIABILITY FOR DAMAGE TO THEM.

2 PROPERTY LINES WERE PLOTTED USING REGISTERED PLANS AND BARS LOCATED IN THE FIELD. TO VERIFY THE ACCURACY OF THESE PROPERTY LINES, A LEGAL SURVEY SHOULD BE PERFORMED PRIOR TO CONSTRUCTION.

3 DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SHOWN. ELEVATIONS AND STATIONS ARE IN METRES.

DRAFTING: KRS
DESIGN: SS
CHECKED BY: BIA
APPROVED BY:

Niagara Region PUBLIC WORKS

PARSONS

RN-13-04
BURGOYNE BRIDGE REPLACEMENT
CITY OF ST. CATHARINES

GENERAL ARRANGEMENT

CONSULTANT FILE No. BT3316
DATE: 2013-08-27
SCALE: AS SHOWN
REF. No.
DWG No.: RR81-ST01
REV.: A

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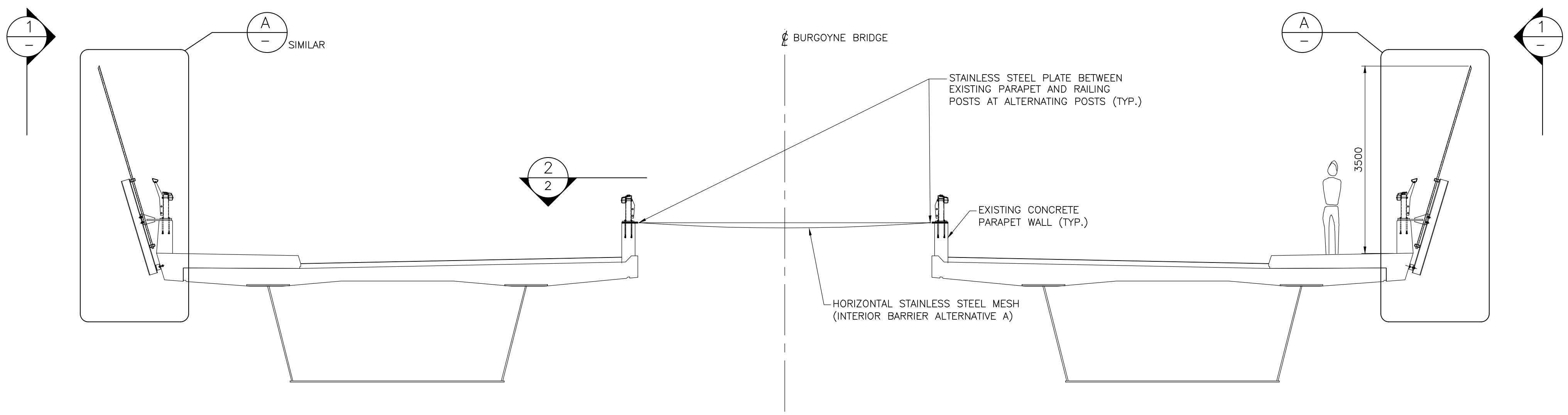
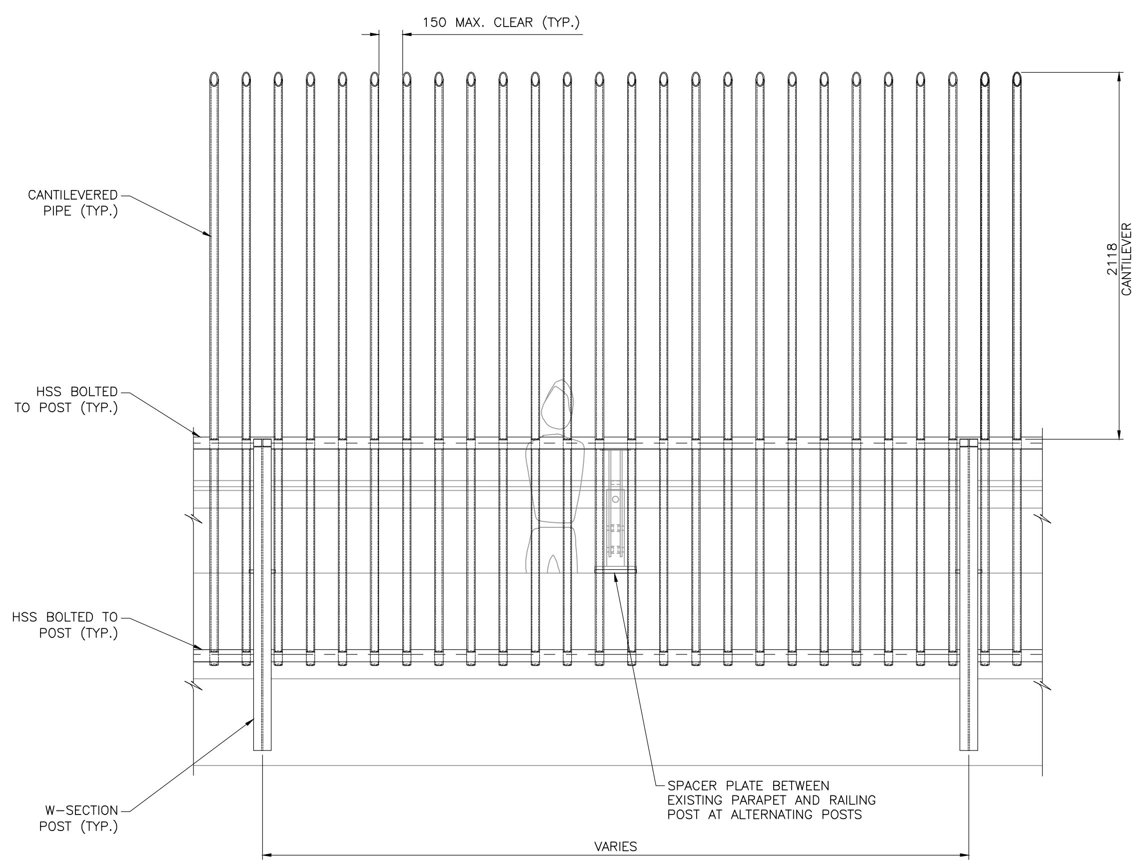
APPENDIX B

BARRIER ALTERNATIVES – DRAWINGS



SECTION – EXTERIOR BARRIER ALTERNATIVE 1, INTERIOR BARRIER ALTERNATIVE A

1:50



SECTION 1 / –

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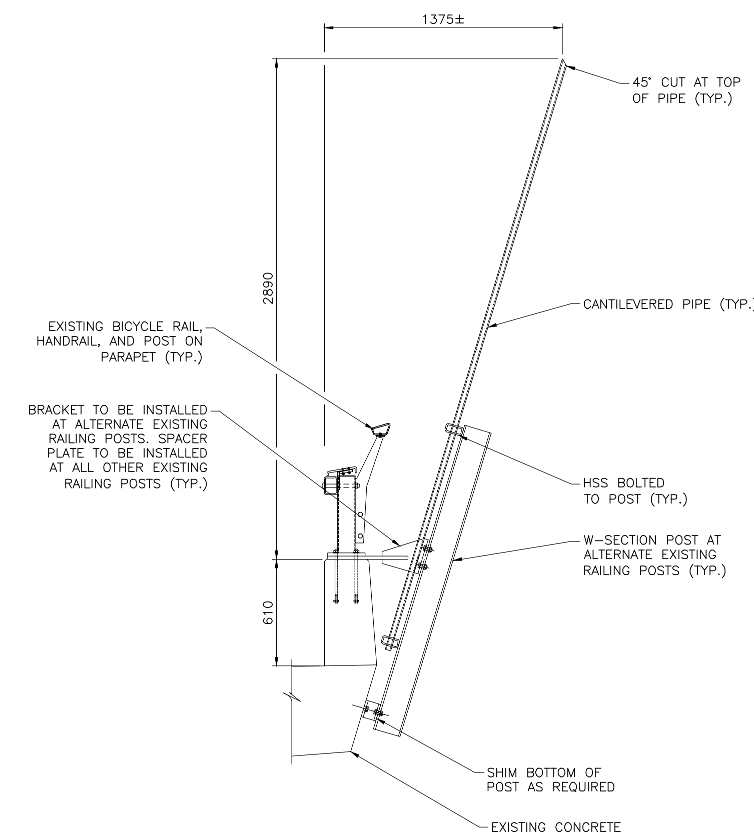

DETAIL A / –

1:20

NOT FOR CONSTRUCTION

NO.	REVISION	DATE	INIT.
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NOTES:

1. DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SHOWN. ELEVATIONS ARE IN METRES.

DRAFTING	R.S.
DESIGN	B.I.A.
CHECKED BY	––
APPROVED BY	

Niagara Region PUBLIC WORKS

PARSONS

2013-T-104 (RN-13-04)
BURGOYNE BRIDGE REPLACEMENT
CITY OF ST. CATHARINES

MEANS PREVENTION BARRIER ALTERNATIVE 1

CONSULTANT FILE No.	-----
DATE	YYYY–MM–DD
SCALE	AS SHOWN
REF. No.	
DWG No.	1
REV.	A

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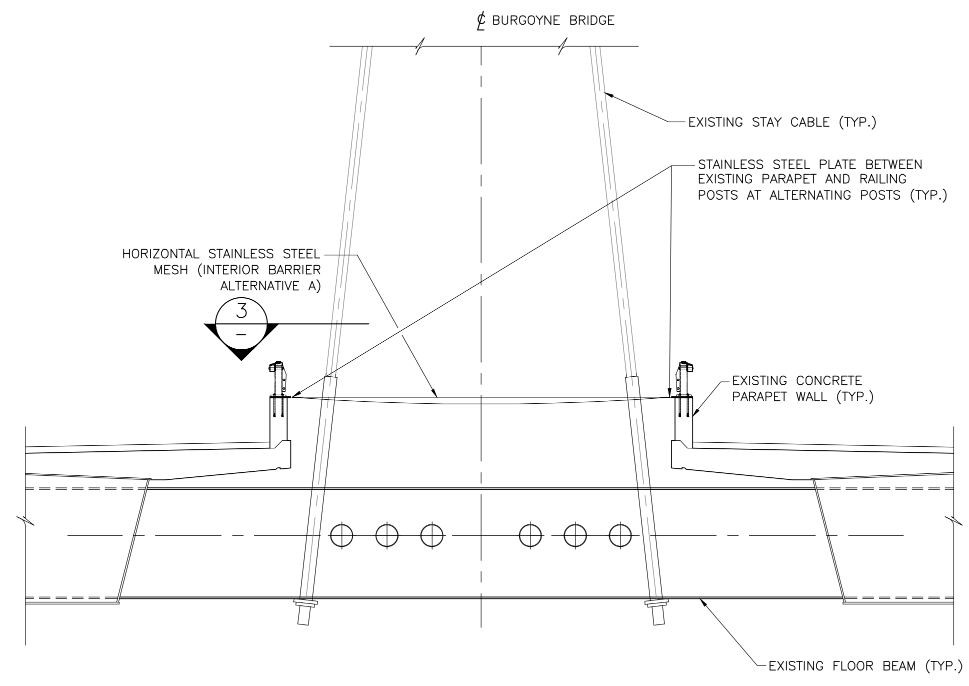
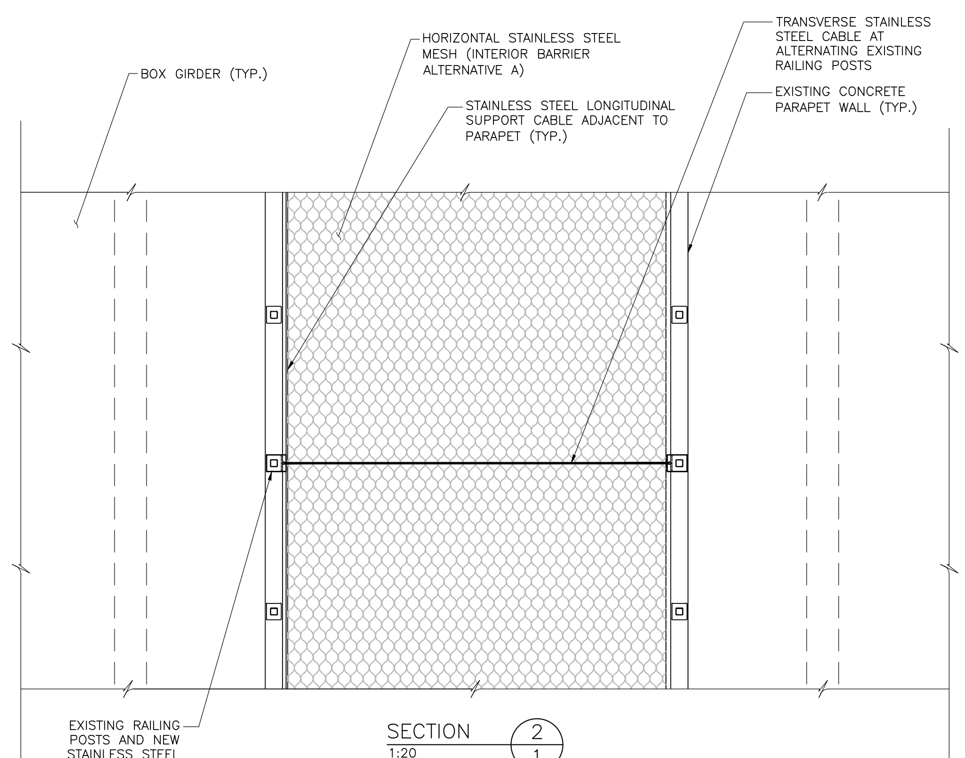


SECTION AT MAIN SPAN – EXTERIOR BARRIER ALTERNATIVE 1, INTERIOR BARRIER ALTERNATIVE A

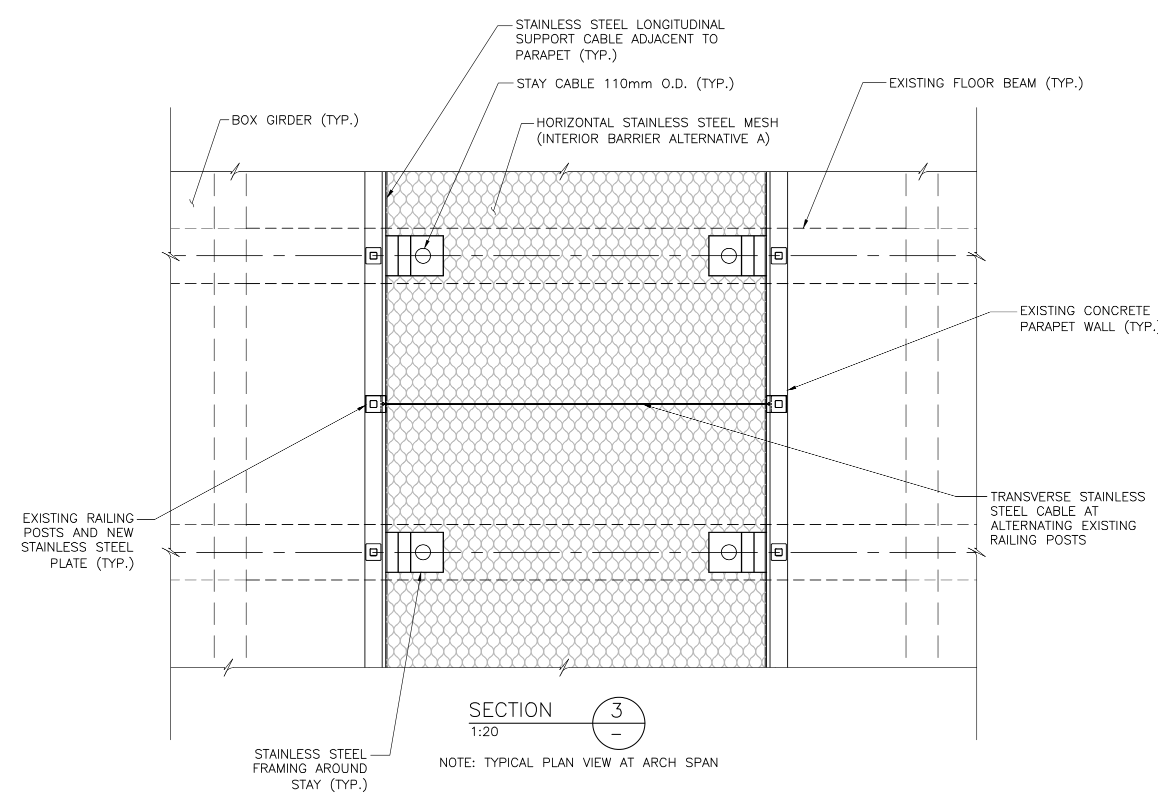
1:50



SECTION 2/1

1:20

NOTE: TYPICAL PLAN VIEW AT NON-ARCH SPANS



SECTION 3/–

1:20

NOTE: TYPICAL PLAN VIEW AT ARCH SPAN

NOT FOR CONSTRUCTION

NO.	REVISION	DATE	INIT.
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NOTES:
1. DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SHOWN. ELEVATIONS ARE IN METRES.

DRAFTING R.S.
DESIGN B.I.A.
CHECKED BY ––
APPROVED BY

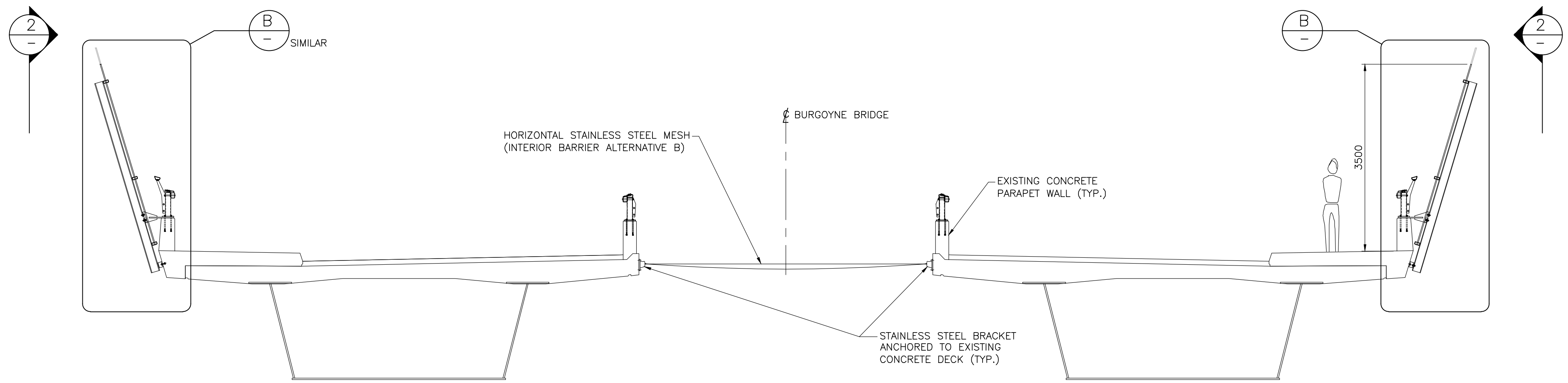
Niagara Region PUBLIC WORKS

PARSONS

2013-T-104 (RN-13-04)
BURGOYNE BRIDGE REPLACEMENT
CITY OF ST. CATHARINES

MEANS PREVENTION BARRIER ALTERNATIVE 1

CONSULTANT FILE No. –––––
DATE YYYY–MM–DD
SCALE AS SHOWN
REF. No.
DWG No. 2
REV. A



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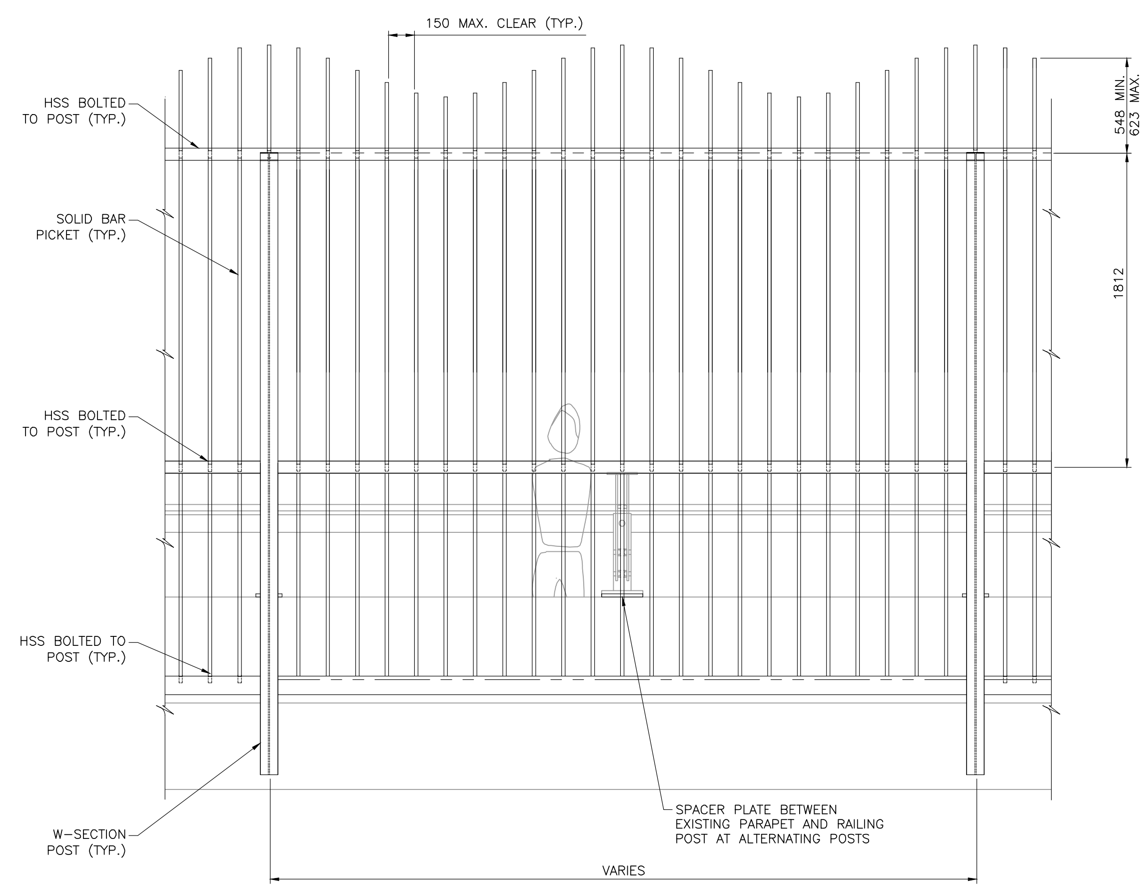
1:50



SECTION 2
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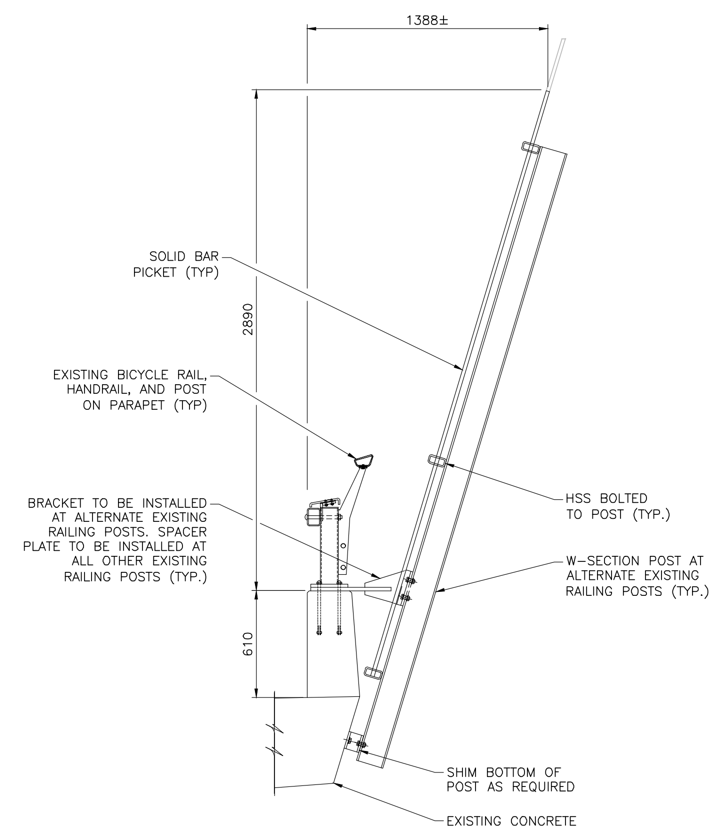

DETAIL B
1:20

NOT FOR CONSTRUCTION

NO.	REVISION	DATE	INIT.
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NOTES:
1. DIMENSIONS ARE IN MILLIMETRES UNLESS OTHERWISE SHOWN. ELEVATIONS ARE IN METRES.

DRAFTING A.F.N
DESIGN --
CHECKED BY --
APPROVED BY

Niagara Region PUBLIC WORKS

PARSONS

2013-T-104 (RN-13-04)
BURGOYNE BRIDGE REPLACEMENT
CITY OF ST. CATHARINES

MEANS PREVENTION BARRIER
ALTERNATIVE 2

CONSULTANT FILE No. -----
DATE YYYY-MM-DD
SCALE AS SHOWN
REF. No.
DWG No. 3
REV. A

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APPENDIX C

COST ESTIMATES

Galvanized Exterior Barrier Total Cost

Total barrier length	666	m	Fabrication rate	16	hrs/pcs
Panel size (average)	4.1	m/panel	Installation rate	5	pcs/day
Total number of panels	162	pcs	Metal tonnage	51598	kg

Cost items		Quantity		Unit rate		Amount
Fabrication and shop work		2592	hrs	$ 75.00	/hr	$ 194,000.00
Galvanizing		51598	kg	$ 2.00	/kg	$ 103,000.00
Delivery cost		162	pcs	$ 200.00	/pcs	$ 32,000.00
Site erection costs	in hours:	264	hrs	$ 800.00	/hr	$ 211,000.00
	in days:	33	working days			
Equipment rental		1	sum	$ 300,000.00		$ 300,000.00
				Construction subtotal		$ 840,000.00
				Material subtotal		$ 397,000.00
				Exterior barrier subtotal		$ 1,237,000.00
				40% Contigency		$ 495,000.00
				Exterior barrier total		$ 1,732,000.00
				Cost/m		$ 5,200.00

Interior Barrier Total Cost

Total span length	333	m			
Panel size (average)	20	m/panel	Anchorage installation	10	days
Total number of panels	17	pcs	Metal tonnage	1407	kg
Border and intermediate cak	760	m	Installation rate	1	pcs/day

Cost items		Quantity		Unit rate		Amount
Freight		1	sum	$ 4,000.00		$ 4,000.00
Site erection costs	in hours:	216	hrs	$ 600.00	/hr	$ 130,000.00
	in days:	27	working days			
Equipment rental		1	sum	$ 300,000.00		$ 300,000.00
				Construction subtotal		$ 434,000.00
				Material subtotal		$ 178,000.00
				Interior barrier subtotal		$ 612,000.00
				40% Contigency		$ 245,000.00
				Interior barrier total		$ 857,000.00
				Cost/m		$ 2,600.00

Total cost

Exterior and Interior subtotal	$ 1,849,000.00
40% Contigency	$ 740,000.00
Total	$ 2,589,000.00
Total cost/m	$ 7,800.00

Aluminum Exterior Barrier Total Cost

Total barrier length	666	m	Fabrication rate	16	hrs/pcs
Panel size (average)	4.1	m/panel	Installation rate	5	pcs/day
Total number of panels	162	pcs	Metal tonnage	35783	kg

Cost items		Quantity		Unit rate		Amount
Fabrication and shop work		2592	hrs	$ 90.00	/hr	$ 233,000.00
Delivery cost		162	pcs	$ 200.00	/pcs	$ 32,000.00
Site erection costs	in hours:	264	hrs	$ 800.00	/hr	$ 211,000.00
	in days:	33	working days			
Equipment rental		1	sum	$ 300,000.00		$ 300,000.00
					Construction subtotal	$ 776,000.00
					Material subtotal	$ 424,000.00
					Exterior barrier subtotal	$ 1,200,000.00
					40% Contigency	$ 480,000.00
					Exterior barrier total	$ 1,680,000.00
					Cost/m	$ 5,000.00

Interior Barrier Total Cost

Total span length	333	m			
Panel size (average)	20	m/panel	Anchorage installation	10	days
Total number of panels	17	pcs	Metal tonnage	1407	kg
Border and intermediate cak	760	m	Installation rate	1	pcs/day

Cost items		Quantity		Unit rate		Amount
Freight		1	sum	$ 4,000.00		$ 4,000.00
Site erection costs	in hours:	216	hrs	$ 600.00	/hr	$ 130,000.00
	in days:	27	working days			
Equipment rental		1	sum	$ 300,000.00		$ 300,000.00
					Construction subtotal	$ 434,000.00
					Material subtotal	$ 178,000.00
					Interior barrier subtotal	$ 612,000.00
					40% Contigency	$ 245,000.00
					Interior barrier total	$ 857,000.00
					Cost/m	$ 2,600.00

Total cost

Exterior and Interior subtotal	$ 1,812,000.00
40% Contigency	$ 725,000.00
Total	$ 2,537,000.00
Total cost/m	$ 7,600.00

Cost Estimate - Exterior Barrier - Material Cost

Galvanized Steel						
Alternative 1: Cantilevered Pipes						
Item	**Unit**	**Unit Cost**	**Quantity**	**Total Cost**	**Linear Cost ($/m)**	**Comments**
Pipe	m	$ 11.10	12622	$ 140,000.00	$ 420.00	48mm OD, 190mm C/C spacing
Horizontal HSS	kg	$ 5.00	26640	$ 133,000.00	$ 400.00	2 HSS per barrier
W-Section Post	kg	$ 5.00	10490	$ 52,000.00	$ 160.00	Installed at every other existing pedestrian railing post. Half-height post.
Filler Plate	kg	$ 5.00	1987	$ 10,000.00	$ 30.00	At all existing pedestrian posts without new bracket
Upper Bracket	kg	$ 5.00	6600	$ 33,000.00	$ 100.00	Installed at every new barrier post
Lower Bracket	kg	$ 5.00	5882	$ 29,000.00	$ 90.00	Installed at every new barrier post
			Material subtotal	$ 397,000.00	$ 1,200.00	

Aluminum						
Alternative 1: Cantilevered Pipes						
Item	**Unit**	**Unit Cost**	**Quantity**	**Total Cost**	**Linear Cost ($/m)**	**Comments**
Pipe	m	$ 13.62	11419	$ 156,000.00	$ 470.00	60mm OD, 210mm C/C spacing
Horizontal HSS	kg	$ 7.50	19980	$ 150,000.00	$ 450.00	2 HSS per barrier
W-Section Post	kg	$ 7.50	8991	$ 67,000.00	$ 200.00	Installed at every other existing pedestrian railing post. Half-height post.
Filler Plate	kg	$ 7.50	936	$ 7,000.00	$ 20.00	At all existing pedestrian posts without new bracket
Upper Bracket	kg	$ 7.50	3108	$ 23,000.00	$ 70.00	Installed at every new barrier post
Lower Bracket	kg	$ 7.50	2769	$ 21,000.00	$ 60.00	Installed at every new barrier post
			Material subtotal	$ 424,000.00	$ 1,270.00	

Cost Estimate - Interior Barrier - Material Cost

Alternative 1: Steel Mesh Net						
Component	**Unit**	**Unit Cost**	**Quantity**	**Total Cost**	**Linear Cost ($/m)**	**Comments**
Steel mesh net	m^2	$ 75.00	1900	$ 143,000.00	$ 430.00	AISI 316 stainless steel, mesh size 180 mm
End bracket	pcs	$ 200.00	34	$ 7,000.00	$ 20.00	Custom, stainless steel, every 10m at cable termination
Intermediate bracket	pcs	$ 150.00	134	$ 20,000.00	$ 60.00	Custom, stainless steel, every 5m between cable attachments
Border cable	m	$ 7.00	760	$ 5,000.00	$ 20.00	DIA 8, AISI 316 stainless steel, Fu = 52.8 kN
Turnbuckle	pcs	$ 30.00	49	$ 1,000.00	$ 3.00	AISI 316 stainless steel
Cable end attachment	pcs	$ 25.00	98	$ 2,000.00	$ 10.00	For DIA 8 cable, AISI 316
			Material subtotal	$ 178,000.00	$ 543.00	

APPENDIX D

LIFE CYCLE COST ANALYSIS

Life Cycle Cost Analysis - Burgoyne Means Prevention Barrier

Site:	Burgoyne Bridge
Exterior barriers (total length)	666 m

Alternative 1: Galvanized		
Year	Activity	
0	New construction	
15	Picket repair: replacement and/or miscellaneous repair	10% of total length
30	Full replacement	
45	Picket repair: replacement and/or miscellaneous repair	10% of total length
60	Full replacement	
75	Picket repair: replacement and/or miscellaneous repair	10% of total length
90	Full replacement	
105	Picket repair: replacement and/or miscellaneous repair	10% of total length
120	Full replacement	
125	End of service life	

Alternative 2: Aluminum		
Year	Activity	
0	New construction	
20	Picket repair: replacement and/or miscellaneous repair	15% of total length
40	Full replacement	
60	Picket repair: replacement and/or miscellaneous repair	15% of total length
80	Full replacement	
100	Picket repair: replacement and/or miscellaneous repair	15% of total length
120	Full replacement	
125	End of service life	

Activity Cost Estimates

Alternative 1: Galvanized

Activity	Quantity	Unit	Unit Cost ($/Unit)	Cost ($)
New Construction	-	-	-	$ 1,732,000.00
Picket Repair	67	m	$ 5,200.00	$ 346,320.00
Full Replacement	-	-	-	$ 1,732,000.00

Alternative 2: Aluminum

Activity	Quantity	Unit	Unit Cost ($/Unit)	Cost ($)
New Construction	-	-	-	$ 1,680,000.00
Picket Repair	100	m	$ 5,000.00	$ 499,500.00
Full Replacement	-	-	-	$ 1,680,000.00

Discount Rate =	5.00%

Residual Value Analysis

Alternative	Replacement Year	Replacement Cost	Residual Year	Value at End of Life Cycle	Residual Value at End of Cycle	Residual Value at Year Zero
1	120	$ 1,732,000.00	25	$ 511,464.40	$ (1,220,535.60)	$ (3,498.12)
2	120	$ 1,680,000.00	35	$ 304,567.68	$ (1,375,432.32)	$ (3,942.06)

Present Value Analysis (Level 3)

Year	Alternative 1: Galvanized		Alternative 2: Aluminum	
	Cost	Present Value (PV)	Cost	Present Value (PV)
0	$ 1,732,000.00	$ 1,732,000.00	$ 1,680,000.00	$ 1,680,000.00
15	$ 346,320.00	$ 166,585.84	$ -	$ -
20	$ -	$ -	$ 499,500.00	
30	$ 1,732,000.00	$ 400,745.74	$ -	$ -
40	$ -	$ -	$ 1,680,000.00	$ 238,636.75
45	$ 346,320.00	$ 38,544.21		
60	$ 1,732,000.00	$ 92,723.53	$ 499,500.00	$ 26,740.99
75	$ 346,320.00	$ 8,918.26	$ -	$ -
80	$ -	$ -	$ 1,680,000.00	$ 33,897.32
90	$ 1,732,000.00	$ 21,454.13	$ -	$ -
100	$ -	$ -	$ 499,500.00	$ 3,798.44
105	$ 346,320.00	$ 2,063.48	$ -	$ -
120	$ 1,732,000.00	$ 4,964.00	$ 1,680,000.00	$ 4,814.97
125	$ -	$ -	$ -	$ -
	Total Present Value (TPV) =	$ 2,467,999.20		$ 1,987,888.47
	Residual Value (RV) =	$ (3,498.12)		$ (3,942.06)
	Net Present Value (NPV) =	**$ 2,465,000.00**		**$ 1,984,000.00**

Life Cycle Cost Analysis - Burgoyne Means Prevention Barrier

Site:	Burgoyne Bridge	
Interior barrier (total length)	333	m

Steel Mesh Net		
Year	Activity	
0	New construction	
38	Partial repair & maintenance: replacement and/or miscellaneous repair	10% of total length
75	Full replacement	
113	Partial repair & maintenance: replacement and/or miscellaneous repair	10% of total length
125	End of service life	

Activity Cost Estimates

Steel Mesh Net

Activity	Quantity	Unit	Unit Cost ($/Unit)	Cost ($)
New Construction	-	-	-	$ 857,000.00
Repair	33	m	$ 2,600.00	$ 86,580.00
Full Replacement	-	-	-	$ 857,000.00

Discount Rate =	5.00%

Residual Value Analysis

System	Replacement Year	Replacement Cost	Residual Year	Value at End of Life Cycle	Residual Value at End of Cycle	Residual Value at Year Zero
Steel mesh net	120	$ 857,000.00	25	$ 253,074.48	$ (603,925.52)	$ (1,730.88)

Present Value Analysis (Level 3)

Year	Steel Mesh Net	
	Cost	Present Value (PV)
0	$ 857,000.00	$ 857,000.00
37.5	$ 86,580.00	$ 13,893.73
75	$ 857,000.00	$ 22,069.04
113	$ 86,580.00	$ 357.78
125	$ -	$ -
	Total Present Value (TPV) =	$ 893,320.55
	Residual Value (RV) =	$ (1,730.88)
	Net Present Value (NPV) =	**$ 892,000.00**