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DESIGN OF A TWO-SPAN CONTINUOUS CPCI GIRDER BRIDGE WITH SEMI-INTEGRAL ABUTMENT

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Abstract: Over the past few years, the significant growth in commuters especially in major cities of Canada emphasises the need to improve and expand our transportation infrastructure. Further, traffic statistics indicate that the Greater Toronto Area (GTA) is one of the most congested areas in Canada. Hence, this project involves building a new two spans semi-integral CPCI girder bridge, which is designed to carry vehicular traffic within the GTA. The bridge has each expansion joint placed at the end of the approach slab which protects the substructure/bearings components. This simplicity and durability led to a growing interest in the significant sustainability contributed by such design concept not only in Canada but world-wide as well. To reach the most cost effective and optimum design, two options of precast/prestressed concrete girders (CPCI I-Girders and CPCI Box-Girders) were investigated. Though few box-girders provide high stability against torsional failure, more I-girders, yet with much reduced weight, can still provide adequate resistance. Moreover, the moderate cost usually associated with I girders fabrication, shipping and installation economically favours the I-girder alternative. However, the overall optimum design criterion addresses other various aspects aiming towards a bridge that is structurally sound, aesthetically appealing and environmentally friendly.

Keywords: Semi-integral Bridge, CPCI girder, Construction Cost, Durability, Sustainability, Aesthetics.

1.0 Introduction

1.1 Background

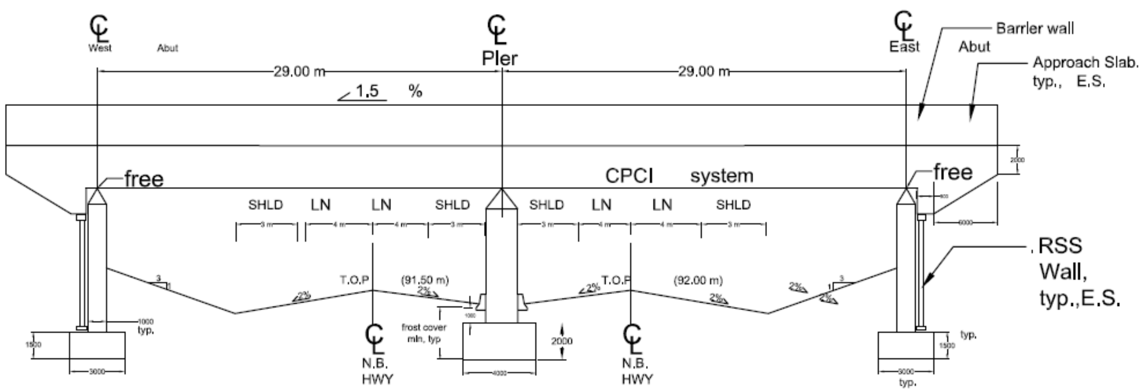
Due to continuous growth of commuters in Greater Toronto Area (GTA), the existing infrastructure is insufficient to accommodate the increase in the traffic flow. According statistics, Toronto is one of the congested cities in Canada. To improve this condition and accommodate the commuters, multi-lane highways, bridges, roads etc. needs to be built. Taking into all these considerations, the decision of designing a two-span continuous semi-integral abutment CPCI girder bridge near Newmarket, Ontario has been finalized. This bridge has been designed to carry the vehicular traffic with a vertical clearance of 5.5m. As a result of this new venture, the road will be less congested during peak hours which will help the commuters to reach their destination with reduced interruptions. This paper herein, describes the design of the bridge and then describes the alternatives girder options that are being investigated for the optimal design of this bridge. Both girder options are judged based on several key factors such as cost, durability, installation, aesthetics etc. and a recommendation is made for the most suitable option for this bridge.

1.2 Project Description

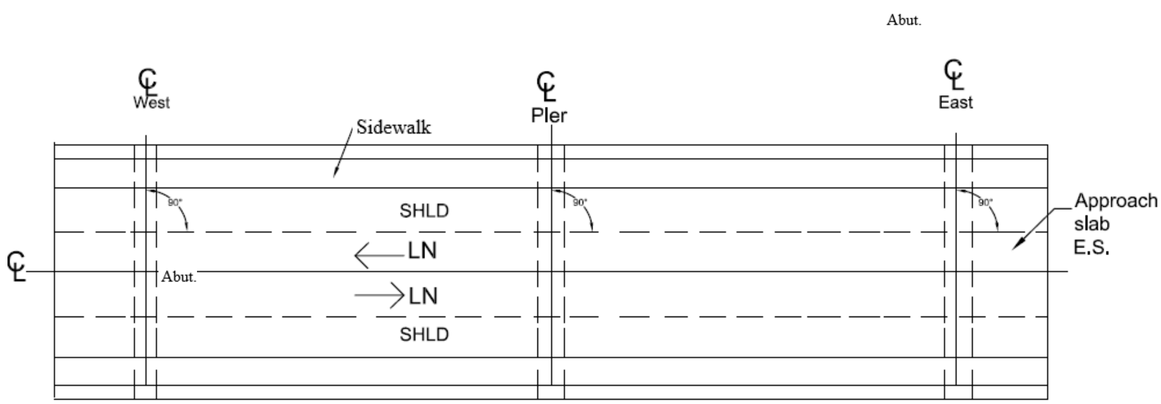
The multi-lane bridge is composed of two equal spans with semi-integral abutment design. Before commencing any construction work, the geotechnical properties of the soil surrounding the construction area especially around the abutments will be thoroughly analysed. Moreover, the project also consists of designing of superstructure. Two alternative options for superstructure design (CPCI I and CPCI Box Girder) are evaluated to recommend the optimum design of this bridge. There are variety of bridge construction practises that are observed all over the world. Precast/Prestressed concrete girders are found to be more effective when used in long span bridges. They are most prominently known for their durability, low-life cycle cost among the many other advantages. Moreover, in recent times there is growing need for Precast/Prestressed girders due to them being readily available in standard girder shapes, reducing construction time and minimal interruption in traffic (Parker et. al., 2012).

2.0 Scope of Work

The bridge is a semi-integral bridge with two spans. The proposed bridge is of approximately 71-metre-long with both spans being equal in length. Figure 1 showcases the elevation and plan view of the proposed bridge.



a) Elevation



b) Plan

c) Figure 1: Elevation (a) and Plan view (b) of the proposed bridge

Two alternative options for the girders investigated. Option A uses I-girders and option B uses box girders. This paper is herein, investigates both alternatives and recommends the option that is optimal for the bridge. All design followed the Canadian Highway Bridge Design Code (CHBDC, 2014), in order to meet the strength and serviceability requirement and provide a safe and sound structure.

3.0 Alternative Design Options

During the preliminary design stage, there were two suggested analytical options for the design of the bridge. The first option is the Canadian Precast/Prestressed Concrete Institute (CPCI) I girder, and the second is the CPCI box girder. The two options were assessed based on cost, traffic constraints, environmental impact, and duration of construction along with other important design factors. Both options were examined analytically, and based on the results a conclusion was reached on which option would be best suited for the design of this bridge.

3.1 Option A: CPCI I Girder

The first option considered the Canadian Precast/Prestressed Concrete Institute (CPCI) girder system which is known to optimize costs because the CPCI girders have large spacing in between each other. The elimination of all formwork and laborers required for its assembly, which can increasingly reduce the initial costs when employing this girder system. Since CPCI girders are manufactured locally, there is little lead time. Also, the precast components are easy to erect under any weather conditions; so this makes the construction process time efficient. The plant produced sections and the speed of erecting a bridge constructed using CPCI girders can significantly minimize traffic interruptions, which is a main concern in bridge design as it can lead to substantial losses.

Span-to-depth ratio, at the minimum can be accomplished by using pre-stressed precast concrete girders. By using pre-stressing and continuity, the depth to a span ratio as low as 1:32 can be accomplished. This guarantees us a minimum clearance and provides overall economy through the use of lesser materials throughout construction. In spite of the positive attributes that the CPCI girders have, there are some disadvantages that can cause major issues. For example, cracking on the end zones of the top flanges can occur and repairing it is costly and dangerous (Deng, 2012). Another disadvantage with the CPCI girders is the low clearance height, in comparison with the Cast in Place (CIP). Also, CPCI girders are more susceptible to harsh weather conditions due to their large surface area. Moreover, when dealing with long, slender CPCI girders they can deflect and twist during handling and erection (Parker et. al., 2012).

Figure 2: View of a CPCI I Girder
(Retrieved from http://www.cpci.ca)

3.2 Option 2: CPCI Box Girder

The second option is the Canadian Precast/Prestressed Concrete Institute (CPCI) box girder. A box girder is formed when two web plates are joined by a common flange at both the top and the bottom. The closed cell that is formed has a much greater torsional stiffness and strength than an open section and this is the main reason for choosing a box girder configuration. Box girders are more suitable for larger spans and wider decks; box girders are to be suitable cross-section. As the span and width increases the beams and bottom slabs should be tied to keep the geometry which leads to evolution box girder. If there is any eccentric load, it will cause high torsional stresses that will be countered by the box section.

Figure 3: View of a CPCI Box Girder
(Retrieved from http://www.precastconcreteconstruction.com)

The advantage of box girders is that the high torsional rigidity of the box girder closed cellular section provides structures beneath is more visually pleasing than open web type system. Single / multi cell reinforced concrete box girder bridge have been proposed recently and are widely used as an economic solution for the over crossings, under crossings, grade separation structures and viaducts in modern highway system. Also, for long span bridges, it is reasonable to use large width of deck to provide prestressing cables at the bottom flange level. In addition, maintaining the box girder is easier in interior space and is directly accessible without use of framework. However, the disadvantage of box girder is that they are difficult to cast due to the inaccessibility of the bottom slab and the need to extract the internal shutter. Either the box has to be design so that the entire cross section may be cast in one continuous pour, or the cross section has to be cast in stages.

4.0 Modelling and Analysis

4.1 General

According to the Canadian Highway Bridge Design Code (CHBDC 2014), the structural loads, and all analysis and design components are obtained for the design truck of CL-625-ONT. The seismic activities were neglected per characteristics and the location of the bridge (CHBDC, 2014).

4.2 Loading Cases

4.2.1 Live Load

According to CHBDC guideline for design truck CL-625-ONT (Figure 4), the vehicular traffic loads were analysed. The loads were used for lane loads and dynamic loads allowance as load impact according to the number of axles truck for each loading condition.

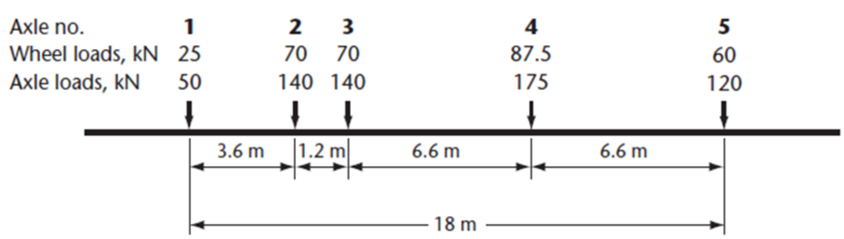


Figure 4: CL-625-ONT Truck (CHBDC, 2014)

4.2.2 Self-weight and Superimposed Dead Load

The overall structure of the bridge created two permanent loads known as the dead load and the superimposed dead load. The dead load comprised of the self-weight of the structural component which is the girder. The superimposed dead load comprised of the weights of the non structural components which are sidewalk, barrier walls, wearing surface and haunch.

4.2.3 Temperature Load

Temperature is one of the important load of the composite bridge due to various temperatures would affect differently on the structure. The temperature at 15º was assumed for the optimal condition during the construction of concrete slab and concrete girder installations. In summer, the maximum temperature of 34º was used, the minimum temperature of -25º was used in winter, and the gradient temperature of 30º was used for deck slab for analyzing the expansion and contraction superstructure.

4.3 Load Combinations

According to CHBDC standards, the superstructure bridge was analyzed at the ultimate limit state (ULS). In order to design for the critical condition, the two spans were subjected to the relevant maximum and minimum ultimate limit state factors load. The wind load was applied to the exposed area of the superstructure resulting from the geometry bridge. Through SAP2000 software (Computers and Structures, 2014), the loading cases for superstructure were analyzed and also obtained the envelope of moment and shear to determine the effect of applied factored loads. Figures 5 through 8 portray the shear and moment envelope diagrams for superstructure that was obtained through SAP2000 software.

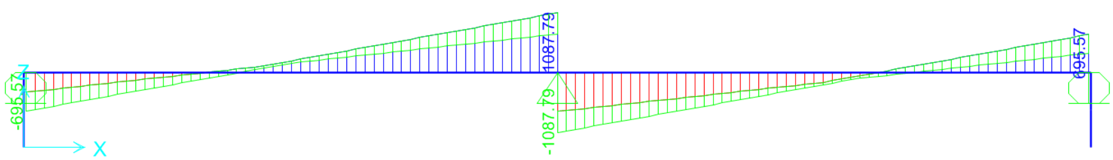


Figure 5: Shear envelope for the CPCI I girder

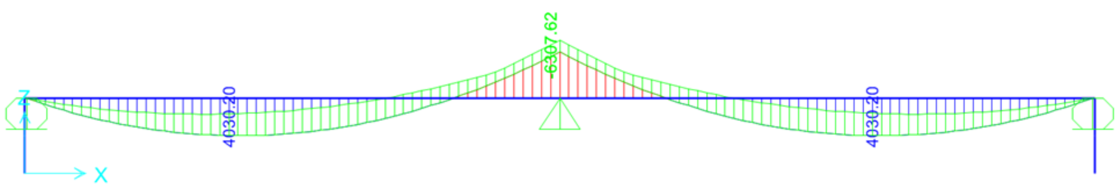


Figure 6: Moment envelope for the CPCI I girder

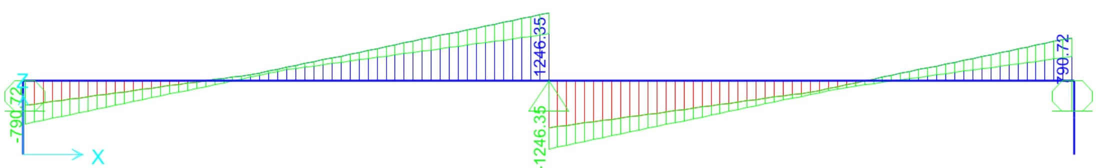


Figure 7: Shear envelope for the CPCI Box girder

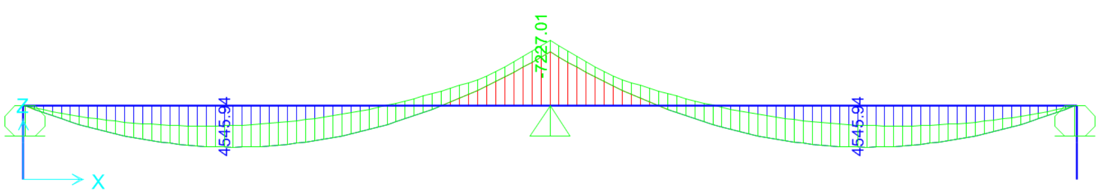


Figure 8: Moment envelope for the CPCI Box girder

5.0 Design

5.1 Girder Flexure Design

According to the Canadian Highway Bridge Design Code (CHBDC, 2014) with bridge design CL-625-ONT, the maximum moments resistance was calculated for the superstructure. From SAP2000 software, the maximum factored moments were obtained. The values of factored moments and resistance moment were compared to ensure the compliance with the code. In Table 1, the results were summarized for the superstructure. As the results, values of resistance moments were greater than the factored moments for both girders types. Therefore, the design was adequate to sustain the applied factored moments.

Table 1: Moment resistance and factored applied moments for the proposed bridge configurations

	Maximum Moment Resistance (M_r) (KN.m)	Maximum Factored Moment (M_f) (KN.m)
CPCI I Girder	20760	4195
CPCI Box Girder	16600	4546

5.2 Girders Shear Design

The resistance shear was generated by the webs of the girders. According to the Canadian Highway Bridge Design Code (CHBDC) with bridge design CL-625-ONT, the maximum shear resistance was calculated for the superstructure of both girder options. From SAP2000 software, the maximum factored shears were obtained for girder options. In table 2, the results were summarized for the superstructure. As the values of shear resistance were greater than the factored applied shear forces for both girders types, the design was adequate to sustain the applied factored shear.

Table 2: Shear Resistance and Factored Shear

	Maximum Shear Resistance (V_r), kN	Maximum Factored Shear (V_f), kN
CPCI I Girder	1920	1138
CPCI Box Girder	2357	1246

6.0 Girder Comparison

To obtain the optimum option between the two alternatives, both options were evaluated based on three impacts, namely: economic, social and environmental impacts. Evaluating both options based on criterions of each of these impacts is what led to recommending the option that is optimum for the bridge?

6.1 Economic Impact

One of the main criteria of designing this bridge is to choose an option whose cost is affordable by the client as well as choosing the option will provide highest durability which can reduce maintenance cost significantly. Therefore, both options were evaluated based on several economic factors.

6.1.1 Initial Cost

From the information obtained regarding the pricing of the girders from several companies, it was identified that CPCI I girder is less expensive compared to CPCI Box girder. Though they are built from similar materials the difference in price is due to specific machineries and labor that is needed to build and fabricate the complex shape of box girder. Figure 9 showcases the difference in price for both girder options.

6.1.2 Fabrication Time

Both alternatives are prefabricated hence the fabrication time needed is somewhat similar for both the alternatives. Hence, when evaluating both options the fabrication time did not play a major factor in terms of economic impact.

6.1.3 Durability

As the both the options are prefabricated their level of durability is somewhat the same. Moreover, these precast components are built to have high durability against hostile environment. They are guaranteed to be durable against harsh situation by the manufacturer as they are tested for repeated cycle of freezing and thawing as well as artificial cycle of weathering and chemical attacks etc. Also as a safety measure by the manufacturer, the precast components are tested with high stresses that they may encounter during their service live.

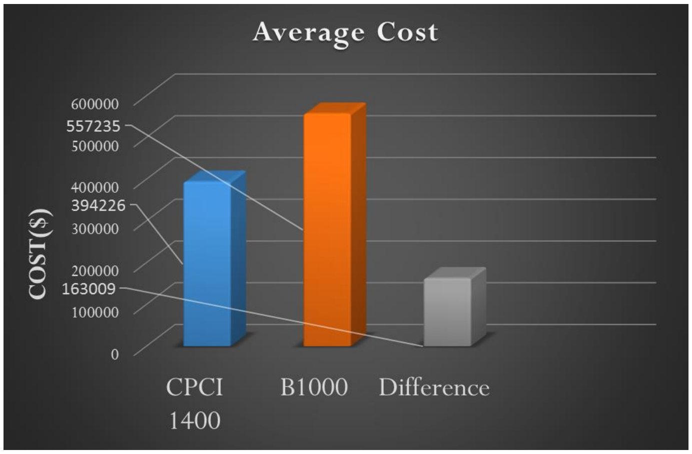


Figure 9: Graph showcasing difference in cost for both alternatives

6.1.4 Maintenance

Between the two alternatives, maintenance of CPCI I girder is much easier than the CPCI Box girder. Repairs to any accidental damage or surface damage for CPCI I girders are done through most economical and less disruptive way. And most often the replacement of the girder can be avoided. Whereas, due to the box girder having confined hollow space in between it makes maintenance a bit difficult. Most often the damages are not spotted until late stage when replacing the girder becomes necessary.

6.2 Social Impact

Another important factor that should be considered in any structural project is the social impacts since it can affect the surrounding areas. For social impacts of the project were evaluated based on traffic interruption and aesthetic.

6.2.1 Traffic Interruption

Both CPCI I girder and CPCI box girder have minimum traffic interruptions due to them being prefabricated. Their impact on the traffic is the same. Any further interruption can be caused when the girder is being replaced.

6.2.2 Aesthetics

Between the two alternatives, the shape of the CPCI box girder is aesthetically pleasing than the CPCI I girder.

6.3 Environmental Impact

Just as economic impacts and social impacts are important factors to be considered when designing any structure, environmental impacts are equally as important as above mentioned impacts. The purpose of this is to identify the alternative that has maximum positive impact and minimum negative on the environment. The goal is to design a bridge that is environment friendly.

6.3.1 Recycling

Both girder is built with somewhat same materials. Hence, their recyclability is almost the same and they have more or less the same impact on the environment.

	CPCI I Girder	CPCI Box Girder
Economical Impact		
♦Initial Cost	✓	
♦Fabrication Time	✓	✓
♦Durability	✓	✓
♦Maintenance/Inspection	✓	
Social Impact		
♦Minimum Traffic Interruptions	✓	✓
♦Aesthetics		✓
Environmental Impact		
♦Recyclability	✓	✓

Table 3: Comparison between CPCI I Girder and CPCI Box Girder

7.0 Recommendation

For the design phase of this project, two alternatives were investigated to achieve the optimum design for the proposed bridge. Both alternatives, CPCI I Girder and CPCI Box Girder were evaluated based on structural analysis, cost analysis, economic impacts, social impacts and environmental impacts.

Based on the results obtained from the above mentioned analysis, we recommend the CPCI I Girder as the optimum alternative option. Comparing both options based on the basis of initial cost, it shows that CPCI I girder cost significantly less than CPCI Box girder. Moreover, maintenance for the CPCI box girder is complicated and often need extensive amount of investigation to detect any deterioration/damage which can result into high maintenance and repair costs.

Both options are highly durable but CPCI I girder is easily repaired and the maintenance cost is significantly less than CPCI box girder. Though CPCI Box girder has advantage aesthetically over the CPCI I girder but low initial cost, lower maintenance and repair will outweigh CPCI Box girder’s advantages. Therefore, CPCI I 1400 Girder is selected as the optimum option for the proposed 2 spans semi-integral bridge abutment bridge.

8.0 Conclusion

The designed bridge consists of two-span continuous system with a semi-integral abutment design. In the preliminary design phase, two alternative options were evaluated to obtain the optimum alternative option for the proposed bridge. The alternatives that were compared were CPCI I Girder and CPCI Box Girder. To perform comparison between these options, several factors were considered, including: initial cost, maintenance, advantages and disadvantages of each option. Moreover, additional factors such as social and environmental impacts were also taken into consideration. The major advantage is that both alternatives are prefabricated. And the materials needed by the manufacturer to construct these girders are easily accessible which results in easy fabrication as well as results in reduction in construction time to build the bridge. Furthermore, both alternatives were analyzed and designed to ensure their structurally adequate to carry different loading cases using SAP2000 software. Maximum factored moment and shear values were obtained from the software and compared against the calculated resisting shear and moment values. It was concluded that the I- girder system led to lower construction cost compared to the box girder type for the considered bridge geometry and material.

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