Moose Creek Bridge, the First Field Application of Fully Prefabricated Bridges in Ontario

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ABSTACT

The Ministry of Transportation of Ontario (MTO) is seeking a way to reduce construction time and cost associated with bridge construction. The conventional construction method for thin-slab bridge decks typically involves on-site casting of the full-depth reinforced concrete desk on top of the naked steel or precast prestressed concrete girders. This method generally requires at least a month of concrete curing time and the quality of cast-in-place concrete is sometimes difficult to ensure on site. The use of precast should serve to accelerate the construction schedule and hopefully to result in a lower total cost of the bridge.

The proposed Moose Creek Bridge, the first field application of prefabricated bridge technology for a bridge replacement project in northern Ontario and scheduled for construction in 2004, is a single span structure and will feature prefabricated abutment wall units as part of the integral abutment system and prefabricated prestressed T-shaped girders. The precast abutment wall elements are supported on a single row of steel H-piles and connected together with cast-in-place concrete. The prefabricated standard CPCI 1200 prestressed girders cast with 2.45 m [8 ft] wide, full-depth concrete deck are placed on thin neoprene bearing pads at both ends. The precast prestressed slab-on-girder elements are connected with cast-in-place longitudinal and end closure strips. The joints of precast deck elements are not only minimized usage of cast-in-place concrete work on site but also ensured serviceability of bridge life. This new precast composite slab-on-girder is very useful in adapting multi-span bridge construction. The system is the first application of a truly integral precast abutment connected to the ends of precast, prestressed concrete girders with deck in Canada.

Keywords: Prefabricated Bridge, Precast, Prestressed, HPC, Integral-Abutment, Rapid Construction, Precast Substructure, Hauling and Transportation, Full-Depth Deck Panel, Construction

INTRODUCTION

The Moose Creek Bridge is located on Highway 101 in Northern Ontario approximately 450 km [280 miles] from Toronto. The existing bridge had been scheduled for replacement by the Ministry of Transportation of Ontario (MTO) due to its advanced state of deterioration. The original structural planning was that 22 m single span, CPCI 1200 standard precast pretensioned concrete girders (1200 mm deep girders), slab-on-girder bridge with integral abutments. Since the project was awarded and a detail design was done by traditional design approach, MTO decided to build this bridge using precast bridge deck with minimal in-fill concrete slab system. The conventional construction method for thin-slab bridge decks typically involves on-site casting of the full-depth reinforced concrete desk on top of the naked steel or precast prestressed concrete girders. This method generally requires at least a month of concrete curing time and the quality of cast-in-place concrete is sometimes difficult to ensure on site. The use of precast technique should serve to accelerate the construction schedule and hopefully to result in a lower total cost of the bridge.

In 2000, the MTO Bridge Office had started a project to investigate the feasibility of constructing/rehabilitating bridges using prefabricated beam elements. Two potential systems were envisaged: (A) precast composite slab-on-girder (steel or prestressed concrete) elements assembled on site and connected together with cast-in-place concrete closure strips (Fig. 1, System A), and (B) full-depth precast concrete deck slab segments laid across new or existing girders on site and connected together with cast-in-place concrete over the girders and between the slab segments (Fig. 1, System B).

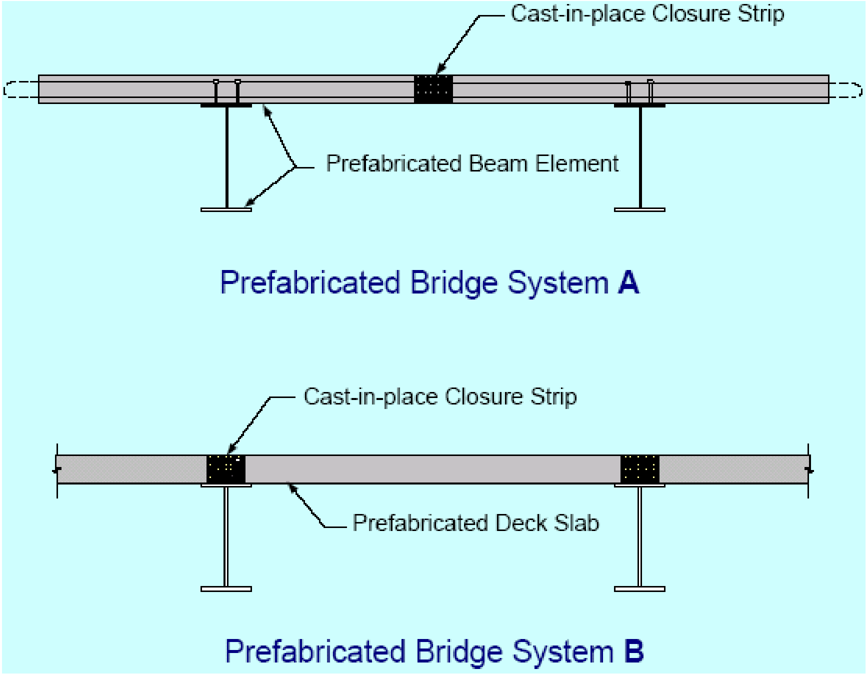

Fig. 1 Prefabricated Bridge Systems

Laboratory tests were performed on a reduced-scale model of system 'A' to study: the structural behaviour of the overall bridge system under service load, the long-term load effect on the longitudinal cold joints, and the ultimate load-carrying capacity of the concrete deck after being subjected to repetitive load cycles as shown in Fig. 2. Seven million load cycles were applied at two locations on the deck, and the results of this cyclic load test showed a little evidence of distress and no major impact on structural behaviour or serviceability. Other than hairline cracks were observed mostly along the cold joints, no major signs of distress were evident. The ultimate load test, performed after the cyclic load test, demonstrated ample strength of the bridge to resist design wheel loads. Overall, the tests attested to the excellent performance and integrity of this system. It was decided, therefore, that this technique was offered an excellent opportunity to employ the methods developed in the MTO research[5] in a full scale prototype application Ontario's first prefabricated bridge.

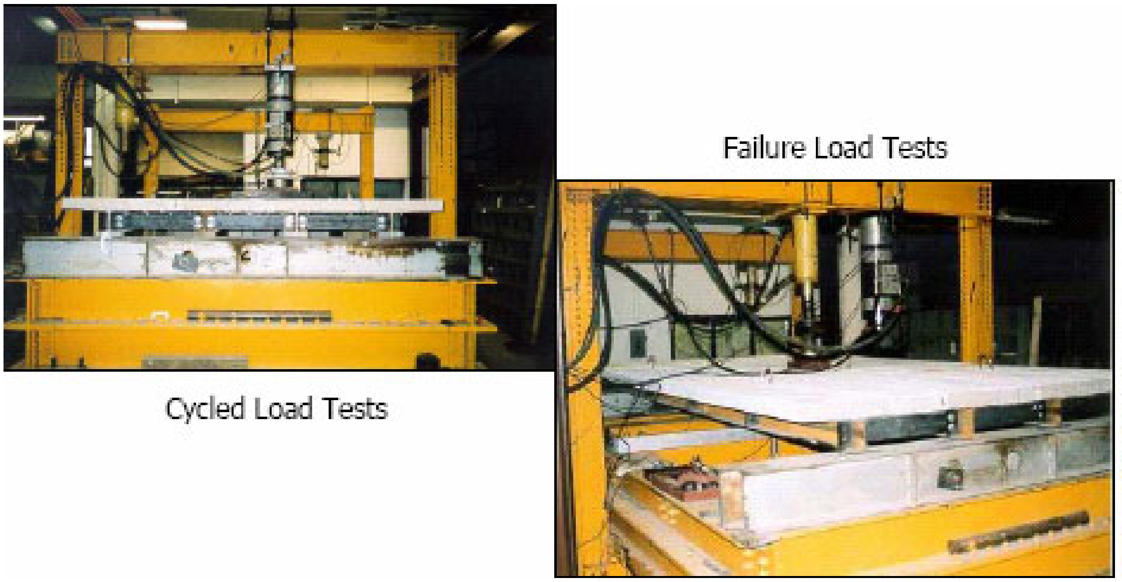

Fig. 2 the Experimental Set-Up and the Loading System

OBJECTIVES AND CONSTRAINTS

Constructability of the precast components received a considerable amount of attention during the development of standards. Means of fabrication, including forms, form removal, form reuse, reinforcing steel bending and placement, were considered to reduce actual product cost. Means of handling the components in the plant and in the field during erection included location of lifting devices and minimizing weights of the component. Reduced weights are also important to minimize shipping costs. The use of simple connection schemes reduces product cost, while simplicity helps reduce the need for very tight tolerance and potential for conflicts during erection. Table 1 summarizes the transportation guidelines for prefabricated bridge elements in Ontario.

Table 1 Guideline of Size/weight limitation for Transportation

Locations	Weight/Size	Description
Maximum Girder Weight	75 tonne [82.7 t]	
Maximum Girder Length	45m [147.6 ft]	CPCI Girders (Fig. 3)
	50m [164 ft]	Steel Girders (Fig. 3)
Maximum Width	5.0m [16.4 ft]	
Maximum Height	4.26m [14 ft]	Including carrying vehicle, or to route clearance allowances
Maximum Recommended Component Weight	75 tonne [82.7 t]	Non-standard units
Maximum Recommended Component Length	17m [55.8 ft]	Depending on trailer deck length (Fig. 4)
Maximum Width	4.5m [14.8 ft]	Subject to route clearance

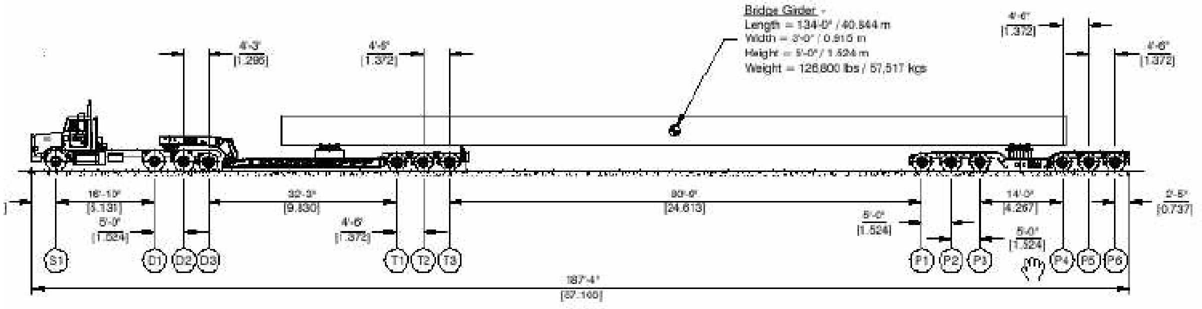

Fig. 3 Transportation for Girders

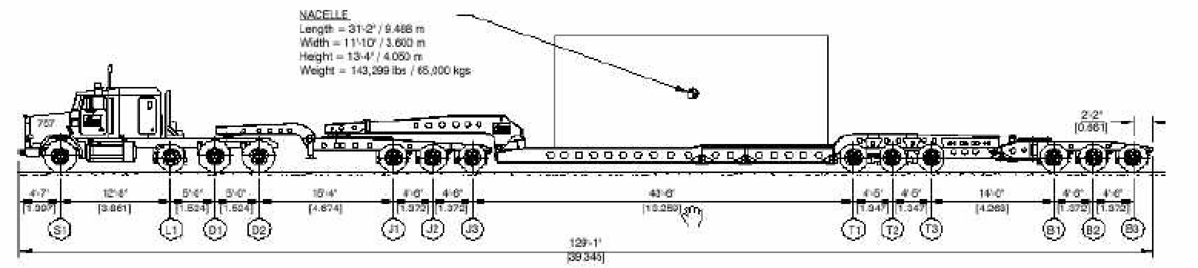

Fig. 4 Transportation for Non-standard Components

DESIGN AND ANALYSIS

The bridge was complied with the 2000 edition of Canadian Highway Bridge Design Code[1] (CHBDC). It was designed using the simplified analysis of methods of the code by idealizing the configuration as a two dimensional frame analysis for the preliminary design purpose.

It is difficult to use the simplified analysis of method for the live load distribution at the service stage after composite action because of geometry of integral abutment bridge. Thus, the finite element method of analysis was selected as the only method capable of predicting the actual behaviour of the structure, considering the three-dimensional nature of loading and its complex geometry.

The three-dimensional finite element program MIDAS/CIVIL[4], utilizing quadrilateral plate elements subjected to in-plane and bending effects, was used to idealize the deck and abutment stems. The plate element has four corner nodes, which node having six degrees of freedom, three translations and three rotations. Three-dimensional beam elements were used for the CPCI 1200 girder sections and steel H-piles as displayed in Fig. 5.

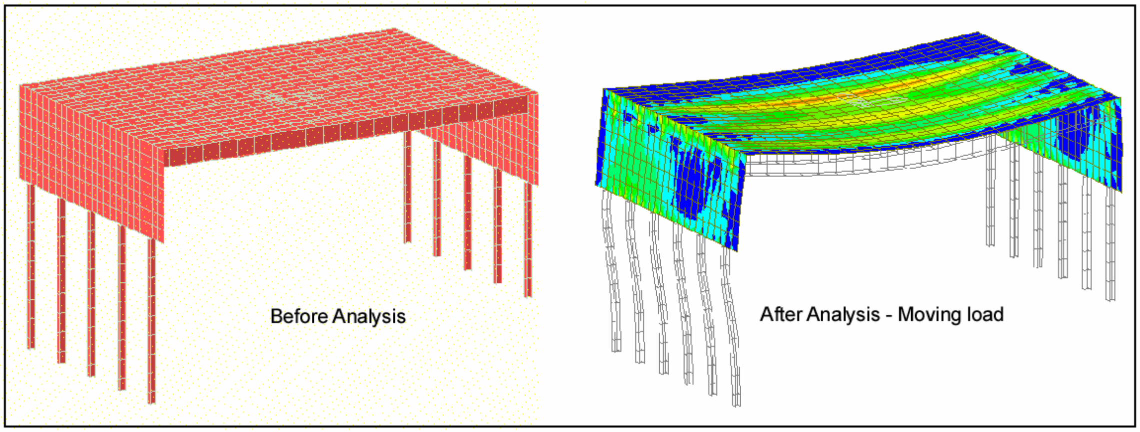

Fig. 5 3D Analysis Model for Composite Action

Six to eight node solid elements were used for T-shaped girders including thin wing section(s), precast reinforced concrete abutment stems and wingwalls as shown in Fig. 6 and 7. The shapes and sizes of elements were made as uniform as possible. The size variations between adjacent elements were kept to less than ½. The 4-node plate elements and 8-nodes solid elements were used for stress calculations. An aspect ratio of these elements was close to a unity (1:1) yields an optimum solution, and at least 1:4 ratios were maintained.

The structure was analyzed for the service stage assuming a completed structure. Fig. 5 illustrates the analytical model used for the design of deck-abutment joints assuming full composite action between the slab, girders and abutments. The superimposed dead loads, live loads, earth pressure and effect of temperature variations were considered for the deck-abutment joints as composite action. However, the correlation between the temperature variation and magnitude of earth pressure was neglected in the design because of the short span configuration. The abutment-deck joints were designed by assuming at-rest earth pressure condition at the abutments because it was assumed that the movement would not be enough to mobilize the passive earth pressure.

Fig. 6 and 7 show that a 3-D model was necessary to analyze each element for the effects of such loads. The self-weight of each unit, superimposed dead loads, construction loads including erection and transportation stages.

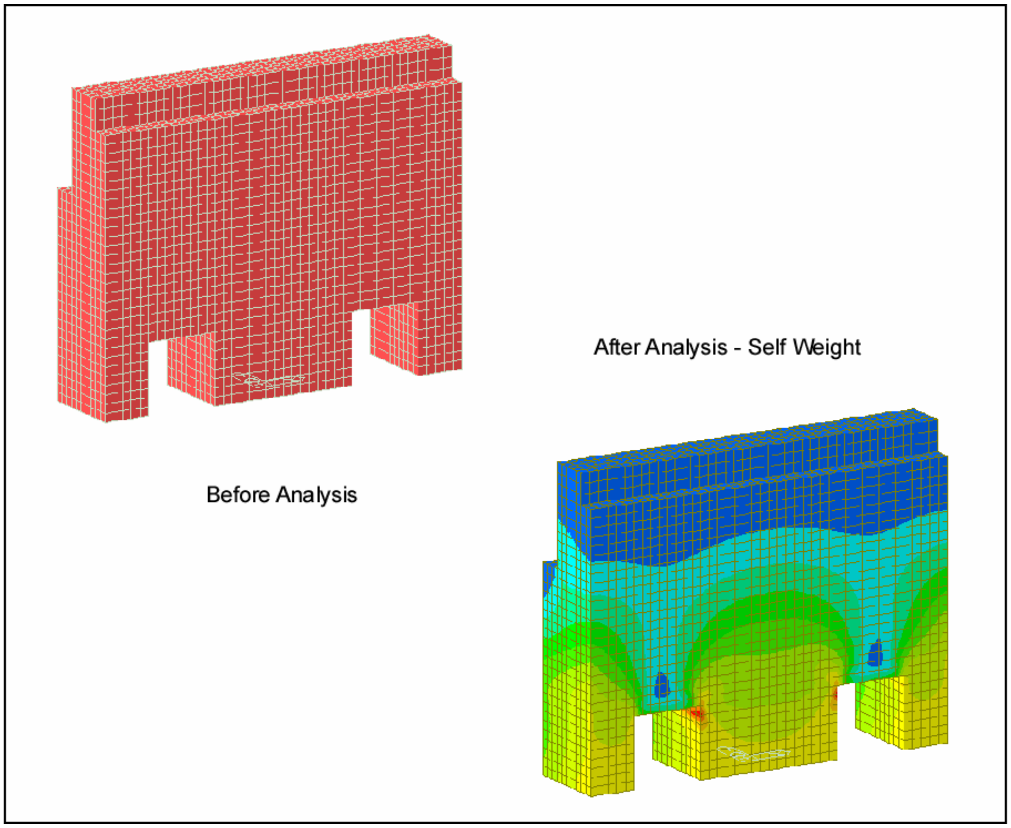

Fig. 6 FEM Solid Element Model for Precast Abutment Wall Unit (Interior)

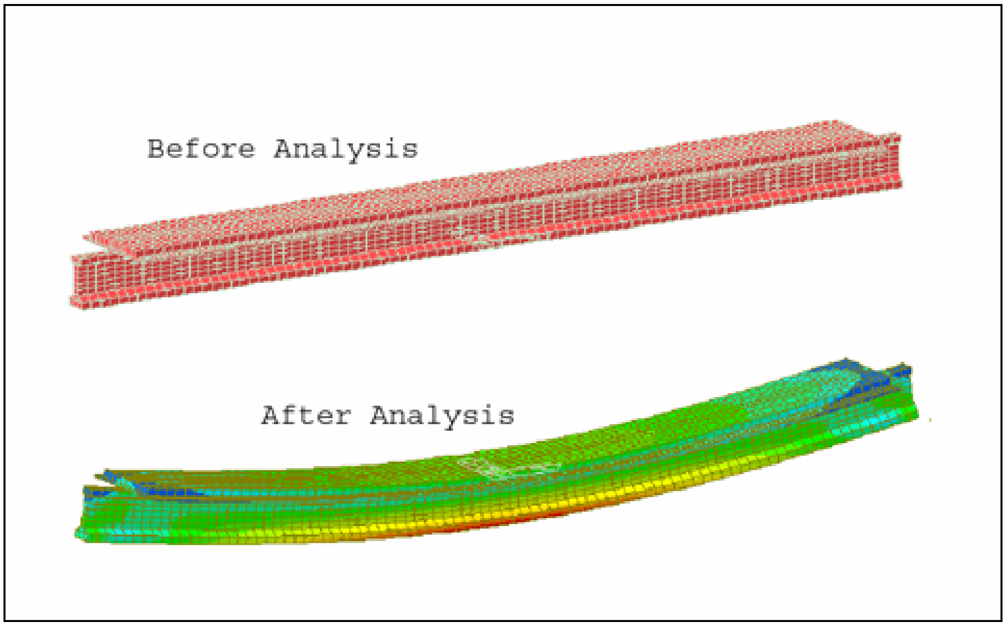

Fig. 7 FEM Solid Element Model for T-shaped girder

ABUTMENT DETAILS

Basically the design of the precast abutment unit is no different from a cast-in-place abutment. The difference is really in the details of connections. The original conventional cast-in-place concrete abutment wall was divided into three equal segments per abutment wall due to their size and weight restriction on shipping as summarized in Table 1. The typical unit is 4.5m [14.8 ft] width x 1.0m [3.3 ft] depth x 3.3m [10.8 ft] height in order to maintain the guidelines of transportation in Ontario.

The performance of the abutment-pile connection is an important aspect in the overall behavior of integral bridges. A single row of piles is used to support the abutments. The connection between the abutment wall and pile top was considered as both pinned and fixed conditions for the pile design. When the connection is considered as pinned between the pile top and abutment, it may allow to have free rotation of the pile top about an axis perpendicular to the bridge longitudinal direction. If the connection is designed as fixed, plastic bending moments may be produced at the pile top due to thermal movements and effect of vehicular traffic. Because the span of bridge is short, it may be speculated that the repetitive variation of temperature and the effect of live load may be therefore cause low cycle fatigue in steel piles.

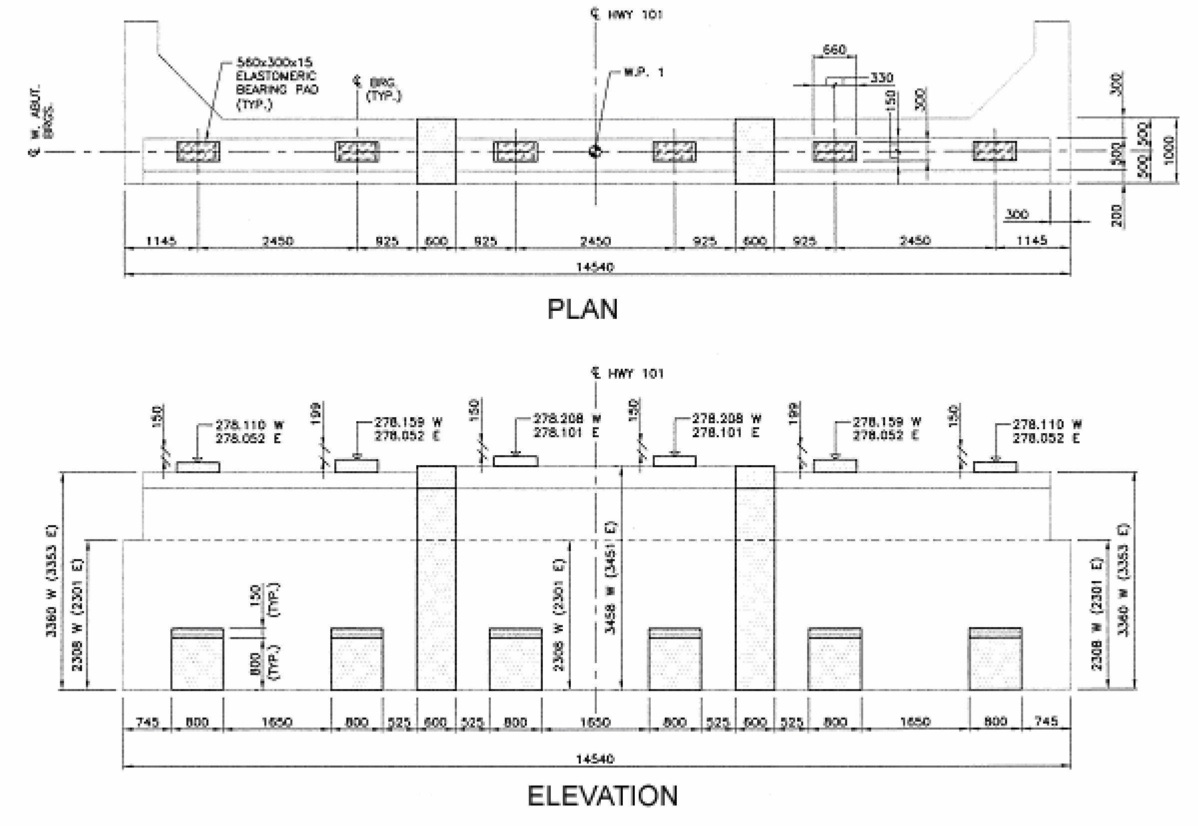

Fig. 8 Elevation View of Abutment Units

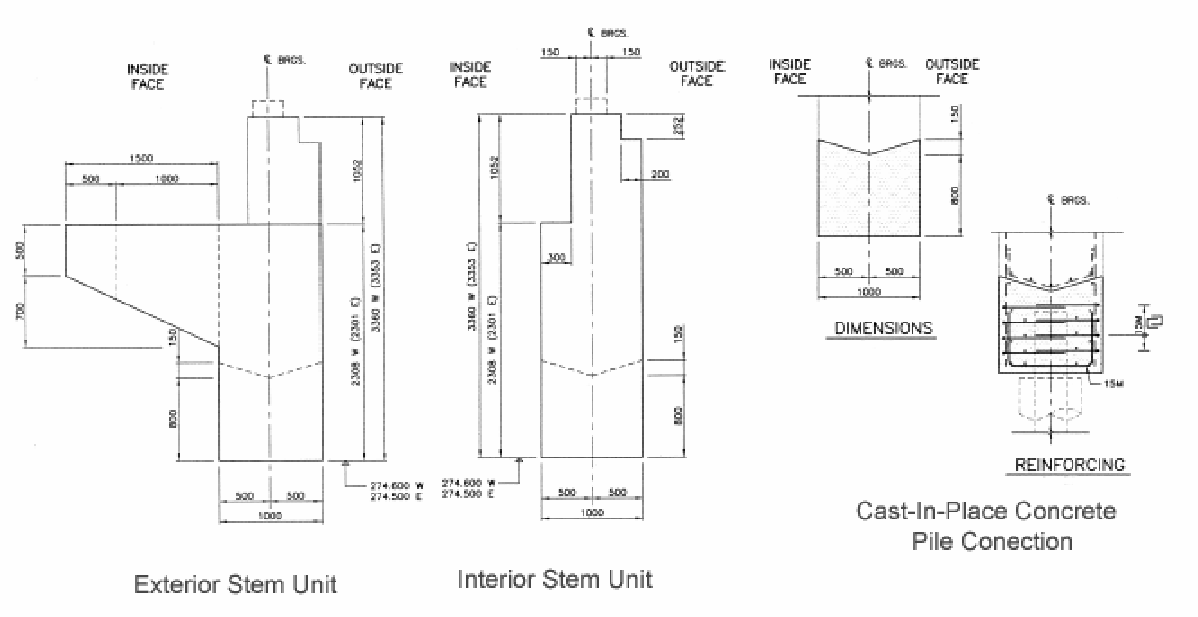

Fig. 9 Typical Abutment Stem Units with Dimensions

Fig. 10 Typical Exterior Abutment Wall Unit

Each abutment wall unit has two openings for connecting pile top as shown in Fig. 8, 9 and 10. The top of piles is embedded at least 600 mm [2ft] into the abutment walls and is adequately reinforced to transfer the bending forces. It was important that the reinforcing steels were carefully detailed in the precast section to allow for maximum construction tolerances of 150 mm [6 in] for each direction in the pile placement. In order to aid for the concrete placement over the piles, the top of opening in the precast section is tapered. Due to driving into stiff soils, the longitudinal displacement may somewhat be restrained. Pre-drilled oversize holes therefore filled with loose sand are provided to reduce the resistance to lateral movements. Once abutment wall units are erected onto the top of the piles, the contractor will hold the wall units in place and set them up for concrete and place reinforcing steels in the vertical closure strips, the pile tops and the bearing seat pedestals. After concrete has reached its specified strength, T-shaped girders are placed their final locations unit-by-unit sequence as shown in Fig 11 and 12. The top portion of precast wingwall units are placed on top of the wingwall section of the exterior abutment wall units. Since all abutment units consisted of three units of abutment walls and two units of wingwalls per each abutment are in secure position, the abutment-deck portion and longitudinal deck joints would be poured concrete.

The primary consideration when designing a structure with precast components is the weight and size of the components. Connection details between units and concrete placement are also very important aspect for constructability, performance and serviceability of structure. The shipping cost is very expensive when oversize components are required or long distance remote area.

T-SHAPED GIRDER DETAILS

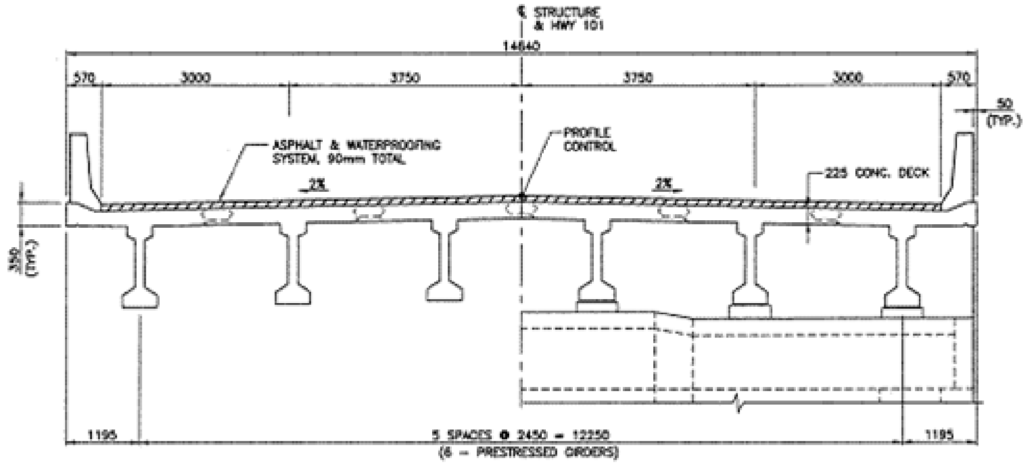

Fig. 11 Typical Section of Bridge

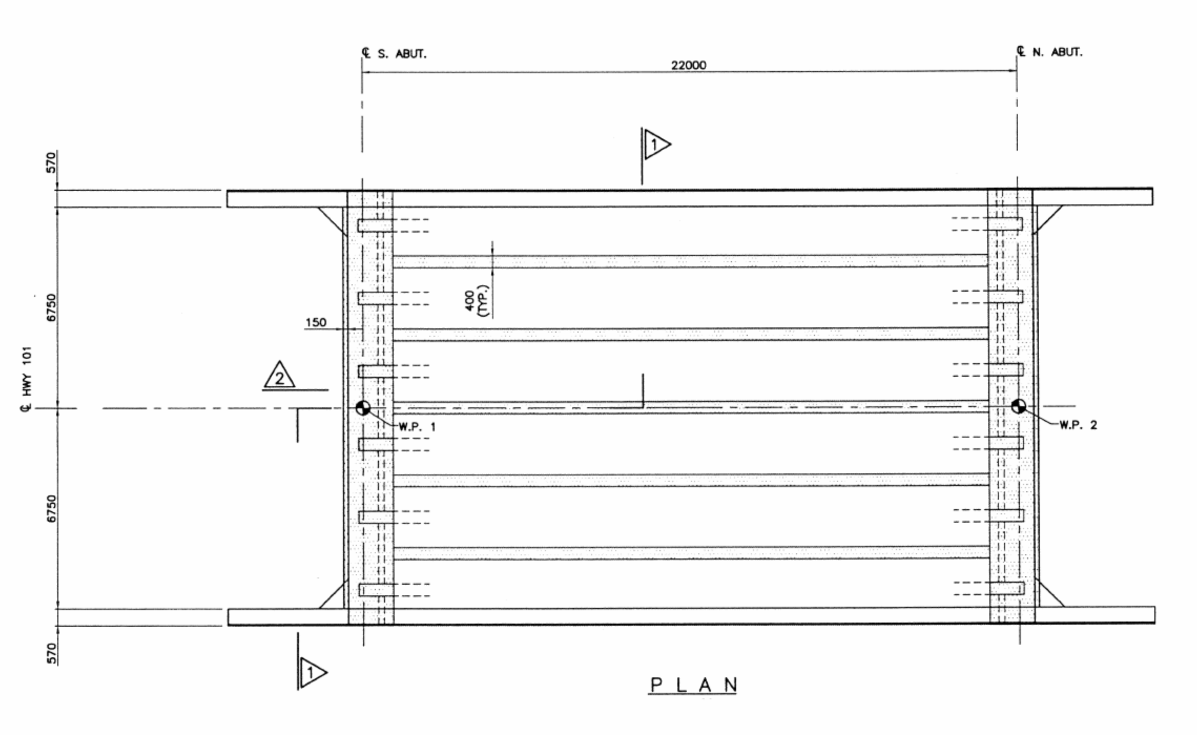

Fig. 12 Plan View of Bridge

Total bridge width is 14.64 m [48 ft] and six precast pretensioned concrete CPCI 1200 girders cast integrally with 240 to 290 mm [9.5 to 11.4 in] thick concrete deck at 2.45 m [8 ft] center-to-centre spacings as shown in Fig. 11 and 12. All girders are prestressed with twenty eight 15 mm [0.6 in] diameter, 1860 MPa [270 ksi] low-relaxation steel strands as shown in Fig. 13 and 14.

The cambering is by-product of prestressing forces applied internally or externally to bridge girders. Camber of a girder at any age is algebraic sum of the upward deflection due to prestressing and the downward deflection due to self-weight and other applied loads. As traditional slab-on-girder type structure, the thickness of cast-in-place bridge decks (or haunch) can be adjusted to compensate for camber and to maintain the required deck profile on bridges. Because a full deck slab is a part of the girder and basically there is no control for any screed elevation on deck. As a result, deck thickness is adjusted to compensate for the increased camber for these girders.

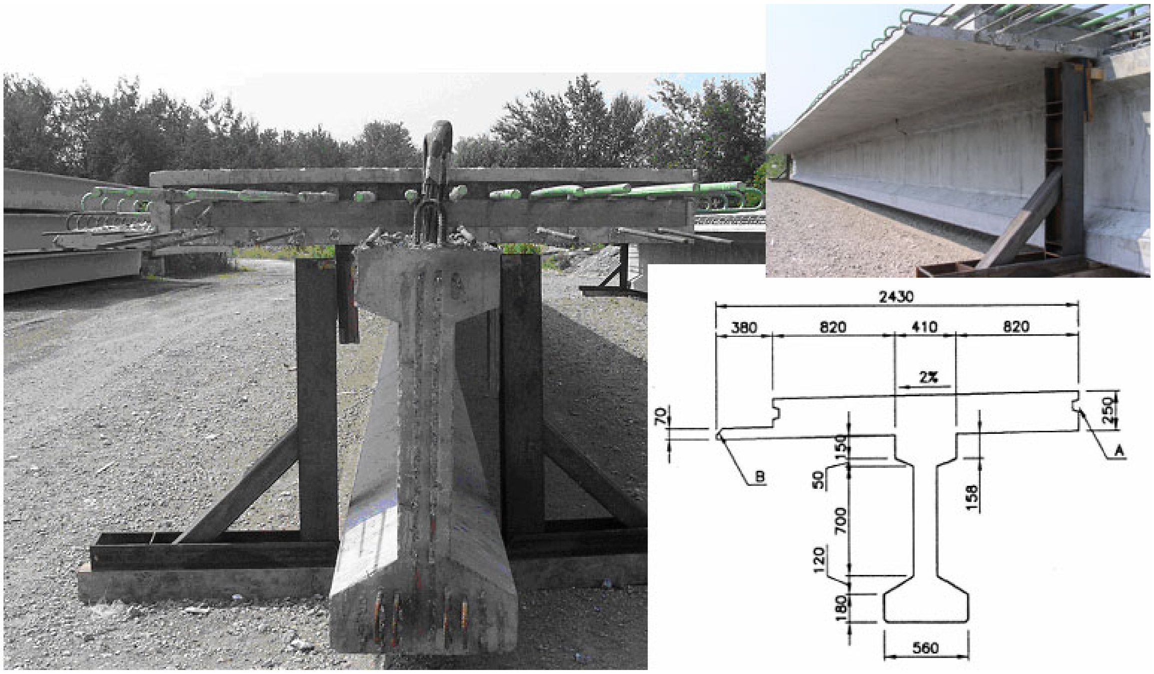

Fig. 13 Typical T-shaped Girder Unit with Dimensions

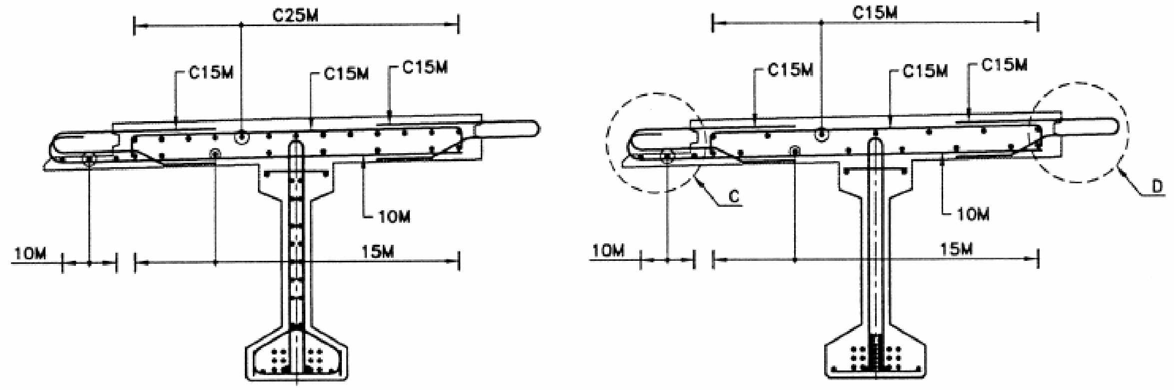

Fig. 14 Typical T-Shaped Girder Unit with Reinforcing Details

Fig. 15 describes the tip section of precast deck was carefully designed for its constructability and performance as short and long term points of view. The 70 mm [2.75 in] thick tip section is not only eliminated formwork during concrete placement on site but ensured structural integrity with new concrete placement on site as illustrated in Detail ‘C’ of Fig. 15. The 40 mm [1.6 in] x 75 mm [3 in] shear key at the end of full deck section would be provided extra structural performance in the cold joints. Detail ‘B’ in the Fig. 15 depicts 40mm [1.6 in] x 40 mm [1.6 in] chamfer at the end of tip section will be allowed to place concrete easily during casting deck joints. A customized wooden form was used for fabricating these T-shaped girders. The deck section on top of girder section had a crossfall of 2% as same as conventional bridges. Only one wooden form was used for all six T-shaped girders with least modification due to the end details of deck sections.

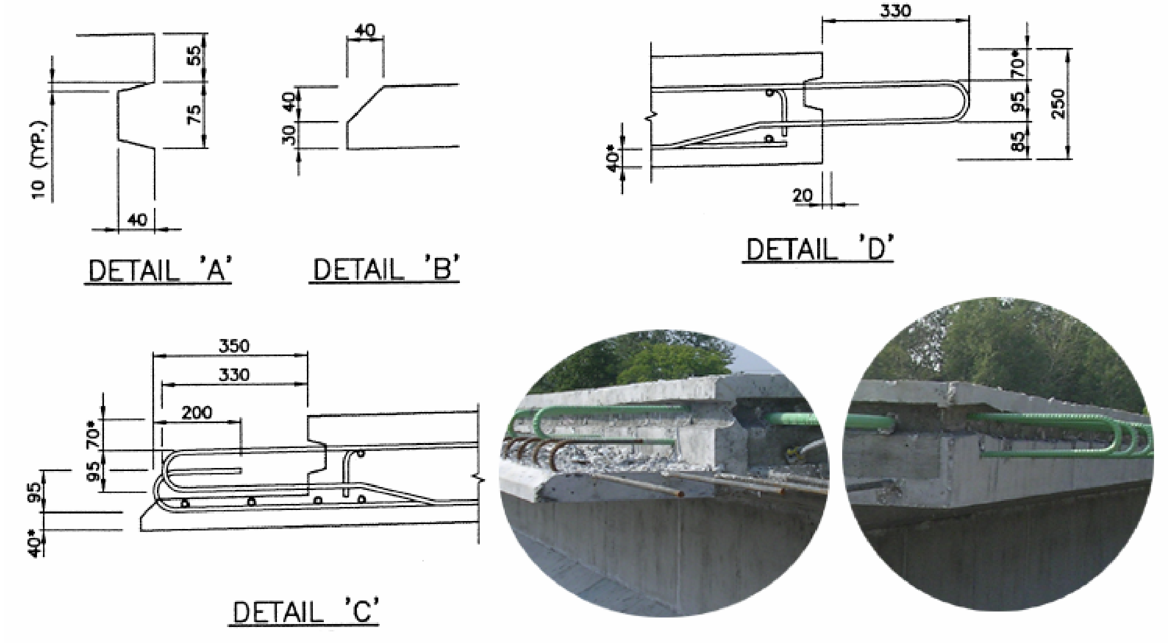

Fig. 15 Typical End Details of Deck Sections

CAST-IN-PLACE CONCRETE JOINTS

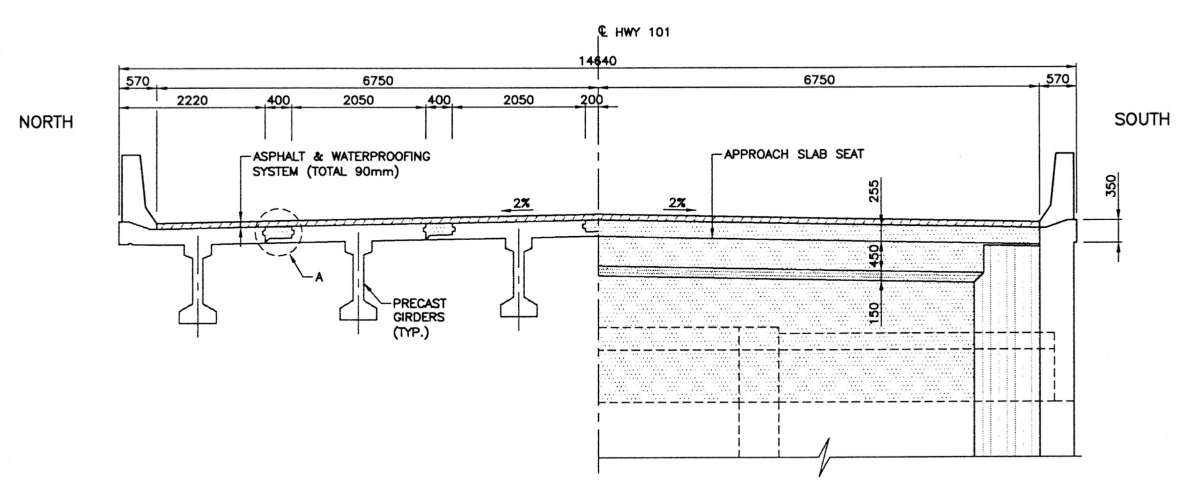

Fig. 16 Typical Section with CIP Concrete

The bridge deck components were designed assuming a continuous frame action at the joints linking the bridge deck to the abutment. To achieve full moment connections between precast units and concrete placement, providing enough continuity of reinforcing steel is essential. Fig. 16 displays T-shaped girder elements were connected together with cast-in-place concrete closure strips at between decks and abutment-deck joints on site

It was considered that the formwork from the underside of the deck would be difficult to access and still need time for curing the concrete. In order to eliminate formwork completely as depicted in Fig. 17, the end of the deck had minimum thickness of thin section. A 25 mm [1 in] diameter Form backer and sealant were used between ends of prefabricated decks. A 40 mm [1.6 in] x 75 mm [3 in] shear key was provided at each end of full precast deck for additional strength of the cast-in-place concrete joint. In order to maintain the required development lengths of the reinforcing steel at each layer of the joint locations, the lap splicing of transverse reinforcing steel for the deck slab in the closure strip joint was executed as a full strength connection with loops. The loop reinforcing steel is alternated with the reinforcing steels of adjacent deck slab. In order to fulfil the high requirements of precision reinforcement work in the precasting works had to be carried out using templates.

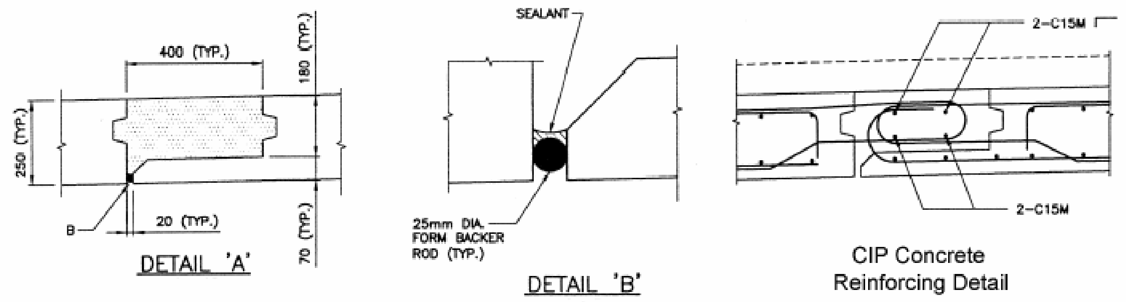

Fig. 17 Typical CIP Deck Joint Details

The ministry's current policy for concrete is using high performance concrete for deck, barriers and approach slab. Since the original design was done using 30 MPa [4350 psi] normal concrete for substructure, due to fabricating of deck with girders integrally, full bridge was using HPC with 50 MPa [7250 psi].

The barrier walls and approach slab would be using only cast-in-place concrete for this bridge other than in-fill joints. In the future, the exterior T-girder sections could be prefabricated integrally with barrier wall or the precast barrier walls could be assembled on top of the prefabricated deck on site.

SUMMARY

The bridge scheduled to be completed by end of this year. The ministry will be monitoring this bridge after its completion. The site will be easily accessible to investigate and monitor from the creek. The system, especially longitudinal deck joints, has to be monitored as long term period.

Changes made during the construction particularly fabrication of the units will be valuable to develop this technology into more routine practice for bridge construction. The ministry is planning to use this technique for another location near future in Ontario.

About 60% of total volume of concrete would be provided with precast concrete. The cost of this bridge is CAD\$3700/m^2 while the conventional method is CAD\$2000/m^2. Initial cost and lack of standardization are the main disadvantages for the prefabricated system. This lack of standardization most often results in a higher construction cost. However, if owners take into account life-cycle cost, in addition to the savings from reduced lane closure time, prefabricated systems may become an economical solution.

In addition to speed of construction using this total precast system, the ministry can develop easily to multi-span structure because of its integral abutment configuration. Adapting into multi-span structure, full moment connections at pier-deck connection elements would be required at each support location. The high quality factory-cast units were used for all precast units. The engineered precast, prestressed concrete solutions provided the owner with quickly installed modular system that would be flexible enough in allowing ongoing traffic flow. Bridges with any skew angles may not be appropriate for this system because the problem of differential camber where adjoining between elements would be more pronounced.

The proposed construction method will significantly shorten on-site construction time, in turn, leads to important safety and economic advantages when traffic disruption or rerouting is necessary.

The successful design and construction of prefabricated bridge requires complete cooperation and coordination among the designer, the fabricator, and the contractor. Owners should strive to provide specifications and design contracts that will permit and encourage innovation in design and construction methods.

To guard against possible accumulation of errors from various sources, precautions should be taken to ensure that the as-built section corresponds to the contract drawings. Any anticipated changes should be properly accounted for in the design. Major factors to be considered in selecting the unit size are the hauling limitations and the type of lifting equipment that is available.

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