DOUBLE-DECK BRIDGES FOR PEARSON AIRPORT FRONTAGE ROAD SYSTEM

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Abstract

This paper discusses the design and construction of the unique bridge system that serves as the access roads to the new terminal building at Pearson Airport in Toronto, Canada. The elevated road system involves curved bi-level double-deck cast in place post-tensioned concrete bridges integral with the terminal building. The development of the bridge structural system and details to meet the functional, architectural and construction requirements are presented. In addition to the unique and complex aspects of this project, high performance concrete (HPC) was specified throughout to address 50-year maintenance-free durability requirements. The use of over 30 000 m^3 of HPC for cast in place bridge construction is one of first such undertakings of this scale in North America. The construction program, including in-situ results are also presented.

1. Introduction

The Greater Toronto Airports Authority (GTAA) assumed the responsibility for the management, operation and maintenance of Toronto's L.B. Pearson International Airport in 1996. As part of their mandate to meet the regional air travel needs, they are undertaking a comprehensive redevelopment plan to upgrade and expand the airport's capacity to meet a target of 50 million passengers per year by 2020. The $4.4 billion project includes the replacement of Terminals 1 and 2 with an expansive new terminal and parking garage, expansion of existing Terminal 3, new infield cargo facilities, central de-icing facility, additional runways and a completely revised internal road system and highway access/egress network. As part of the new terminal development (T1-New), and to integrate the road system with the terminal, a 3-level road system fronting the terminal was required.

These "frontage roads" consist of an at-grade road and two levels of elevated bridges. The first level of bridges provides arrivals level access while the bridges above provide departures level access. The road system is curved in plan, interfacing with the terminal building for over 400m, with the upper departures level bridge staggered over the arrivals level bridge in plan towards the terminal.

The integration of the bridge with the terminal imposed significant structural, functional and architectural requirements on the design. The bridges are also a key component of the construction plan for the project since their early construction allows construction access to all levels of the Terminal, saving on craning/access costs and schedule, and provides a valuable staging area in a congested brownfield site.

2. Design Criteria

2.1 Cross-Section

The Airport Master Plan required each roadway level to have 3 traffic lanes and a sidewalk, closest to the Terminal, for commercial vehicles, and a separate outlying 4 lanes and sidewalk for standard passenger vehicles. The inner and outer traffic sections of each level were required to be nominally separated to allow for natural light and ventilation breaks through the wide sections of roadway. Pedestrian crossings and the ability to enable vehicular cross-over between the inner and outer set of lanes in the event of an emergency situation is also required at discrete points along the length.

2.2 Interface with the Terminal

The departures level of airport terminals require less floor area than arrivals. To address this fact while reducing capital costs, the upper departures level bridges were partially staggered toward the terminal and over the arrivals area below. This layout dictated that the bridge columns would have to be aligned with the column grid used for the terminal framing. Additionally, the bridge decks that were staggered over the terminal space would also have to act as the roof structure for the inhabited space below.

The elevations of each deck level also had to match exactly with that of the building. The arrivals level is controlled by the elevation of the airport apron area. The departures level elevation is based on the Terminal building design needs for intermediate floors, structural framing and mechanical systems. At the same time, the bridge deck elevations had to satisfy vehicular clearance requirements. While the intended use of the roadways is limited to passenger vehicles and busses, an allowance for standard highway clearances was required. The Ontario bridge code specifies a 4.50m clearance during construction, recognizing the reduced likelihood of overheight vehicles during a limited construction period. Since the traffic use for the airport would statistically see even fewer overheight vehicles throughout its design life than a typical highway during a construction season, the 4.50m clearance envelope was selected as the best compromise.

A section of the bridge-terminal interface is shown in Figure 1.

<u>Figure 1 – General arrangement of Elevated Frontage Roads</u>

2.3 Miscellaneous Requirements

In consideration of the extensive terminal interface requirements and the flagship nature of this structure, the design was carried out as part of the New Terminal Development design team, Airport Architects Canada. Architectural design features were incorporated into the bridge appurtenances and all exposed concrete surfaces and details. Instructions were also received from the Owner’s maintenance division to ensure a maintenance-free approach to all material selection and design details. The following sections will present the many and varied design requirements, the final structural design and a review of the project construction.

3. Structural Design

3.1 Bridge Type Selection

Using the basic geometric model dictated by the design criteria, bridge alternatives were developed and a preferred option selected based upon the following criteria:

- Structural Depth
- Construction cost
- Schedule
- Safety (bomb blast resistance)
- Durability
- Feasibility of multi-level construction
- Aesthetics
- Maintenance

The limitation of structural depth in conjunction with the multi-level framing eliminated most traditional bridge types. Since all 3 levels are in line with each other, superstructures that rely on bearing on a secondary beam to tie into the substructure (i.e. girder system) would also have to consider the depth of the support beam as part of the structural depth affecting the available clearance. Therefore, the deck must be fully integral with the columns. With additional considerations given to durability, aesthetics and safety concerns, a cast in place post-tensioned concrete bridge system was selected.

To facilitate the clearance envelope with an allowance for soffit-mounted lighting fixtures without impacting on the established elevations of the terminal building levels, the structural depth was limited to 1000mm. The terminal building’s column spacing is based on a 2.25^o spaced radial grid. To align with this grid and considering the most efficient span to depth ratio for a 1000mm deep deck, a 9° radial column grid was utilized for the bridges. This provided average spans from 24 to 28m.

Typically, a solid slab post-tensioned bridge deck is efficient within this range as the need for transverse post-tensioning over voided sections to control cracking is eliminated. To further reduce the dead load, voided and T-Beam cross-sections were also considered. However, the Owner's preference to eliminate voids and provide a flat soffit lead to the selection of solid deck bridges, fully longitudinally post-tensioned and transversely post-tensioned only at the common pier beams.

A three dimensional model and corresponding as-constructed section of the basic structural system is provided in Figures 2 and 3, respectively.

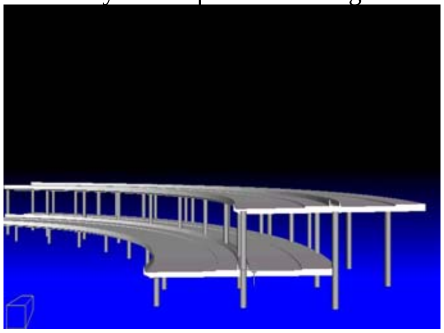

Figure 2 – 3-D Frontage Roads Model

Figure 3 – Partially Completed Section

3.2 Geotechnical

Weak layers of silt/clay overburden on variably weathered shale bedrock exist throughout the project site. Drilled cast in place concrete piles (caissons) was the only foundation alternative recommended. Each pier column was integrally connected to a caisson advanced to and socketed in the shale bedrock, at an average depth of 25m. Caisson load tests verified an allowable bearing capacity of 10 MPa.

3.3 Loading

Since the frontage roads bridges act as highway roads as well as assembly areas and a roof for a public building space, the design had to consider both the Ontario Highway Bridge Design Code (OHBDC-91) and the National Building Code of Canada (NBC) for design loading. For live loading, the governing truck or lane loads from the OHBDC were considered in combination with sidewalk loading given by the NBC. The bridge also had to be designed in accordance with NBC seismic loads and consider the bridge-terminal building interaction under seismic events.

The structural loading due to temperature differential between the top and underside surface of the decks was another major consideration for these bridges, particularly for the spans over the terminal building. While the top surface is subjected to the range in seasonal and daily temperatures, the underside is subject only to the relatively constant temperature of the interior building space, thus producing significant temperature differential-induced forces.

3.4 Analysis

Three-dimensional structural analysis was carried out to assess the behaviour of the inner and outer decks in combination with the common pier beams as well as the overall interaction of all levels together with the rock-socketed caissons and surrounding soil stiffness. This modelling was critical in defining the most efficient column diameter to be able to resist the structural responses while at the same time being sufficiently flexible to minimize the amount of hogging moment. This was particularly important in minimizing the effects of one bridge level on the other. The number of continuous spans between expansion joints was optimized at 3 to address prestressing limitations and the effects of multiple fixity on the arrivals level bridges.

The analysis of the behaviour of the inner and outer decks with the common pier beams indicated the relative independence of the decks and the agreement with simplified two-dimensional models. The longitudinal span ranges encountered on this project are efficiently handled with longitudinal post-tensioning within the 1000mm depth.

However, for the transverse design of the common pier beams, the spans between columns of over 20m is well in excess of what is normally encountered for transverse pier beam designs. This is complicated by the heavy loads and the reduction in available eccentricity caused by the presence of the longitudinal tendons. To at least consistently provide the maximum available eccentricity and to avoid conflict between the two directions, the longitudinal tendons were maintained at their high point across the full width of the pier beams. The width of the pier beam was selected to optimize the transverse post-tensioning design. To maintain the desired long-term durability of the bridges, the serviceability limit state design was limited to zero tension in all cases.

4. Use of High Performance Concrete

As part of the means to address the Owner’s needs for a durable structure in the absence of a formal maintenance program, high performance concrete was specified, primarily targeting low permeability characteristics. While large-scale applications of cast in place HPC had yet to be carried out for bridge construction in North America, the designers had championed it use in other applications and were confident of the work to date in this field as carried out by many transportation authorities.

4.1 HPC Specifications

The specifications were primarily based on the performance-based provisions developed at the time by the Ministry of Transportation of Ontario. The specified performance criteria were:

- Minimum 50 MPa compressive strength at 28 days (defined as the low-end strength threshold for HPC)
- Maximum 1000 Coulombs rapid chloride permeability at 28 days
- Minimum in-situ total air content of 3% and average spacing factor per lot no more than 250µm and no individual test greater than 300µm.

The specifications also mandated the following:

- Type 10SF (8-10% pre-blended silica fume) cement shall be used.
- Up to 25% replacement with fly ash, slag cement or a combination thereof may be used
- A superplasticizer shall be used – the slump measured just prior to placing or pumping shall not exceed 230 mm.
- The temperature of the concrete at discharge from the truck shall be between 10°C and 25°C.
- Maximum temperature during curing of 70°C and maximum differential of 20°C; the Contractor must monitor and establish method of controlling temperature.
- Mandatory curing procedures involving continuous fog misting upon surface finishing, followed by application of pre-soaked burlap within 4 m of the finisher and application of soaker hoses on the burlap and moisture barrier for a 7 day period

A field trial batch (truckload), to provide evidence of the performance aspects of the mix design, and a trial slab with the same equipment and crew to prove his capability to handle, place and cure HPC, were also required. All aspects of the use of HPC were continually reviewed and implemented through mandatory pre-pour meetings.

4.2 Related Protection Measures

To fully realize the cost benefits of HPC as well, standard uncoated reinforcing steel was used almost extensively throughout the bridge construction. However, since barrier walls, sidewalks and expansion joint dams are subjected to increased chloride exposure and are prone to early deterioration, stainless steel reinforcing bars were used in conjunction with HPC to provide additional protection to satisfy both long term maintenance and aesthetic issues.

The deck surface is protected with the application of waterproofing and an asphalt wearing surface. As per typical practice in Ontario, a hot-applied rubberized asphalt waterproofing compound with protection board, having a nominal thickness of 10mm is used in conjunction with 40mm of heavy duty binder course and a 40mm surface course. This treatment was provided on all bridges except those over the terminal space where the Owner insisted upon the highest level of long term confidence in the waterproofing product. “Eliminator” waterproofing by Stirling Lloyd was used in this case.

5. Construction

5.1 Scheduling and Staging

As previously noted, the frontage road bridges were critical to the construction of the terminal building and impact on a number of adjacent contracts. The construction schedule was aggressively fast-tracked with a number of interim completion dates for specific sections interfacing or conflicting with other work.

To provide as much construction time as possible, the designers promoted several means to advance the start of construction activity during the design stage. Separate site grading and caisson contracts were issued in advance. Then, the bridge contract was tendered on a unit price basis using the 60% design package to enable the tendering and award process to take place as the design was being completed. These steps enabled extensions to the schedule while maintaining the required completion dates. The process also allowed for a cooperative effort with the Contractor as the design was finalized.

5.2 Shoring System

As part of the design process, it was assumed that each bridge level, consisting of the inner and outer decks and common pier beams would be constructed in one continuous pour. Additionally, the arrivals level bridge could not be subjected to the falsework loads from the departures level bridge above.

For the lower arrivals level bridges, the Contractor utilized a conventional frame-type shoring system. However, for the upper departures level bridges, the total height of shoring required imposed significant cost and schedule difficulties to the Contractor if similar shoring was used. As part of their original bid, the Contractor proposed a proprietary, “Hi-Load” shoring system, utilizing structural steel beams, trusses and pipe columns to shore the upper decks. Solid steel pintles through temporary sleeves in the lower arrivals level deck were used to transmit the upper deck loads directly to grade. The high capacity of the shoring system enabled a relatively small amount of sleeves to be used through the deck while ensuring no load would be transferred to the lower deck. Despite the fabrication costs of this system, the Contractor saved approximately $1 million over conventional shoring system as well as major benefits to the schedule. Since this system assured transfer of loads through the deck, the designers accepted the system provided full attention is paid to sealing the sleeves through the lower decks. A testing program was carried out to select the most durable patching methodology.

5.3 Bridge Deck Construction

Concrete supply originated from three of the Contractor’s concrete plants, using the same aggregate sources for all. Concrete was placed in the deck forms by means of concrete pumps fed to spreader booms. Four pumps and approximately 60 concrete trucks were used to place approximately 240 m^3 per hour. Independent deck finishers finished the inner and outer decks with hand screeding between the two decks at the common pier beam areas. Deck finisher-mounted and hand-held fog misters provided continuous fog misting of the finished surface. Photos of a typical deck pour and the completed structure are provided in Figures 4 and 5, respectively.

Figure 4 – Deck pour in progress

Figure 5 – Complete Structure

5.4 In-Situ Results

The Owner's independent materials testing agency carried out quality control monitoring and testing. The first five loads from each plant were tested for slump, air and temperature with the frequency changing to every fifth load from each plant once control was established. Concrete cylinders for compressive strength testing were taken in accordance with provincial standards. Representative concrete cores were sampled from the bridge deck and tested for in-situ air void and rapid chloride permeability parameters. No difficulties with the plastic or hardened concrete properties were identified and no single test has failed to meet any of the specified requirements,

Inspection of the concrete surface after the 7-day curing period and thereafter has not revealed any visible shrinkage cracking. The finished condition of the deck surface in the first deck pour was noted to be somewhat rough in areas as the finishing pan tended to stick to the paste. With subsequent pours, attempts to improve this situation using a weighted pan or stainless steel pan were not as successful as simply removing this part of the finishing process. The roller finish without the pan has provided the preferred surface for future application of waterproofing membrane and asphalt.

This project was successfully completed using design ingenuity, flexibility and innovative but responsible use of available knowledge and materials, producing a very unique piece of transportation infrastructure.

6. Acknowledgements

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