ABSTRACT

The King Road at-grade crossing of CN’s Oakville subdivision couldn’t be in a worse place from the point of view of the railway, the municipality or the engineering and construction team tasked with designing a constructible grade separation. This section of the Oakville Sub, locally known as “The Throat”, has five separate subdivisions feeding over 100 trains per day through this three mainline track gauntlet. The 80 mph (129km/hr) corridor hosts Metrolinx commuter trains, VIA and Amtrak inter-city passenger traffic as well as the transcontinental and international gateway freight traffic of CN and CP. Further complications include an environmentally protected stream crossing paralleling the track and an adjacent CN freight yard entrance with its associated signal plant.

In recent years, this rail corridor has expanded and the increase in rail traffic volume, along with the development of the communities surrounding King Road has made the need for a grade separation imperative. The challenge was to develop an installation scheme which would allow for a grade separated crossing while minimizing the disruption to rail traffic. It became evident in preliminary design and consultation with the clients and stakeholders that a conventional approach to construct the bridge in situ through phased construction and long-term shut down of individual mainline tracks was not an acceptable method to consider.

The design team had to ‘think outside the box’ and proposed an alternate strategy to construct a concrete reinforced bridge structure ‘off-line’ to the south of the location of the grade separation and then slide the entire completed four track bridge into place using an open-cut bridge jacking methodology. This is the first time this method has been used anywhere on the CN network. This methodology minimized the shutdown of the track to a single long weekend, for the entire installation process. This paper will recount the entire process describing the projects constraints and challenges, the technical solutions developed, operational processes and communications and coordination protocols. In addition to the leading edge engineering and construction; success, in large part, can be attributed to careful coordination and commitment to
executing the plan exactly in accordance with agreed upon milestones and the flexibility of the design team to deliver solutions through various stages of the projects evolution. The paper will be a valuable tool for anyone faced with getting a large rail bearing structure installed under a very heavily used rail corridor while minimizing train disruption.

INTRODUCTION

The project is located in the City of Burlington (‘the City’), Ontario. Located within what is known as ‘The Golden Horseshoe’, Burlington is part of the Greater Toronto and Hamilton Area, specifically located approximately 36 miles (56 Kms) outside of Toronto City Centre. Like most boroughs along southern Ontario, through the years Burlington has grown from a cluster of villages and townships into a full-fledged City, and many arterial roads established along the CN Railway corridor now serve the community for much broader demands, connecting major rail and freeway corridors (Figure 2), bringing approximately 100 trains per day servicing passenger and commercial, inter-modal needs, through its territory. When the rail lines were first established in the early 1800’s, all of the road/rail crossings were “at-grade” with rail crossing bells and gates. In time with increasing road and rail traffic, it became apparent that road/rail grade separations were needed. Through its urbanization and master planning, numerous grade separations have been constructed in the City over the years as shown on the attached Figure 1, with several more planned over the next 10 to 15 years.

Figure 1: Rail Corridors through Burlington.
One particular arterial road at-grade crossing in need of a grade separation, and the focus of this paper, is King Road. King Road serves as a primary connection between the community of southern Burlington to Ontario’s provincial Highway 403, serving the communities between Mississauga and Hamilton, with connections to Toronto and Windsor through Highway 401. To support growth within the City while at the same time provide the community safe and accessible passage across this rail corridor (known henceforth as ‘Oakville Subdivision’ or ‘Oakville S/D’), in 2005 the City initiated a project with the commencement of an Environmental Assessment to establish a grade separation of King Road and the Oakville S/D.

**ESTABLISHING THE GRADE SEPARATION: ENVIRONMENTAL ASSESSMENT & PRELIMINARY DESIGN**

The at-grade crossing of King Road in its original states is a rural two-lane, bi-directional road complete with granular shoulders, crossing CN’s Oakville Subdivision comprised of (from north to south) a lead track into their Aldershot yard and three (3) mainline tracks with the latest (southern-most) track being constructed by CN as part of the GO Transit’s (now known as ‘Metrolinx’) Expansion project in 2009.

The Class Environmental Assessment concluded two feasible options to be considered for a grade separation of the CNR tracks with King Road; a two lane overpass over the railway and a two-lane underpass.

As the proposed grade separation is located near the east entrance to CN’s Aldershot yard on the Oakville Subdivision (refer to Figure 2), CN had installed a considerable amount of switching and signal equipment to improve the access to their yard in the area. This made any diversion of the railway to facilitate bridge construction, a costly undertaking. At this particular crossing, the relocation of power switches, overhead signal bridges and cantilever signal bridges, complete with their temporary rewiring, would cost in excess of $2 million CAD. As such, it was concluded that the overpass option was not practical as it created a profile that would result in a required road reconstruction in excess of 650m with access being restricted at three adjoining intersections as well as seven residential and two industrial/commercial properties.
In this circumstance, the ‘road underpass’ became the less expensive alternative to the ‘road overpass’, with underpasses typically more desirable in an urban area as they are less visually obstructive and help mitigate road noise.

Where boundaries and constraints allow, most road underpasses in Burlington have been constructed by temporarily realigning both the rail lines and the roadway, thus creating a clear site for an open cut excavation and construction of the underpass structure in its final location. However, in the case of King Road, property allocation for temporary or permanent easements was not possible or sufficient enough to allow for a realignment of the road and/or track. Furthermore, due to the Oakville Subdivision’s designation as a major rail corridor, it was not permissible to take these tracks off-line for any significant duration as it would be costly to commuter business and inter-modal freight service. Therefore, alternate strategies were conceived to make the underpass option viable without significant interruption to the railways. The strategy engineered became the precipice of the bridge jacking concept.

**BRIDGE JACKING: CONSIDERING THE OPTIONS**

Jacking the precast box involved constructing the subway box structure on site and then jacking it under live tracks (refer to Figure 3). The advantages of this technique were the maintaining of the rail traffic at all times. The disadvantages were the lack of local...
contractors with the knowledge and equipment required to complete the work as well as the tracks being at different elevations.

The open cut method involved installing the precast box as above by open cut and jacking into place over a long weekend. The advantages of this are that it is quick with very low risk and is a safe proven method with local contractor expertise. The disadvantages of this method were the closure and removal of 3 of the 4 tracks with service being halted throughout the area.

As the costs for each technique were comparable, the preferred method of an open cut installation was chosen due to the low risk and the minimal impact on the businesses, neighbouring residents and train traffic.

**BRIDGE JACKING: THE CONCEPT**

The principle behind the jacking of a structure of this size (designed to be a 5,100,000 lbs/4500 kg structure) is to push the structure into place with hydraulic jacks on an engineered surface designed to mitigate the effects of friction. To accomplish this, the
structure was built upon a ‘sandwich layer’ installed between the box structure and the jacking pad, comprised of corrugated galvanized steel, industrial ultra-high molecular weight (UHMW) polyethylene sheeting, and industrial grease. Furthermore, in an effort to further reduce frictional loss, a system of air hoses are introduced within the corrugated cavities that serve to transfer some of the weight of the structure from the middle to the ends positioned on the jacking slab. This allows the structure to be pushed under a fraction of its own weight using relatively small and mobile set of four 150-tonne hydraulic jacks.

The box itself when pushed is kept within horizontal and vertical tolerances by system components. The air hoses are controlled with a manifold to allow individual hoses to be repaired or replaced and to enable the ability to pressurize the different lines of the hydraulic system to adjust to the behavior of the structure when in motion. This is complemented by the function of the jacks themselves, which are engaged independently, controlled by the operator using mobile ‘joysticks’, so that hydraulic force can be adjusted to effectively steer should the structure be discovered to divert from measured targets. Lastly, the jacking pad is designed with keys and guides cast into the concrete of the structure and precast support panels.

The appropriate selection of the where to construct the box to begin with also took careful consideration. Working ‘off-line’ allowed construction to occur unabated by working restrictions otherwise imposed by CN when inside the rail right-of-way. This method also served to benefit cost as the need for flagging was minimized to the extent of working outside CN’s regulated area. Furthermore, the work could be expedited faster than within the right-of-way, which results in shorter working days and planned shut downs imposed by slow work orders (known as ‘Rule 42’). Because of the short duration in which the tracks were permitted to be taken out of operation for the open cut push, the estimated rate of push was also considered to ensure there was sufficient time to push the given distance, also considering the other tasks involved during this period.

The area to the immediate southwest of the existing grade separation was selected as the optimal location for the box to be constructed for a couple significant reasons; (1) the presence of Indian Creek running parallel along the side of the tracks required a more complicated diversion (part of the design assignment and discussed elsewhere in this paper) and could not be done in advance of the grade separation, and (2) as a condition of this methodology, CN imposed a requirement to maintain one (1) track as a diversion track during the planned shutdown for the jacking exercise, and the north pull-back track was designated as the diversion track because it could be temporarily realigned without significant impact to the three (3) mainline tracks.

Therefore the design approach was to prepare the designated southwest quadrant to serve as the ‘launch pad’. Advance works were required to establish this area for the launch pad, including relocation of utilities and installation of support of excavation (SOE) to allow the box to be constructed at the designed elevation while protecting the
work zone from both King Road and the Oakville Subdivision; both kept in operation for much of the projects duration (apart from planned shutdowns).

The structure being pushed and eventually serving as the underpass is essentially a 'box'; the cross-section width of the box (61ft/18.6m) was dictated by the City’s requirements established in the EA to achieve the desired urbanized roadway geometry, which included (in both directions) a 11-ft (3.5m) wide vehicular lane, a 4-ft (1.2m) wide dedicated bike lane delineated by curb and 3.0m gutter with sidewalk and boulevard. The length of the box (16.6m, with additional 3.5m of wingwalls constructed on the south side) was dictated by the diversion track required on the north side. The structure was designed to AREMA loading (E90), resulting in structural walls of reinforced concrete approximate 3 feet (1m) thick, resulting in a structure weighing approximately 5,100,000 tons (4,500 kg)

THE JACKING PAD

Another key feature of this system is that the net propulsion of the structure is the result reaction of internal forces. The jacking pads themselves are pre-cast reinforced sections, 12ft x 12ft, 18-inches thick, with longitudinal conduits to allow post-tensioning rods to connect the precast sections on each to prevent buckling or rising of the sections when the hydraulic force is applied. Anchor rods connecting the jacking pad to a reinforced base slab below serve as additional support. Within each jacking slab are a series of steel reinforced, ‘v-shaped’ slots. These slots house the footings of the 150-tonne hydraulic jacks used to advance the structure. With the jack head bolted to the box so that when propelling forward, its footings exerts force against the back of the slot and the resistance allows the jack to extend forward. Once fully extended (approximately the length of the precast sections, i.e. 12-ft/4m), the jacks are engineered to be ‘self-propelled’ in that the head of the jacks are bolted to the box structure and once they are fully extended, the jacks are recoiled causing the footings to slide out of the v-shaped slots, advancing forward to the next set of anchor holes and re-anchor to repeat as required (refer to Figure 4).
The function of the diversion track was to allow safe passage of trains during the closure of the mainline tracks for the bridge jacking. The pull-back track serving CN’s Aldershot Yard serves as an ideal candidate for the diversion track as it extended through the intersection and could be connected to the existing mainline track (northern most, known as ‘T1’) within the east and west limits of existing signal bridge without modification to the signal infrastructure. Furthermore, the diversion track gauge is consistent with the track gauge of the main line (115lb) and therefore would be able to accommodate CN and commuter trains (Metrolinx, VIA and Amtrak). When planning the diversion alignment, several factors were considered. The ideal position of the diversion track would be to clear all four existing mainline tracks centrelines so that the constructed box could be jacked under the full width of the right-of-way without need for additional staging or construction within the right-of-way. However, there were two key constraints on the north side preventing the diversion track from being in its ideal location, notably Indian Creek located approximately 13 feet (4m) to the north of the right-of-way and equally as significant is a signal bungalow on the northeast side of the existing crossing that would incur significant costs if relocated. Therefore, the diversion track was designed to pass between these constraints and the mainline tracks. The resulting location of this diversion track meant that the construction of the underpass had to be done in two (2) stages; the first stage being the jacking of the box, followed by a second stage wherein the mainline tracks would be reinstalled on the box along with the fourth (diversion) track, and the remaining portion of the box (approximately 7 feet/2-metres) be cast-in-place construction.
THE PREPARATION

To prepare for the eventual jacking of the structure, the site required some advanced preparation. Existing utilities through the area had to be relocated, including a 600mm watermain, as well as telecommunication infrastructure, both overhead and underground.

With all utilities cleared or relocated from the area, the support of excavation was designed and issued as a separate tender package (the ‘piling contract’) in advance of the construction of the box (the ‘main contract’). Interlocking steel pipe pile walls (or caissons) were chosen as the preferred method to support both King Road as well as the headwall supporting the diversion track once the right-of-way was open cut. The design called for the headwall to be constructed using approximately 131 feet (40 linear meters) of caisson wall constructed with 55 interlocking caissons with a diameter of 4 feet (1180mm) each. For both size retaining walls, the interlocking component consisted of augured steel h-piles reinforced with 30-35 megapascals (MPa) concrete at an average length of 61 feet (18.5m) and unreinforced caisson fillers with up to 6-8 MPa concrete at an average length of 28 feet (8.5m). The piles along King Road were 880mm diameter and included two rows of diagonal tiebacks. The retaining wall serving as the headwall was designed with a single row of horizontal tie-backs, connected to a dead-man system consisting of interlocking sheet piles. The benefit of the dead man system over the traditional installation of diagonal tiebacks at various depths was that it required less interruption to the mainline tracks, requiring periodic closure of track to excavate down to install the horizontal anchor, whereas to install the horizontal tiebacks meant deeper excavations and longer track interruptions.

Due to the close proximity of the work to the existing tracks and the neighbouring businesses and residents, it was planned to utilize an auguring technology to install the caisson walls. Such cased or lined drill shafts can be installed without the requirement for vibratory diesel
hammers which are prone to noise and vibration impacts. The small footprint of the compact auguring rigs would make them more suitable for the limited space along the live tracks.

The caisson wall construction began in April 2012 with periodic closures of King Road to allow for piling equipment to be positioned on King Road. With King Road being one of the main emergency routes for Burlington and the location of the businesses along King Road, full road closures for this long of a duration was not an option. Additionally, portions of the wall supporting King Road as well as the head wall are within the CN right-of-way, and therefore had to be installed during arranged track closures, typically one at a time, during evening or off-peak periods. (See photo illustrating the shoring system constructed within the right-of-way.)

Once the caisson walls were installed, the main contract was awarded, allowing the contractor to commence construction of the box structure. The construction of the box structure began May 2012 and was completed in just two months, primarily because of the contractors’ ability to work more efficiently outside of the CN right-of-way. An additional retaining wall was constructed south of the existing tracks to allow for the box to be positioned even closer to the right-of-way (decreasing the distance of the slide). Additionally, a system of approximately 200 4-inch (100mm) diameter micro-piles (also called ‘soil nailing’) were installed across the right-of-way. The micro-piles were installed in an interlocking diagonal web and consequently jet-grouted. The micro-piles allowed for a 1:3/4 excavation slope (over the traditional 1:2 slope of unsupported excavations), resulting in a smaller excavation area which is of great benefit given the abbreviated closure period.

With the excavation for the jacking slab being approximately 33 feet (10m) from existing ground, and 3m below the groundwater table, another key element to overcome was dewatering the site, especially due to the close proximity of the creek and the sandy soil conditions. The solution was to install a system of inductor wells connected to a manifold, treating and discharging groundwater in accordance with requirements of the Permit to Take Water.

CN had also contracted a bridge jacking specialist to assist in the design of the jacking system, and to supply the jacking system materials including the ‘sandwich layer’, the pre-cast slabs, and the hydraulic jacking equipment. The sequence to construct the box meant CN had to carefully coordinate between the main contractor and the jacking specialist. The main contractor was responsible for excavating the area of the jacking slab and placing the base slab. The jacking specialist then occupied the workzone and installed the precast panels, and the sandwich slab (corrugated steel, UHMW sheeting, etc.). The main contractor then returned to the workzone to form and construct the reinforced box over top of the jacking layer.

As a means of assessing the performance of the system in advance of the actual push, it was decided to undertake ‘trial pushes’ of the structure at predefined stages of construction. The structure underwent its first trial push once the base and bottom
section of the walls were poured. This represented roughly 20% of the structure and therefore an equal scaled version of the hydraulic force was used to push the structure approximately 3 to 4 inches (75-100mm). A similar trial push was conducted upon completion of the full-height walls, with the ceiling slab formed but not poured. Similar to the first test, the total weight of the structure, including any forms, was pushed under a representative scale of hydraulic force.

Leading up to the scheduled slide October 5th – 8th, the project team, led by CN, held several preparatory meetings and workshops to review the sequence of the work as well as identify potential risks and ways to mitigate them. As a continuous 24-hour series of events, each task had to be planned precisely, considering the staffing, materials and equipment necessary to perform the task effectively and efficiently. CN outsourced the excavation and handling of materials to a civil contractor, who was able to provide at CN’s request, additional equipment to serve as standby in the event of equipment damage, replacement or repair. CN also prepared their Bridges & Structures, Signals & Communications and Flagging teams for each shift. Management of the site was relegated to a rotating crew of supervisors, keeping each other posted on progress. Furthermore, key stakeholders, including the City of Burlington, Metrolinx, and VIA were updated regularly, identifying any slippages and corresponding corrective actions to recover. Ultimately, with all plans and procedures in place, the public were advised through notices and other media, and the plan was ready for its execution.

**OPEN CUT INSTALLATION OF PRECAST STRUCTURE**

**72 Hours: Executing the Jacking**

The planned shutdown of Oakville subdivision commenced at 20:00hrs on Friday October 5th, 2012, with the passage of the last Metrolinx commuter train. From this point on, all rail traffic will use the diversion track on a slow work order, advanced through the site through direct communication between the flagman and locomotive engineer.

The tracks were subsequently disassembled as complete sections with ties left in place, and stored nearby on the right-of-way. Once the site was cleared of track work, the civil work began to excavate to the design depths. Due to time and space constraints, several excavators were working at the same time, with material temporarily stockpiled in designated locations near the workzone and subsequently transported to an established stockpile area to clear the area for mobility and other tasks.

The work was staged in such a way that the excavation of the east subgrade was completed first, allowing for preparation of the subbase and installation of the precast segments to occur while the west side follows.
Once the east and west rows of six (6) precast panels were installed and tensioned, the jacking equipment was assembled, calibrated, and energized. The pneumatic system operated under approximately 700psi (5 MPa) pressure, measuring a lift of approximately ¾ inch (20mm), while the four hydraulic jacks exerted a force of approximately 12% of the total weight of the structure. The total duration of the slide was approximately 5.5 hours, however, with approximately 2.5 hours of accumulated time attributed to resetting the jacks.

On the evening of Sunday Oct 7th, approximately 55 hours into the 72 hour time block, the structure reached the headwall to complete the slide. This was followed by backfilling around the sides of the structure using granular fill, followed by placement of sub-ballast and ballast. The track sections were reinstalled, with the southern-most track installed first as it was the designated track that the Metrolinx GO Train would be using for its first commuter train of the morning. At 05:30 hours, all tracks were reinstalled and operating as intended.
Summary

This project served as an example of how creative engineering, combined with effective planning and cooperation, can overcome significant physical and timeline constraints. This project was the largest of its kind performed on a CN mainline subdivision, and should be under consideration as an alternative to traditional diversion staged alternatives. Like most projects, this project should be studied to determine improvements on efficiencies; for example, the time it takes for the jacks to recoil could be considered an inefficiency to time, and may be mitigated by installing a second set of jacks designed to extend while the first set of jacks are retracting, keeping the structure in virtual constant motion. With continuous application, knowledge and experience will develop within the industry to make this method of constructing grade separations an industry standard.
King Road Grade Separation
Burlington, Ontario

Presenter: Terry Kelly
The Project Location

- Locally known as “The Throat”
- Has five (5) separate subdivisions feeding over 100 trains per day through this three mainline track gauntlet.
- The 80 mph corridor hosts Metrolinx commuter trains, VIA and Amtrak inter-city passenger traffic as well as the transcontinental and international gateway freight traffic of CN and CP.
- Further complications include
  - an environmentally protected Indian Creek crossing paralleling the track
  - an adjacent CN freight yard entrance with its associated signal plant.

Project Objective (The Need)

- Benefits to Rail
  - Safety - Eliminates at-grade crossings
  - Improves train speed (Commuter, Freight)
- Benefits to Road
  - Safety (Eliminates influence on train movement)
  - Urbanization of existing King Road
  - Re-establishes Emergency Route

The Challenges

- Maintain existing track operations
- Aldershot Yard must remain in service
- Maintain traffic to King Road
- Indian Creek - environmentally sensitive work zone

The Clients

- Structure
- Options Study 2011
- Jack Box Options
- Roadway
- Aqueduct

The Options

- Caisson Pile / Cast in place substructure and Precast double voided box spans
- Tunnel Jacking Precast Subway under existing tracks (grillage support)
- Open Cut Method / Track Diversion
- Full Open Cut & Jack in Precast Subway

The Conventional Approach…

Grade Separation (Full Work Zone)
Option 1: Cast in Place Substructure (Precast Spans)
- Staged Closures of Mainline Tracks
- CN Aldershot Yard ladder track modifications
- Extended closure(s) of King Road

Option 2 - Tunnel Jacking Under Existing Tracks
- Challenge to place grillage
- Changes to track elevations
- Replacing existing switches
- Inexperience of contractors
- Interruption to Mainline Track Service
- Track Slow Orders (TSOs) during placement of grillage and throughout construction
- King Road Closures were minimized (vs Cast in Place)

Option 3 - Jacked Box Cut & Cover Method
- Minimal Closure of Mainline Tracks (72 hours)
- Controlled Short-Term Closures of King Road (Crossing Adjustments)
- Construction of Subway Box ‘Off-Line’

Selected Option
Option 3 - Cut & Cover Jacked Box
- CIP Concrete Box Adjacent to Tracks
- Slide into Place During a 72 Hour Weekend Track Closure

Advantages
- Minimized Railway Closures
- Controlled Risk/ Quality of Structure
- Ensured Client Familiarity

Track Configuration - Diversion

Site Plan
CN Assignment Integrated Design and Construction

- 4 Separate Construction Contracts
- 2 Additional Design and Construction Contracts
- 1 Integrated Design Team HMM/CN/WM
- 0 General Contractors (CN acted as their own representative)

Temporary Piling

Construct Launch Pad

- 1. Construct Box Structure
- 2. Construct Diversion Track
- 3. Open Cut Right-of-Way

Jack Box (on slabs)
- 80 hour Weekend Track Block

Backfill and Reinstate Tracks
Support of Excavation (Contractor 1)

Box Casting (Contractor 2)

‘The Box’
8m x 18m x 18m
5 million pounds

Micropiling (Design / Construct Contract 1)
- Permitted 1:3/4 sloped excavation
- Decreased excavation volumes (and time) by about 20%

Jacking System (Design / Construct Contract 2)
- Two Sets of 150T Hydraulic Jacks
- Jacking Slabs with Anchor Slots
- Industrial Grease

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Excavation / Weekend Push
(Contractor 3 - Contact Duration 80 Hours)