DINGMAN DRIVE BRIDGE – REINSTATEMENT OF SEVERED STRANDS ON PRESTRESSED GIRDERS DAMAGED BY VEHICLE IMPACT

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ABSTRACT

Bridges over freeways are particularly vulnerable to impact damage by over height vehicles and can suffer severe damage. In August 2010, a tractor-trailer carrying a hydraulic excavator struck the four-span, Dingman Drive Bridge over the westbound lanes of Highway 401 near London, Ontario, Canada. The vehicle hit three of the five AASHTO Type lll girders, severing three strands in two girders and causing significant concrete damage.

Traditional repair methods range from accepting the broken strands and reinstating the concrete if the beam has sufficient strength, to complete beam replacement. In this case, beam replacement was considered, but the Ministry of Transportation Ontario (MTO) believed that reconnecting the strands was a viable option. A unique design was developed using a mechanical strand coupler system to reconnect all the strands. The design incorporated a number of innovative applications, which resulted in a repair that was 50 % less costly than the replacement option.

This paper describes MTO's first ever application of this technique to reconnect and re-stress the broken strands, the testing conducted to measure strand tension and concrete stresses, the use of carbon fibre reinforced polymer (CFRP) strips to reinforce the girders and the use of a mobile barrier system for worker protection.

Keywords: Mechanical Couplers, Self Consolidating Concrete, Carbon Fibre Reinforced Polymers, Mobile Traffic Barrier.

INTRODUCTION

On August 3rd, 2010, the Dingman Drive Underpass, located on Highway 401 near London, Ontario, Canada was struck by a vehicle carrying an over height load. A tractor-trailer carrying a hydraulic excavator travelling in the westbound lanes of Highway 401 caused significant damage to the four-span bridge when the knuckle of the excavator struck three of the five AASHTO Type III girders over the westbound lanes. In addition to the spalling, cracking in the webs and loss of concrete section in the bottom flange at the impact locations, three prestressed strands in each of two girders were severed by the impact, resulting in temporary closure of the bridge to vehicle traffic.

EXISTING BRIDGE

The Dingman Drive Underpass (Site No. 19-368) is a 4-span, slab-on-prestressed concrete girder bridge built in 1968. The spans lengths are 13.7, 23.5, 23.5, 13.7 metres and the bridge is 10.4 metres wide. Each span is simply supported, with expansion joints at the abutments and piers. The minimum vertical clearance over the westbound lanes of Highway 401 is 4.66 metres. (In Ontario, an “Oversize Permit” is required when the height of the vehicle and load exceeds 4.15 metres). The bridge carries two lanes of traffic on Dingman Drive which crosses Highway 401 at a 37 degree skew. The 190 millimetre thick concrete deck is supported on five AASHTO Type III girders. Each girder contains 32 - ½ inch nominal diameter, 7 wire prestressing strands (18 straight and 14 deflected).

Fig. 1: Highway 401/Dingman Drive Underpass, West Elevation

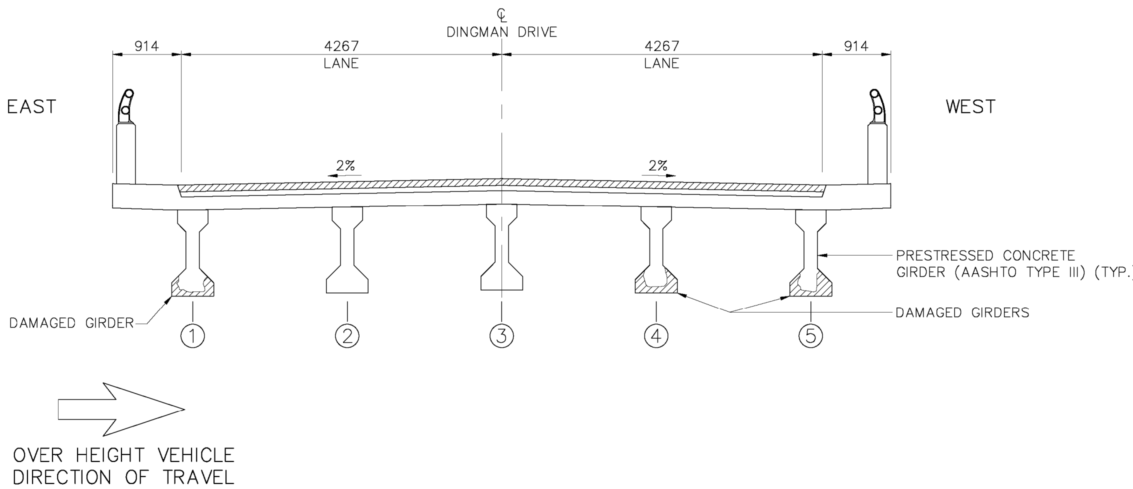

Fig. 2: Highway 401/Dingman Drive Underpass, Deck Section

DESCRIPTION OF DAMAGE

Highway 401 carries three lanes of westbound traffic under Dingman Drive. The point of impact was centred over the right lane (Lane #3) of Highway 401, at approximately the third point of the span, eight metres from the north pier.

Fig. 3: Dingman Drive West Elevation

Fig. 4: Oversize load

Damage to the three girders, numbered #1 (east girder), #4 (west interior girder) to #5 (west girder), was as follows:

Girder #1 – Severe spalling of the bottom flange of the girder occurred over a length of approximately 4.2 metres. Three ½-inch diameter prestressing strands in the bottom row and two #5 longitudinal reinforcing bars in the bottom flange were severed. Two rows of prestressing strands in the bottom flange debonded over a length of approximately 1.7

metres. A hairline (less than 0.1 mm wide) to narrow (0.1 to 0.3 mm wide) crack, approximately 11 metres long developed at the interface of the girder web and top flange.

(a) Side View (b) Soffit View

Fig. 5: Girder #1 Impact Damage

Girder #4 – Severe spalling of the bottom flange of the girder took place over a length of approximately 3.6 metres. One longitudinal #5 reinforcing bar was severed. Three rows of prestressing strands in the bottom flange were debonded over a length of approximately 3.6 metres. Although there were small nicks in two prestressing strands, no wires were severed. A hairline to narrow crack, approximately 4 metres long developed at the interface of the girder web and top flange.

(a) Soffit View (b) Side View

Fig. 6: Girder #4 Impact Damage

Girder #5 – Severe spalling of the bottom flange of the girder occurred over a length of approximately 5.2 metres. Three ½-inch diameter prestressing strands in the bottom row and one prestressing strand in the second row (4 wires) were severed, as was one #5 longitudinal reinforcing bar in the bottom flange. Three rows of prestressing strands in the bottom flange debonded over a length of approximately 3.4 metres. A hairline crack, approximately 8 metres long developed at the interface of the girder web and top flange.

(a) Soffit View (b) Severed Strands

Fig. 7: Girder #5 Impact Damage

Following the impact damage to the bridge girders, Dingman Drive was closed and traffic detoured until an assessment of the damage was undertaken by Ministry of Transportation Ontario (MTO) engineers and the MTO's consultant. A structural evaluation was carried out by MTO's consultant to determine if the post-impact structural capacity of the bridge was sufficient to support a single lane of traffic located directly above the two undamaged girders. The evaluation, which assumed that 60% of the live load (a single CL-625-ONT truck) would be distributed to a single girder, determined that the two undamaged girders were adequate to support a single lane. Traffic signals were installed at each end of the bridge and flexible drums (TC-54's) were used to demarcate a single lane of alternating traffic on Dingman Drive (Figure 8). The bridge was reopened to a single lane of traffic two weeks after the initial closure.

Fig. 8: Single Lane Traffic on Dingman Drive

REPAIR ALTERNATIVES CONSIDERED

The repair alternatives shown in Table 1 were considered to restore the bridge to pre-impact state.

Table 1: Repair Alternatives Considered

Rehabilitate Girders	Replace Damaged Girders	Replace Span
- splice severed strands using mechanical connectors - splice damaged reinforcing steel - form and pump proprietary concrete to replace spalled concrete - repair cracks using epoxy injection - add Carbon Fibre Reinforced Polymer (CFRP) for durability, shear and flexural capacity	– remove portion of deck and three girders – replace girders with three new modified CPCI girders – construct new portion of deck to match existing deck thickness – construct/modify expansion joints	- remove entire span over westbound lanes - replace with new girders and concrete deck
- 4 weeks construction duration, 3 weeks of two lane night time closures on Highway 401	– 7 weeks construction duration, 7 nights of rolling closures on Highway 401	- 6 weeks construction duration, 5 nights of rolling closures on Highway 401
- Estimated cost CAD$350,000	– Estimated cost CAD$700,000	- Estimated cost CAD$760,000

For all alternatives, it was assumed that Dingman Drive would be closed for the duration of the construction. Since Highway 401 is a strategic highway in Ontario, selection of an alternative that minimized disruption and delays to traffic was a considered a high priority.

Construction for the “Replace Damaged Girders” and “Replace Span” alternatives assumed that rolling night time closures on Highway 401 would be required to facilitate removal and installation of the girders and deck. However, the “Replace Damaged Girders” alternative was considered to be challenging due to difficulties associated with matching the remaining portion of the deck with new, modified girders. The “Replace Span” alternative had a higher cost compared to the “Replace Damaged Girders” alternative, but would restore the bridge to a condition better than the pre-impact condition for a relatively small premium and less risk during construction. The disadvantage of these two options was that there would be insufficient lead time to design, fabricate and complete the installation of replacement girders before the 2010/2011 winter season.

SELECTED REPAIR METHOD

The "Rehabilitate Girders" option was selected as the preferred alternative. Although this alternative had the lowest construction cost and shortest construction duration, impacts to Highway 401 traffic would be higher, as two of the three traffic lanes would be closed at night (9:00 pm to 6:00 am) for about three weeks. However, given the lower night time traffic volumes, the disruption to traffic on Highway 401 due to the temporary closures was considered acceptable. Also, the materials required for the repairs were readily available and construction could be completed before the onset of the winter season. Completion of the repairs by the end of October 2010 would enable re-opening of Dingman Drive to two lanes of traffic, thus avoiding the difficulties associated with snow maintenance activities on the single lane bridge deck.

Innovations used for the Dingman Drive Underpass repairs included the use of mechanical couplers, self consolidating concrete, carbon fibre reinforced polymers and a mobile traffic barrier.

A proprietary mechanical coupler system was used to permanently reconnect broken strands in the bridge girders, restoring the load carrying capacity of the structure, without having to replace the damaged girders. The initial pre-set length of the device is approximately 490 millimetres with a maximum outside diameter of 42 millimetres. The mechanical coupler device is attached to each end of the severed strand and a threaded coupler is tightened (similar to a turnbuckle), thereby reinstating the prestressing force in the strand. Although MTO had been aware of the mechanical coupler system for a number of years, this repair project was the ministry's first opportunity to use the device. Before the couplers were used on the repair itself, MTO staff practiced with the mechanical coupler on a model and developed a detailed procedure for the contractor to install the devices. A total of six mechanical couplers were installed on two girders.

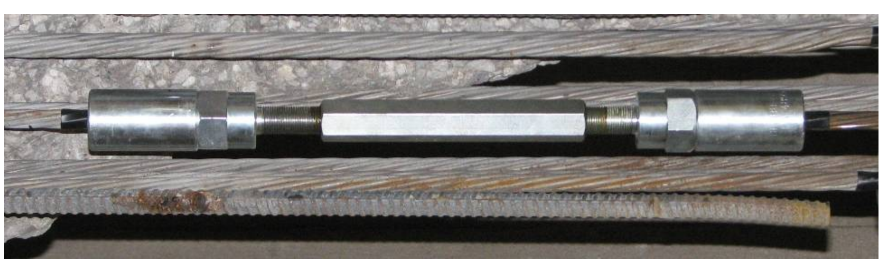

Fig. 9: Installed Mechanical Coupler

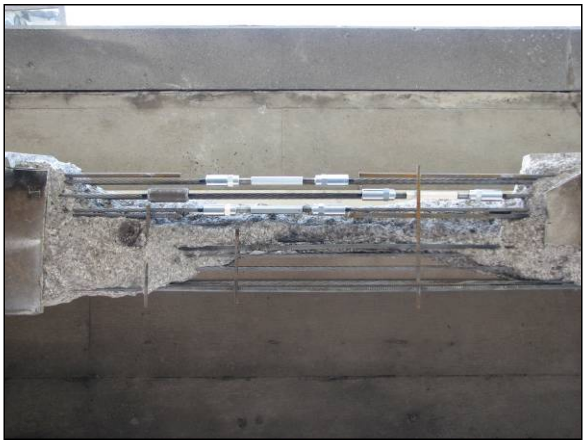

Fig. 10: Mechanical Coupler Layout

Fig. 11: Instrumented Mechanical Couplers

Self Consolidating Concrete (SCC) was used to reinstate the damaged concrete girders. SCC is a highly flowable concrete that does not require vibration-based consolidation and can be readily pumped. It is well suited for use in highly congested areas where consolidation during the placement of concrete is a concern. Although the installation of mechanical couplers caused significant congestion around the exposed prestressing strands and reinforcing steel in the repair areas, the use of SCC resulted in high quality and durable concrete that required minimal finishing when the forms were removed.

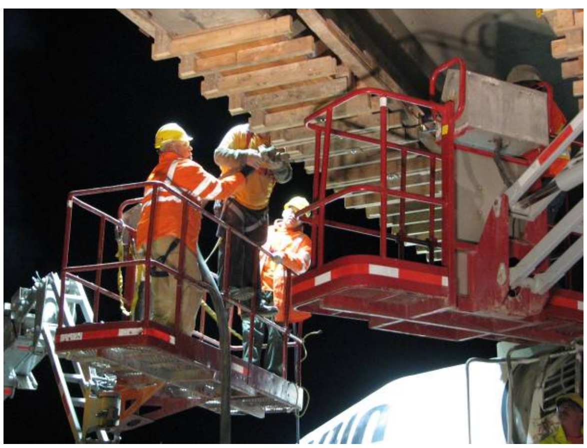

Fig. 12: Pumping SCC

Fig. 13: Finished Concrete

After the cracks in the girder webs were repaired using epoxy injection, sheets of woven Carbon Fibre-Reinforced Polymer (CFRP) fabric were installed over the concrete repair areas to further strengthen and protect the girders. CFRP fabric is light and can be readily attached to the contours of a concrete girder with an epoxy adhesive system. Three layers of CFRP strips 500 mm wide were installed at the underside of the girders and evenly spaced vertical strips of CFRP 250 mm wide were installed on the webs of the girders using a multi-step process. The proprietary process included diamond grinding all sharp concrete edges, application of a primer and an epoxy putty, rolling the CFRP fabric onto the epoxy putty, coating the CFRP with a saturant and finally covering the entire repair area with an ultra-violet protective coating.

Fig. 14: Installation of CFRP

Fig. 15: CFRP Strengthening

A proprietary mobile traffic barrier system was used for the duration of the Dingman Drive Underpass repairs to protect construction workers from freeway traffic. The mobile barrier unit consists of a trailer that is towed into place by a standard truck tractor and then parked to provide worker protection. This is only the second time this system has been used on a MTO project and the mobile traffic barrier continues to impress MTO and contractors because of its ease and speed of set-up compared with conventional work zone protection equipment, such as temporary concrete barriers. To minimize disruption to Highway 401 traffic, two of the three westbound lanes were closed on a nightly basis at 9:00 pm. The lane closure set-ups, including mobile barrier, advance signing and flexible drums, were completed in approximately 15 minutes. At 6:00 am each morning, the mobile traffic barrier was removed and all three lanes of Highway 401 were re-opened to traffic in time for the peak morning traffic.

Fig. 16: Mobile Traffic Barrier

Fig. 17: Mobile Traffic Barrier

MECHANICAL COUPLER INSTALLATION

A detailed sequence of construction for repairing the girders was provided on the contract drawings. The contract required that the mechanical couplers be torqued such that 1060 MPa (0.57 fpu) of stress be induced into the repaired strands. Prestressing strand elongation was calculated and a wedge set of 6 millimetres per wedge was estimated. Using data provided by the manufacturer for the mechanical couplers, a torque of 0.30 kNm (221 ft.lb) was required to be applied to the couplers.

The mechanical couplers were torqued in 0.03 kNm (25 ft.lb) increments and elongations were measured on the coupler threads using a digital vernier caliper. The tensioning of the mechanical couplers was a three person operation and proved to be more difficult than anticipated due to limited access to the couplers and slipping of the open face wrench off the coupler nut at higher torques. On average, a maximum torque of approximately 0.27 kNm (200 ft.lb) (90% of the target torque) was applied to each mechanical coupler before the operation was terminated.

INSTRUMENTATION AND TESTING

Based on the greater extent of damage sustained by Girder #5, it was selected for instrumentation to study the characteristics and effectiveness of the splicing procedure.

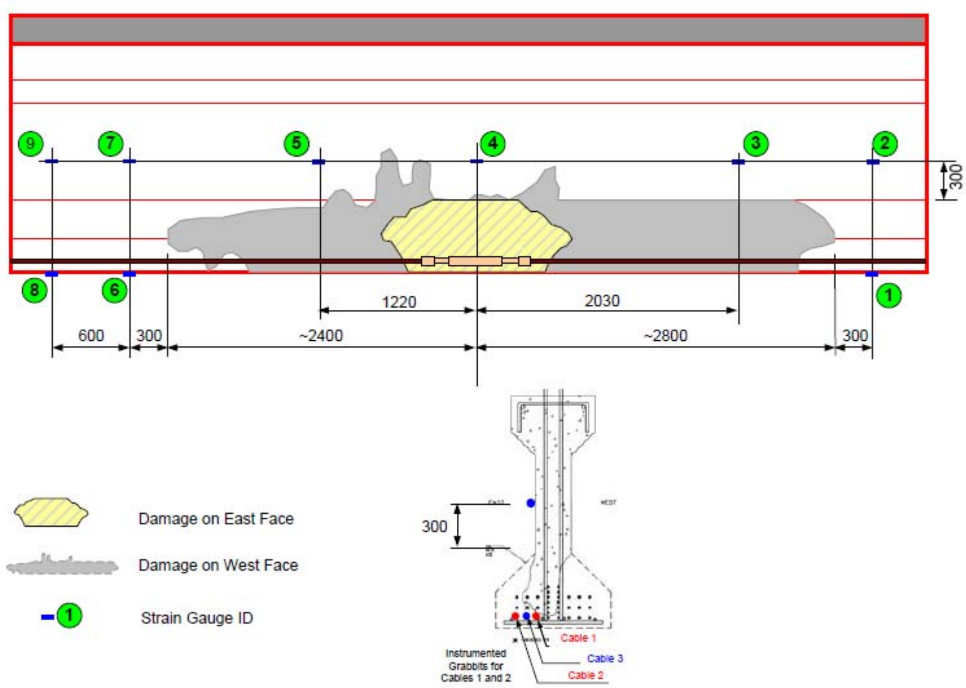

Fig. 18: Instrumentation Plan Details (All dimensions in mm)

A total of thirteen electrical resistance strain gauges were installed, nine at different locations around the damaged area to study the stressing effect on the concrete and four on two of the mechanical couplers to investigate the force development in the couplers.

The two instrumented couplers, connecting cables #1 and #2, were tightened incrementally and for each increasing torque value, the strain data from all the strain gauges were recorded on a data acquisition system. Concrete strain data were also collected during the splicing of the last cable #3.

The experimental strain data obtained during the splicing of the three severed strands are shown in Figure 20. Note that for display purposes, the torque values shown in the plots are cumulative values to show the effect of tensioning each individual cable on the concrete strains and cable forces. The following observations can be made:

(1) The maximum force measured in the mechanical coupler was about 65 kN.

(2) The stressing of the strands did not have a significant effect on the concrete around the damaged area with maximum strains of about -25 $\mu\varepsilon$ measured by gauge 5 and 28 $\mu\varepsilon$ by gauge 2. This corresponds to a concrete stress of less than 1 MPa, which indicates that the prestressing force caused by the tensioning of the mechanical couplers was effectively neutralised by the large stiffness of the deck system around the damaged area.

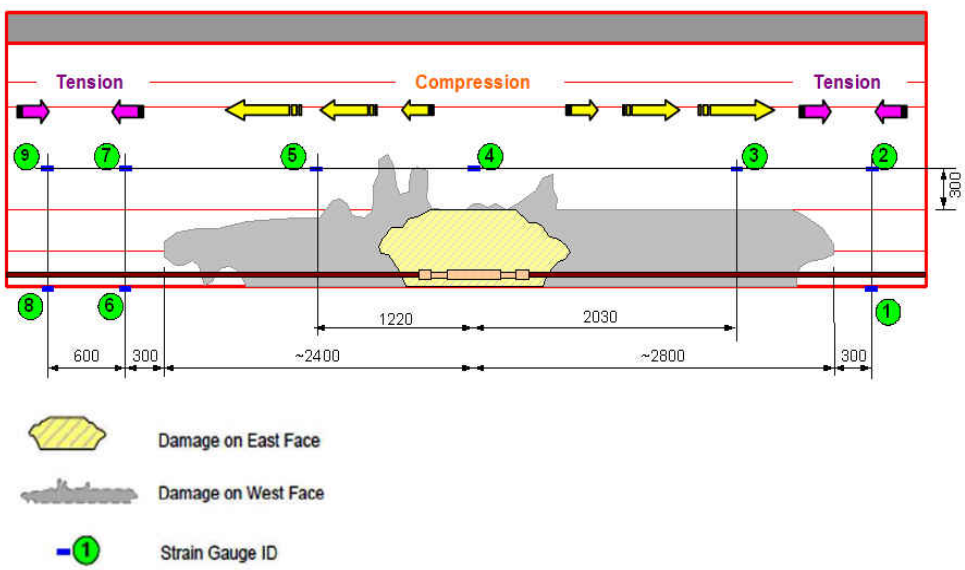

Fig. 19: Effect of Mechanical Coupler Tensioning

The design force for each prestressing strand after all loses was 105 kN. The prestress in the strands was checked by measuring the elongations, which were close to calculated values. Due to the variability of the two measured results, the final force in the strands is estimated to be between 60% and 90% of the design force. Since the three broken strands in each girder represented less than 10% of the total number of strands, this was considered acceptable.

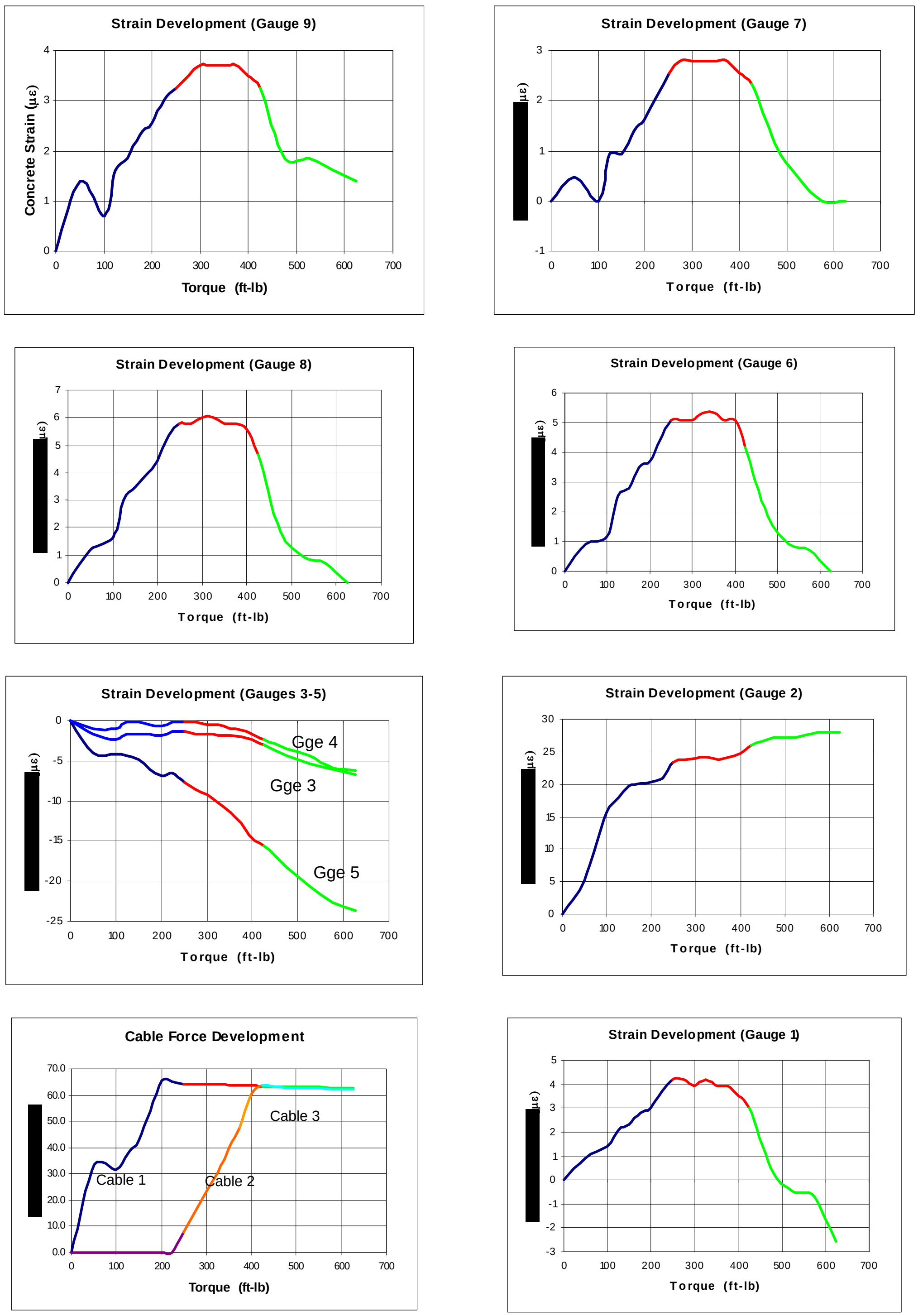

Fig. 20: Concrete Strains and Strand Forces

REPAIR SEQUENCE

Following the tensioning of the mechanical couplers, the bridge deck was pre-loaded with concrete blocks at midspan of the three damaged girders. The purpose of the pre-loading was to introduce residual compression into the concrete girder repairs under dead load. A total of 18 tonnes (6 tonnes over each damaged girder) of concrete blocks were placed on the bridge deck. The pre-loading was maintained on the deck until concrete repair of the damaged girders was completed and the SCC used for the repairs had attained a minimum compressive strength of 20 MPa. After the concrete pre-loading blocks were removed, cracks in the girder webs were injected using an epoxy resin, followed by the application of the CFRP repair system.


Fig. 21: Tensioning Mechanical Couplers


Fig. 22: Preload on Bridge Deck


Fig. 23: Completed Repairs

PROJECT SUMMARY

A suite of innovative techniques well matched to the project's needs and a collaborative relationship between ministry staff, the consultant and the contractor allowed the project to be completed in a short duration of four weeks for a total cost of CAD$322,000. The selected innovations met the project goal of repairing the damaged girders, improved the speed of repair and significantly reduced costs when compared to girder replacement. With the experience and knowledge gained from this project, we anticipate that in the future, similar repairs will be completed in less time and at a lower cost.

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