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CENTRAL LRT STATION REHABILITATION IN EDMONTON, ALBERTA

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Abstract: Opened in 1978, the station structure, located directly underneath Jasper Avenue, Edmonton's major artery, consists of precast pre stressed concrete cross beams supported by L-beam edge girders. The structure has been leaking from the road surface and vulnerable to decades of chloride attack from the road salts used during prolonged winter road clearing operations. A study performed in 2008 found that the two major concrete L-beam support girders, spanning over 200 m each, supported by a series of concrete piles, were corroded at the bearing seat. The pre stressed concrete beams which the girders were supporting, and which were ultimately supporting the roadway, were found to have been affected to a lesser extent and were rehabilitated using CFRP wrap. The corroded bearing seat of the L-beam was relieved of the load from the pre stressed concrete beams by transferring the load directly to the piles using steel support members installed where such measures were feasible. Shear friction reinforcement was used to transfer the load directly from the cross-beams to the areas of concrete L-beam that were unaffected by chloride attack and where steel columns were not practical to install.

The rehabilitation of Edmonton's Central Light Rapid Transit (LRT) Station required the use of adaptive design approaches to overcome substantial existing special restrictions, co-ordination to ensure that a multi-disciplined team approach was ultimately successful and that the station could maintain full functionality during construction. A sustainable approach to the design was implemented to ensure that the work completed would help sustain Edmonton's infrastructure for generations to come.

1 INTRODUCTION

The Central LRT station is an underground station located in the east side of the downtown of the City of Edmonton below Jasper Avenue between 100th St and 102nd St. Originally constructed in 1977, it has a total length of approximately 200 m. The station structure consists of two levels; a platform level and a concourse level. At platform level, approximately 500 tangent piles, each with a diameter of just over 1.0 m and placed side by side forming the perimeter of the structure. At concourse level, piles spaced at 5.2 m extend upwards to support the roof structure. In the absence of the tangent piles steel sheet piles are placed to retain the earth. The roof structure consists of 164 precast pre-stressed concrete FC type (inverted U) cross beams. These beams are 18.6 m long and supported on the north and south sides of the station by longitudinal L-shaped concrete girders. Above the station roof, the concrete beams supported 700 mm of roadway structure consisting of 200 mm of reinforced concrete, 400 mm of fillcrete, and 50 mm rigid insulation and asphalt 'vapour barrier.'

After 20 years in service, the structure was experiencing water leakage problems, and so in 1997 a leakage control program was undertaken and the structure was partially repaired. A study conducted in 2007, however, showed that a more comprehensive repair strategy was required in order to address the leakage and structural deterioration of the station.

After various options were considered during pre-design, including a post-tensioning option which was ruled out due the requirement of this option to completely close Jasper Avenue during construction, it was decided that the design would consist of replacing the existing roadway with a 200 mm thick HPC concrete roadway slab reinforced with stainless steel reinforcement, a layer of 50 mm thick rigid insulation, and a variable thickness (100 mm minimum) topping slab, also HPC and reinforced with stainless steel) cast integral with the station cross-beams.

The station structure itself was also in need of rehabilitation. Most notably, the bearing seats of the L-shaped girders were corroded and were no longer structurally sound. The cross-beams and piles, however, were still structurally sound, and therefore a rehabilitation option, as opposed to a complete replacement which would have been very costly, was deemed feasible. The rehabilitation measures are described below.

2 STEEL COLUMNS AND BEAMS

The loads on pre-stressed concrete cross-beams were calculated using the latest edition of the Canadian Highway Bridge Design Code (CSA-S6-06). Analyzing the station superstructure as a 5 lane bridge deck, and applying appropriate lane modification factors and Dynamic Load Allowances, and using an Alberta standard CL-800 vehicle, the reaction, under the worst case scenario, was calculated at approximately 1100 kN. As it had been determined that the concrete in the bearing seats of the L-shaped girders was no longer sound and could therefore no longer be counted on to carry this load, different methods of transferring this load to the concrete piles below the station's concourse level had to be found.

The most direct method to accomplish this goal was to place Hollow Structural Section steel columns directly below two adjacent beam legs and grouting it into place. The load would then be taken up by the thickened concrete beams in the concourse floor deck and transferred to piles, effectively relieving the L-shaped girders' bearing seats of any structural requirements. HSS 152 x 152 x 13 columns were sized as they had capacity for the required load, steel plates were welded onto each end so the they could then be grouted into place both at the top and bottom. The bottom plates were then anchored into the concrete below. See Figure 1 for typical column design.

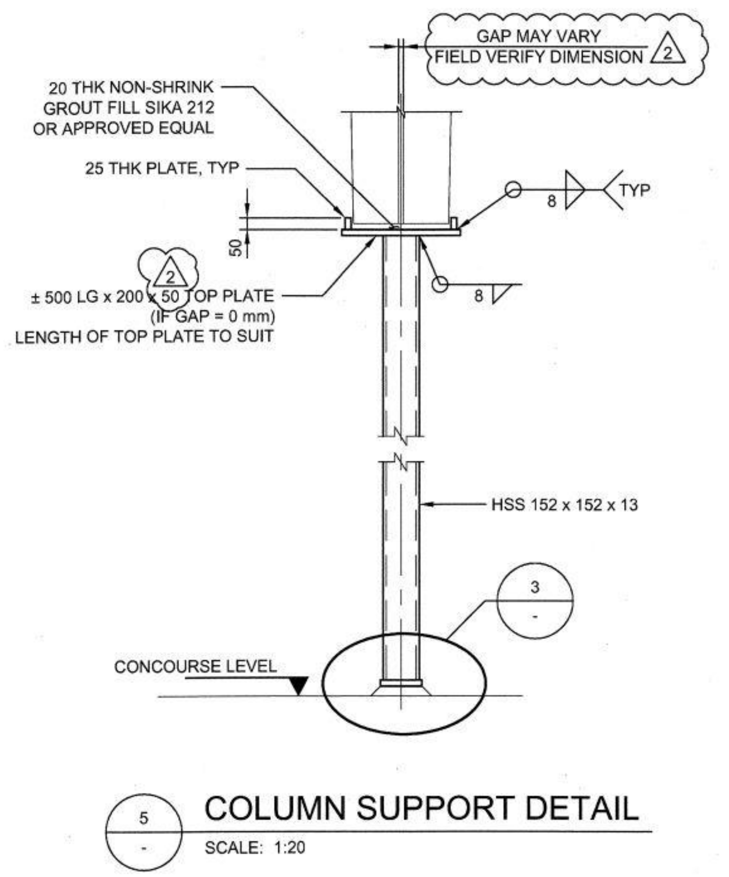

Figure 1: Typical column design

While this approach worked to support the majority of the beam legs, there were instances where locations where one or two columns could not be placed adjacent to each other. Reasons that columns could not be used in these locations included interferences with doorways from the main concourse to the service area where the columns were placed, as well as directly in front of the concrete piles where there was no thickening in the concourse cross-beams and punching shear through the 190 mm floor deck was shown to be a concern. In these locations, the HSS members were increased to 254 x 152 x 13 columns and the area where columns could not be placed were spanned by W 610 x 101 were placed at the top of the columns and below the pre-stressed concrete beams, thus supporting up to 3 sets of beam legs. See Figure 2 for beam and column design.

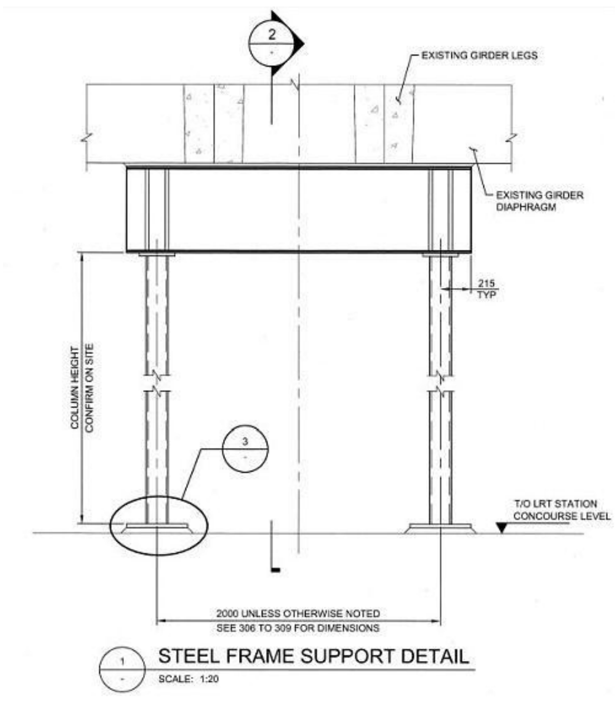

Figure 2: Beam and column design

3 SHEAR FRICTION REINFORCEMENT

While the combination of steel columns and steel column and beam systems worked to relieve the structural requirements of the L-shaped concrete girder bearing seats throughout most of the station structure, there were locations where this solution was simply not viable. These areas included entrances into the station and locations where there simply was no thickening in the concrete floor below. At the entrances, columns spaced every 1.2 m would not only be an inconvenience to those using the LRT station, but would also be a violation of the Alberta Building Code for fire exit requirements., and as discussed above the 190 mm floor slab where there was no thickening would fail in punching shear around the column base plate were the column fully loaded. At these locations, the spans between where columns could be placed were 5.1 m, and so a beam and column system was deemed impractical. An alternate design was required.

As the corrosion in the L-shaped girders was primarily in the bearing seats, and the vertical legs were inspected and deemed structurally sound, shear friction connections were designed using section 11.7 of the ACI 318-11 Building Code Requirements for Structural Concrete. Capacity for these connections was calculated using equation 11-23.

$$V_n = A_{vt} f_y \mu \qquad \text{[Eqn 11-23]}$$

Where: A_{vt} = area of shear friction reinforcement, mm^2

f_y = yield strength of reinforcement, MPa

μ = coefficient of friction

For each pre-stressed concrete beam which required this type of support, 9 holes would be drilled through the beam's diaphragm and into the leg of the L-shaped girder behind. 25M reinforcing bars would then be grouted into place in the holes using non-shrink grout, thus transferring the load from the pre-stressed beam into the girder and by-passing the corroded concrete. Stainless steel reinforcing bars were used in order to mitigate any potential future corrosion. See Figure X for the shear friction reinforcement design.

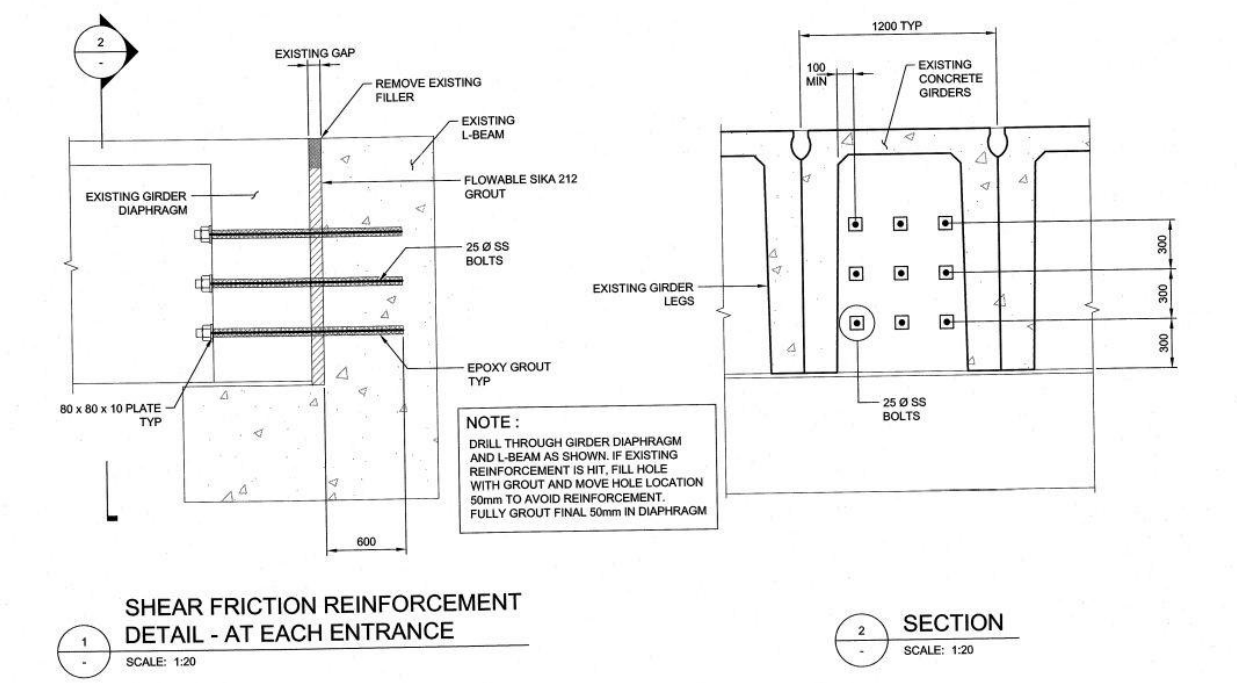

Figure 3: Shear Friction Reinforcement

4 CARBON FIBRE-REINFORCED POLYMER (CFRP) WRAP

A preliminary inspection performed prior to the commencement of work, when access to the space above the station ceiling was limited, noted that the pre-stressed concrete beams which support Jasper Avenue were for the most part structurally sound and free from the corrosion noted in L-shaped longitudinal girders. When the station ceiling was removed during construction and a more detailed inspection could be performed, however, 15 locations were noted where the concrete had deteriorated and the pre-stressing steel strands were exposed. To rehabilitate these areas, all delaminated concrete was removed and the surfaces were properly prepared in order to accept the bonding agent for the SikaWrap Hex 113C Bidirectional CFRP wrap to be applied. The lengths of cracks repaired varied from 0.2 m to 8.0 m. See Figure 4 for the Carbon Fibre wrap design detail.

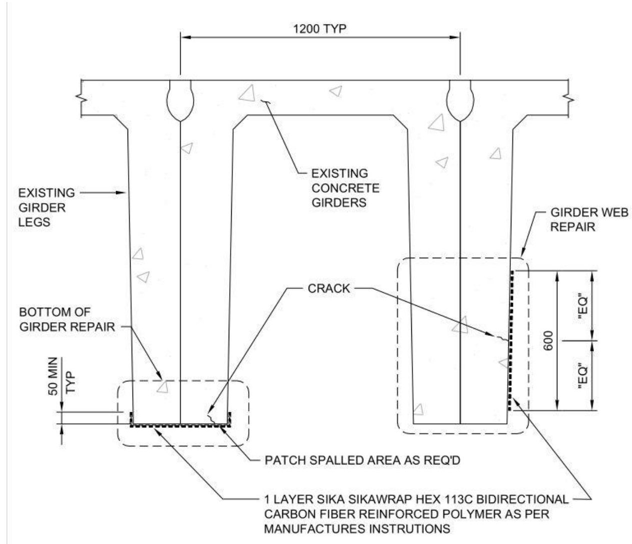

Figure 4: CFRP Wrap

5 ROADWAY

The roadway above the station structure, completely replacing the existing, was designed as a 200 mm thick reinforced roadway slab, a 50 mm thick layer of rigid insulation, and a variable thickness (100 mm minimum) concrete topping slab crowned at the centre-line of Jasper Avenue. The topping slab was made integral with the pre-stressed station roof beams by fully roughening and wetting the top surface of the cross-beams prior to pouring the topping slab, as per CSA-A23.1 specifications. Making this slab integral with the existing structure increases the capacity of these beams thus prolonging the service life of the station.

In keeping with the City of Edmonton's Vision 2020 strategic initiative and the City's commitment to sustainable design, the concrete for both the topping and roadway slab were specified as 45.0 MPa HPC concrete and the reinforcing steel was specified as stainless steel. The heightened requirements for the materials used on this project ensure maximum protection against corrosion, a protection especially necessary given that Jasper Avenue is the major traffic corridor of downtown Edmonton. In addition, a waterproofing membrane between the topping concrete and the rigid insulation layer ensure that the station itself is completely protected from the run-off of any surface water.
Please see Figure 5 for a detail of the roadway design.

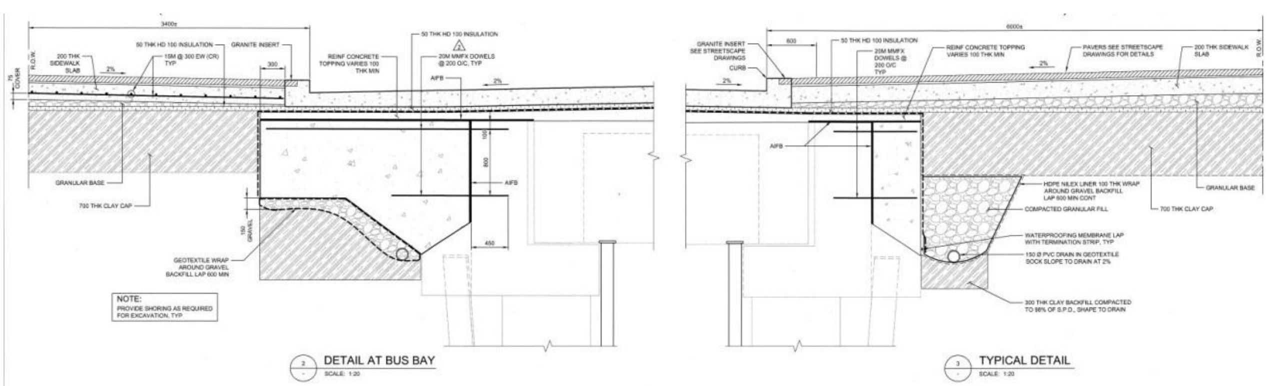

Figure 5: Roadway design detail

6 SUMMARY AND RECOMMENDATIONS

Similar to any other rehabilitation project, the design for the Central LRT Rehabilitation project was limited by several constraints that were inherent with the existing location. One of these considerations was limited space in the service area where the pre-stressed beams were supported by the longitudinal L-shaped girder. This limited access was taken into account when choosing to support the beams with new HSS columns, as they were slender enough to fit in the designated areas. As well, the station had to remain open to the public throughout the duration of the project, with only limited closing during night hours, which meant that sequencing was especially important. Furthermore, in keeping the City of Edmonton's Vision 2020 strategic initiative, the had to provide a long term and sustainable solution. To account for this, the design not only re-established the original design capacity of the structure, but also strengthened it. Use of materials such as HPC concrete and stainless steel reinforcement also increased the life-span of the station, and fully waterproofing the station ensured that further rehabilitation will not be necessary for years to come. A variety of design approaches were utilized to address individual project requirements and challenges, and in the end the people of Edmonton are left with a downtown station that can be used by generations of residents.

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