# Replacement of a Timber Trestle with an MSE Retaining Wall System
# CN Rail, Yale Mile 118.93 Trestle Replacement

## Innovative use of MSE and Staged Construction Techniques

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**Paper prepared for presentation**
**at the Innovations in Bridge Engineering(A) Session**

**of the 2005 Annual Conference of the**
**Transportation Association of Canada**
**Calgary, Alberta**

## ABSTRACT

This timber trestle caught fire in the early 1990's. The structure required replacement due to subsequent deterioration over time, coupled with ever increasing rail demands. Canadian National (CN) had to ensure minimal rail disruptions during replacement of this section of mainline, with upwards of 40 trains per day.

This paper will discuss the innovative approach adopted by CN using Mechanically Stabilised Earth (MSE) to replace the ageing structure, and support the overhead rail. The project was challenging from the construction and staging perspectives. Canadian Pacific (CP) and Front Street were located immediately parallel to each side of the trestle. Construction was further complicated by limited headroom as MSE panel placement proceeded directly below the existing trestle deck.

The MSE system selected was Reinforced Earth®, designed and supplied by the Reinforced Earth Company Ltd., and consisted of precast facing panels, inextensible steel reinforcement, and precast coping. Precast MSE panels were placed around the timber bent structure. MSE panel placement then proceeded upward, and as close to underside of deck as practical. CN opted to finish panel placement/backfill at the top of wall during two separate track closures work blocks. The first was for 12 hours and the second was for 18 hours. The timber pile cap, deck, and rail were removed by crane. The removal of the deck enabled CN to complete the top of wall placement, and resume backfilling by more conventional backfill techniques. The rail was re-installed by use of jointed rail sections. The precast coping was placed atop the wall and handrails completed. The mainline was back in service being fully supported atop the MSE wall. Construction commenced in January of 2004, and was substantially completed in May of 2004. MSE provided a successful staged construction solution, while allowing CN to maintain safe rail traffic throughout the construction corridor, during the entire course of structure replacement.

This paper will illustrate the technical considerations of using MSE, along with the various construction stages, and safety considerations associated with this project.

## INTRODUCTION

Canadian National Railway (CN) required replacement of this timber trestle at Mile 118.93 of the Yale Subdivision. The structure had been damaged by fire during the early 1990's. Fortunately, prompt action by local fire forces resulted in minor damage to the trestle. Fire damage, coupled with deterioration over time, along with increased rail demands prompted CN to make the decision to replace the timber structure. The overall structure replacement was comprised of three distinct phases as follows:

i) MSE approach / false abutment walls to support heavy rail.
ii) CN Rail over Front Street Bridge deck replacement.
iii) Precast lagging wall c/w soil anchor's.

This paper will feature the details associated with MSE component of this structure replacement.

The site is located along the West Bank of the Fraser River in the City of New Westminster (Greater Vancouver, BC). The trestle forms part of CN's approach to the West End of the Fraser River Rail Swing Bridge, and the trestle provides the necessary approach grade to the Swing Bridge. Refer to figure 1 for the overall site location.

The trestle forms an integral part of CN's mainline. The track at this location often carries 35 to 40 trains per day (comprised of four different freight and passenger lines). The majority of this rail traffic often bound for the busy Port of Vancouver.

CN initially considered a variety of options. It was decided by CN/UMA Alliance to use an MSE System designed and supplied by Reinforced Earth Company Ltd. (Reco).

## CHALLENGES TO CONSIDER

A number of challenges became immediately apparent when considering this structure replacement.

The rehabilitation was challenged by constricted access (Figure 2). The CN mainline was directly overhead during MSE wall construction. Immediately adjacent to the trestle (along the east / riverside) is Canadian Pacific Railway (CP) mainline at grade. An elevated rapid transit line (Millennium Line) is located immediately East of the CP line. Immediately to the west (landside) of the trestle is Front Street. Front Street is a busy primary commercial traffic bypass route for the City of New Westminster often carrying commercial truck traffic. Construction access was severely constricted by the close proximity of adjacent facilities. The construction phase was further complicated by two active rail lines (CN & CP) throughout the entire course of construction.

The nature and location of this project posed three primary constraints on the design. Firstly, that rail traffic must continue to use the track on an hourly basis. Secondly, that the construction access was severely limited by the close proximity of the CP line and Front Street. Thirdly, the timing of staged construction had to be carefully planned, executed, and achievable in the field.

CN could not have the rail removed from service for any significant length of time. To further add to the challenges, total road closures were not an available option along Front Street.

The structure could not encroach onto neighboring properties and needed to be confined within the out to out distance of the existing trestle.

Distances between timber bents of approximately 12 feet apart in the rail direction, and comprised of 12" timber piles of 12" × 12" timber posts (Photo A). Any structure component locations required careful design and planning to avoid the vast array of timber bents.

At the approach to the owner's rail over road bridge deck (Front Street), the wall would encase the H Pile Arrangement (supporting the bridge seat).

A staged construction method was required to allow CN crews flexibility on site. The field crew had to accommodate changing rail schedules without delay on the CN and CP lines.

The solution needed to allow for the transition between newly supported rail sections and those still being supported on the trestle being replaced. The installation had to allow CN to place any one section of jointed-rail (39-ft section) at any one time.

The structure had to accommodate Cooper E 90 loading, and to tolerate the anticipated settlement of 25 mm. Another challenge on this project was the presence of poor foundation soils immediately under the location where the wall was to be founded.

## THE SOLUTION

The solution selected was back to back MSE walls. The system used was Reinforced Earth® designed and supplied by Reinforced Earth Company Ltd. (RECo). The face to face distance between walls was 5.380 m.

The MSE system was erected while rail traffic continued overhead on CN's mainline. MSE construction was successfully completed with limited vertical clearance beneath the trestle for the majority of construction. To maintain movement of rail traffic at all times, the trestle deck / mainline could not be removed, until the final top of wall panels were completed, and the new rail re-instated.

CN opted to construct the MSE wall system with it's own bridge & maintenance forces. Reco provided technical guidance to the CN's work forces during the installation of the MSE approach and abutment wall. CN also utilized local suppliers to assist with aggregate supply, precasting, backfilling, pile driving, and associated crane lifts necessary for the final installation of rail sections.

The MSE portion of this work was comprised of:

Precast facing (977 $m^2$)

Precast coping c/w handrail + safety refuge barrel (187 Lin m)

The MSE system consisted of precast facing panels, inextensible (steel) reinforcing strips, and hardware (Figure 3). This composite structure resulted in a strong versatile material created by the frictional interaction of granular soil & steel reinforcing strips. Steel strips and connecting hardware was hot-dipped galvanised to accommodate the 100-year service life for this structure replacement. The wall backfill was comprised of a clean structural backfill ($\varphi = 35\ °$).

Precast facing consisted of smooth form finish, 30 Mpa, air-entrained, and steel reinforced panels. Panels for the MSE wall were 140-mm thick and measured 1500 mm $\times$ 1500 mm when viewed in elevation. A typical panel for this project weighed approximately 1 tonne.

High Adherence steel reinforcing strips were employed due to the critical nature of dynamic heavy rail loads. Strips connected to the back of panel with A325 structural fasteners, connected in double-shear (Figure 4). The MSE system selected allows the strips to be rotated at their bolted connect to the panel. Skew angles to the perpendicular of 20 degrees or less can be used without a change in design. This feature was particularly important at the false abutment location (Figure 5). In areas where soil reinforcement could not be skewed, galvanised angles were utilised to span panel tie strips cast in the back of panels (Figure 6).

A nominal 20-mm construction joint is around the entire periphery of the panel, thus creating an inherently flexible wall. The flexibility of such a wall becomes particularly important under continued dynamic loading, or under a potential seismic event typical of the greater Vancouver region.

Panel joints were lined with filter fabric to retain the soil while allowing the relief of any potential hydrostatic build-up within the retained mass. The filter fabric is further protected from UV Degradation / Vandalism by a shiplap joint on all panel edges. Each panel rests upon two 25 mm elastomeric bearing pad, thus avoiding point loads between facing elements.

The MSE system was placed upon a cast in place levelling pad 300-mm wide $\times$ 150-mm deep. In this application, where settlement is anticipated, it's important to avoid an overly rigid foundation pad. For this reason, the leveling pad is cast with no steel reinforcement. In case of settlement, the leveling pad is intended to displace vertically along with the entire soil mass, and thereby avoiding attracting additional loads/stresses on the connection system.

The optimised panel size (2.25 $m^2$) was selected for this "high performance structure" and was easily positioned with an excavator. The MSE system required very little space from a material storage point of view. The precasting and construction sequence was carefully predetermined by CN and the wall supplier. Materials were produced and fabricated to closely mirror the anticipated construction schedule. Panels were sequenced in staged deliveries to facilitate smooth erection production, but to not excessively tie up the limited storage space at site. The wall was erected from the backside of panel. This allowed CN to stay clear of the adjacent CPR right-of-way during the passage of trains.

## CONSTRUCTION

Panels were placed around the timber bent structure effectively wrapping the trestle, within the MSE volume (Figure 7).

The initial course of panels was placed on the gently curved alignment (Photo A). Since the panel system is comprised of 1500-mm wide panels. Panels were placed in straight-line segments of 1500 mm to approximate the curve required.

One of the biggest concerns was that the wall and backfill could only be constructed to about 1 meter below the deck support. At that point, the rail would need to be taken out of service so the wall could be completed to full height. It was considered using lean concrete to accomplish this phase might be the fastest but later agreed that the MSE construction would be faster and more predictable.

Successive panel courses and backfill lifts were placed to as close to underside of timber deck as practical (Photo B). The existing timber deck and rail were removed by CN's force. Top wall panels were installed. The final lifts of backfill were completed. The rail line was reinstated and again carrying vital mainline traffic (Photos C and D and E).

To assist in the placement of backfill a clean coarse granular material was selected which required a minimal amount of effort to compact and provided high frictional resistance with the soil reinforcement.

A Special precast coping was designed for the top of wall, to accommodate a walkway and handrail along with a safety refuge bay (Figure 8).

The poor foundation soils were addressed in two different ways. The first was my selecting a MSE system that could tolerate differential settlement without distress to the wall. The second was the removal and replacement of the top two meter's of poor soil.

## DESIGN PARAMETERS

Design Codes

AREMA
(Volume 2, Chapter 9, Part 1, "Seismic Design for Railway Structures"
(Volume 2, Chapter 9, Part 7, "Mechanically Stabilized Embankments"
AASHTO – Working Stress Design
Service Life 100 years (based on corrosion)

Metal Loss Rates

a. ZINC (first 2 years) 15 μm / year
b. ZINC (subsequent years to depletion) 4 μm / year
c. CARBON STEEL(after depletion of zinc) 12 μm / year
d. CARBON STEEL(75 to 100 years) 7 μm / year

Loading

Live Load Surcharge 100 kPa
Lateral Load 4.0 kN/m applied at the head of each rail
Allowable Bearing Capacity of Foundation Soil 200 kPa
Allowable Differential Settlement 1% - Long Term 50 mm in 5000 mm (Longitudinal Direction)
Allowable Differential Settlement 3% - Long Term 165 mm in 5500 mm (Transverse Direction)
Min Wall embedment 0.53 m

Soil Properties

RE Backfill
Density = 22 kN/m3
Friction Angle (phi) = 35 degrees
75 mm Max. Well Graded Free Draining Gravel

Reinforcing Strips

$F_y$ = 450 Mpa

Since back filling occurred around the supporting timber piles, the piles when cut-off would permanently remain with the backfill. CN anticipated that the timber piles may deteriorate in the future and that this may cause local loosening of the soil near these piles. Given the MSE system utilized reinforcing strips of continuous, length it was determined that localized loosening / pile decay at some strip locations would not pose a problem to the wall system.

## VIBRATION FROM TRAIN LOADING

Vibrations from heavy trains need to be considered in design. Numerous tests have been conducted Reinforced Earth walls in the United States, Germany, and France where heavy vibrating rollers have been placed directly above R/E structures. The investigation revealed that the vibrations slightly increase the forces in the upper strips. Under dynamic / seismic loading the importance of a strong connection is critical. Hence, the use of an A325 structural fastener connected in double-shear, to ensure a strong panel to soil reinforcement connection.

## NUMERICAL ANALYSIS OF MSE WALL UNDER RAIL LOADING

The engineers at CN Rail and the Reinforced Earth Company recognized the unique nature of this application during their pre-design discussions. Although similar structures had been completed in the United States, there had never been such a narrow MSE embankment constructed, where most of the length of soil reinforcement strips were overlapped with the strips from the wall on the opposite side of the embankment.

The design approach used by the MSE designers was to design the walls on each side of the track independently, assuming no effect from the opposite wall or its overlapping soil reinforcement. It was felt that this assumption would be generally conservative but the Flac analysis would be used to verify this assumption. The base design was performed using the MSE Company's proprietary program, Valdez that is a limit state, local equilibrium program.

Once the base design with Valdez had been completed the designers requested a Numerical Analysis of the walls to be carried out by their technical research department, (Soil Tech), in Nozay, near Paris, France. Under the direction of N. Freitag, K. Silveria performed the analysis using the finite difference program, FLAC (Fast Lagrangian Analysis of Continuum). FLAC version 4.0 was used with a two-dimensional plane-strain mode.

## MODEL

The model used represented 6 m high, "back to back" embedded walls 5 m apart with 4.5 m long soil reinforcement overlapped for most of the length as shown in Figure 9.

The vertical spacing of the soil reinforcement was 0.75 m with two strips at every level, one attached to the right panel and the other one attached to the left panel. There are four basic types of material modeled: foundation soil, reinforced soil backfill, ballast, and rail (see Figure 10).

In addition to the four materials above, three structural elements were used in the model: concrete panels, steel reinforcing strips and rubber pads, which are in the horizontal joints between panels. These rubber pads form a crucial part of an MSE wall since they allow the facing to "compress" under vertical loads that occur especially on high walls or highly loaded walls. The steel strips were modeled using FLAC's "cable elements". See Figure 11.

## ANALYSIS

Modeling of the wall's construction was approximated by inserting backfill layers 0.75 m thick, one at a time. The simulation of compaction was achieved by the application, then subsequent removal of a 10-kPa live load surcharge. After all phases of backfilling had been simulated two different, permanent live loads were applied. The first case was a 100 kPa applied over the width of the rail ties. The second case had no live load but two line loads of 113 kN per meter per rail. Both of these were used to represent a Cooper E 90 load.

## RESULTS

Results of the two loading cases were similar so only, the 100 kPa loading case is presented here.

Displacements shown on Figure 12 indicate a maximum vertical consolidation of 35 mm estimated near the base of the wall. As this zone is inside the MSE volume much of this consolidation will occur as the wall is being built. The estimated consolidation at track level is only 15mm. Observation and post construction monitoring indicates that the actual settlement was not any more than the amount predicted by Flac.

Also of interest is that the surcharge from the wall and train has negligible affect on the adjacent land use of Front Street/CP Rail line.

Of most interest in this study were the axial forces in the soil reinforcement shown in graphical form in Figure 13. As can be seen in Figure 14, the values for which the walls were designed, with the Valdez program, are generally conservative when compared to the values obtained by the more rigorous FLAC program.

## CONCLUSIONS

This is the first instance of an MSE wall directly supporting a permanent heavy rail application in Canada.

This MSE wall system proved a viable staged construction solution. More importantly, it allowed the client (CN) to maintain safe rail traffic throughout the construction corridor, during the entire course of existing timber structure replacement.

## ACKNOWLEDGEMENTS

UMA Engineering Ltd. and BGC Engineering Inc. for their design input to the project.

Con-Force Structures Ltd. for the precasting of the concrete facing panels.

CN for the invaluable input throughout the design and construction phase.

All of the CN work forces who performed an excellent job in the execution of the wall under challenging conditions.

## REFERENCES

K. Siveira, and N. Freitag, *Numerical Simulation of Trestle Replacement Project with FLAC* SOILTECH, Terre Armee – Departement R & D.

T. Evans, *Information Package Yale Mile 118.93 Trestle Replacement Retaining Wall and Earthwork Design Options*, Canadian National Railway, Pacific Division Engineering, Edmonton, Alberta

Reinforced Earth Valdez Design Method

Reinforced Earth Structures for Railway Applications

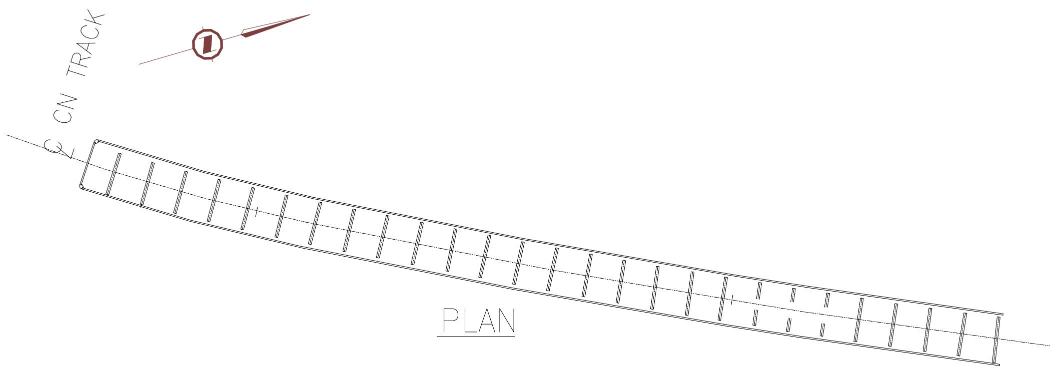


**Figure 1:** **General arrangement of MSE approach walls.**

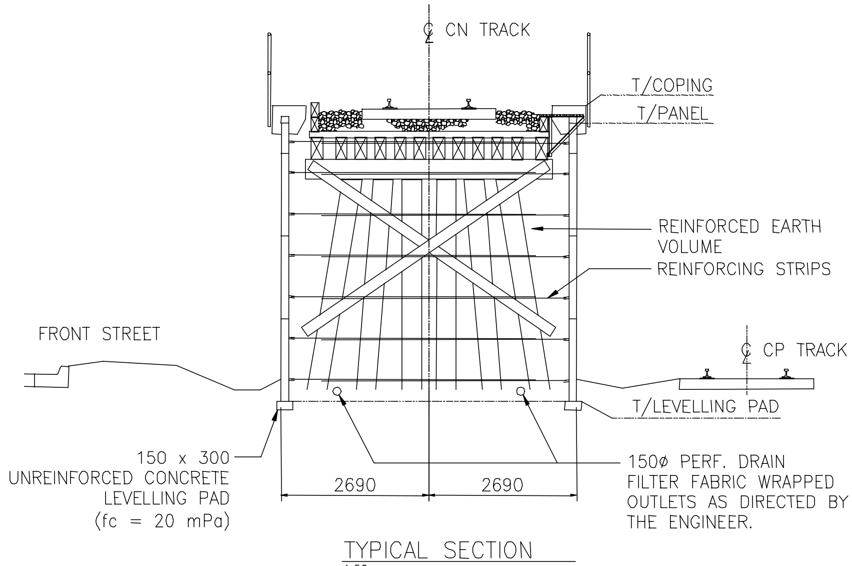


**Figure 2:** **Illustrates the close proximity of Front Street, and CP track to the proposed MSE wall construction. Also of interest is the extensive array of timber piles transverse to the rail direction. Note the narrow back-to-back MSE walls in this view.**

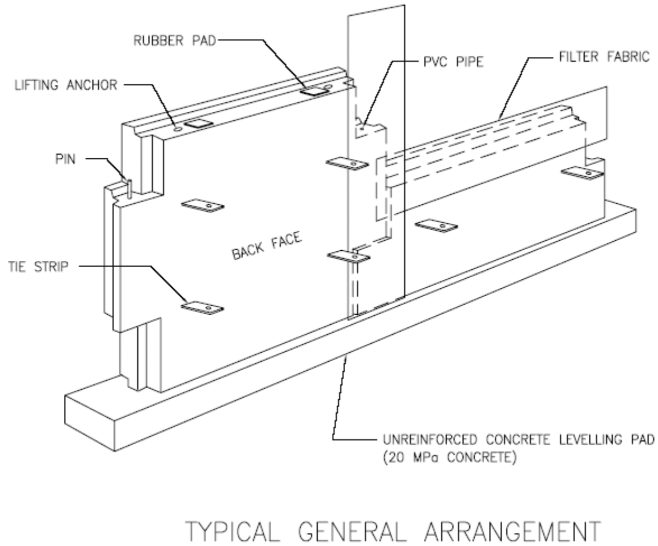


**Figure 3: Typical MSE panel detail c/w bearing pads, filter fabric, and tie-strips.**

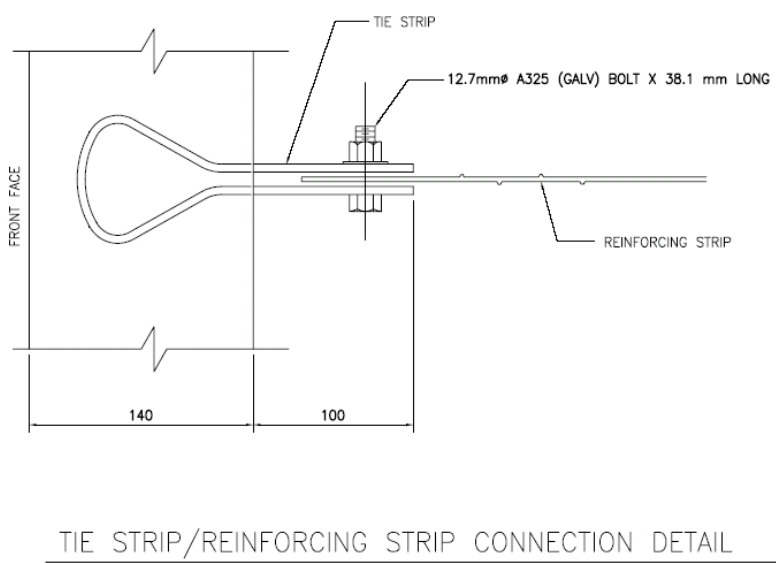


**Figure 4: Panel to soil reinforcement connection A325 fastener (in double- shear).**

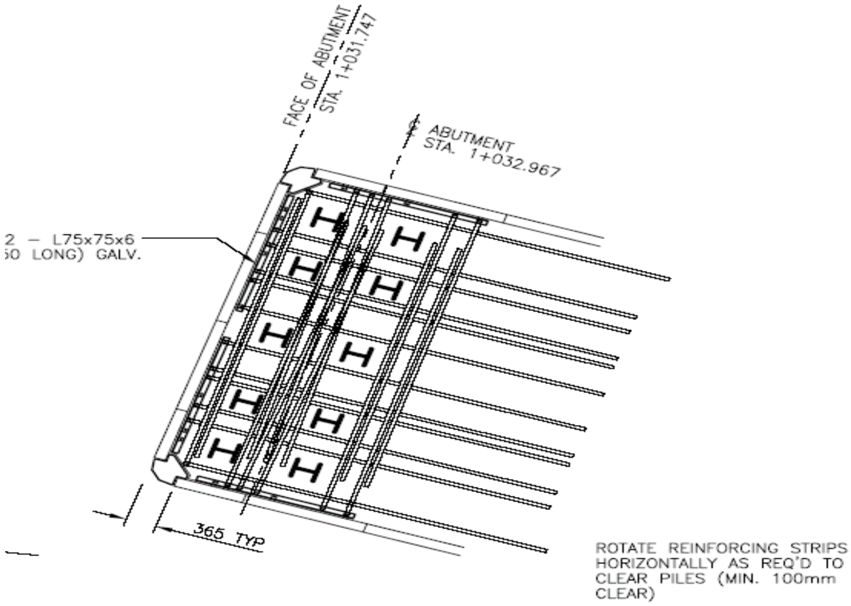


**Figure 5:** **Plan detail at abutment. Reinforcing strips required careful design/skewing to avoid the H Pile arrangement at the false abutment location.**

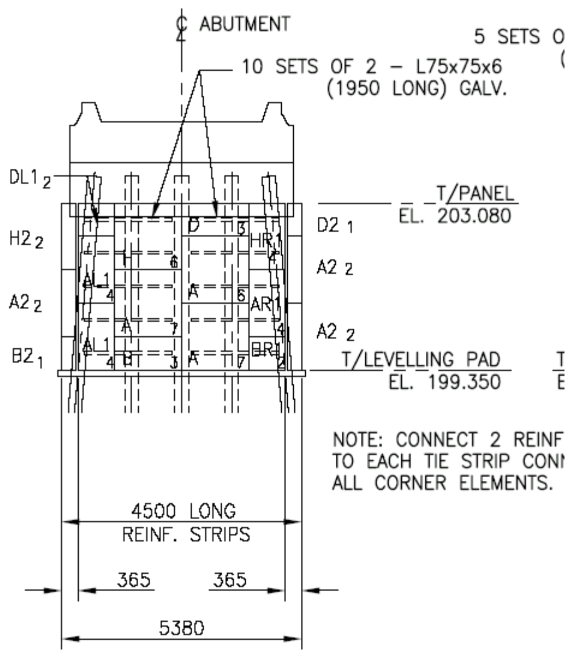


**Figure 6:** **Galvanized angles (1950 long) were used to span locations where soil reinforcement could not be directly connected to the panel tie strips.**

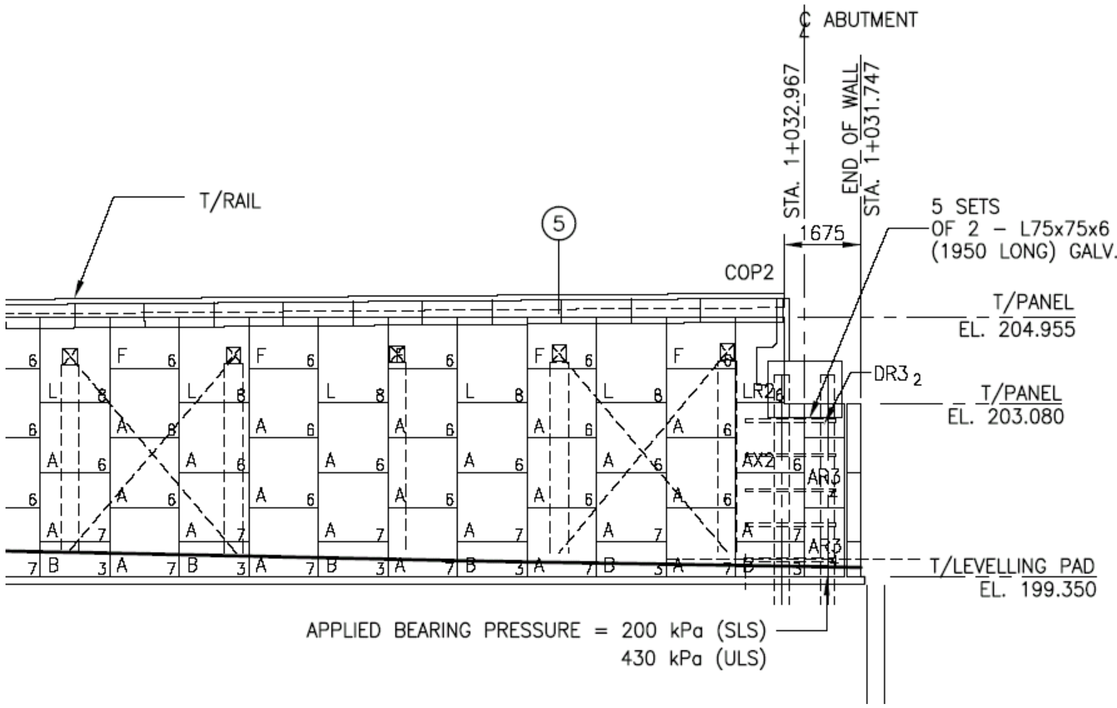


**Figure 7: MSE panel elevation projected onto the existing pilings.**

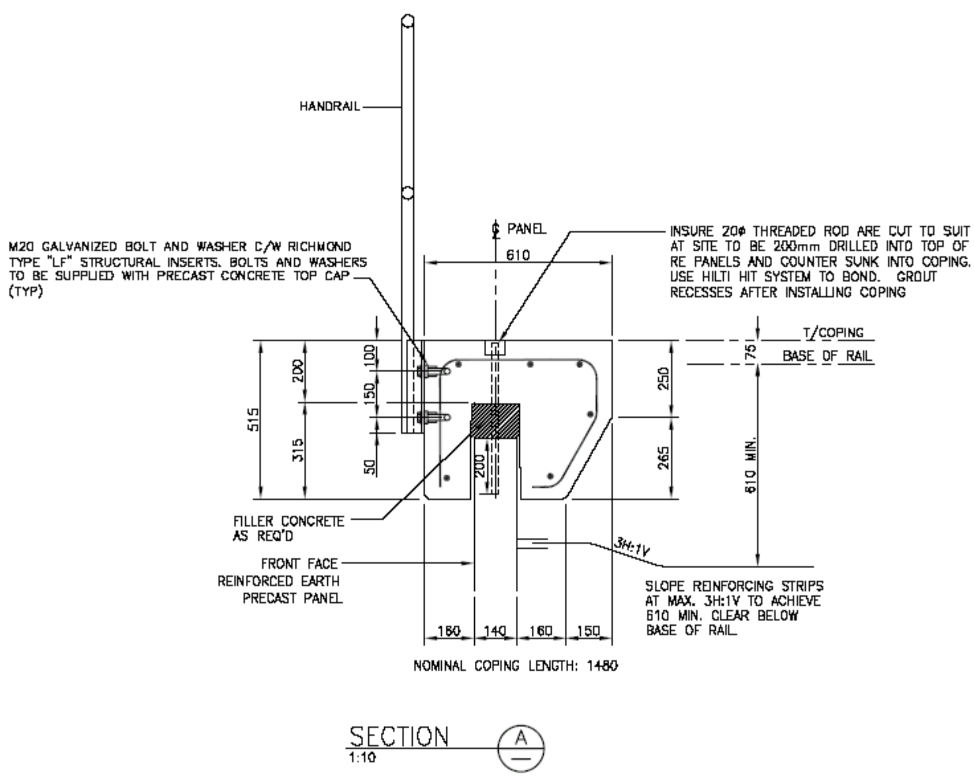


**Figure 8: Special precast coping detail c/w handrail.**

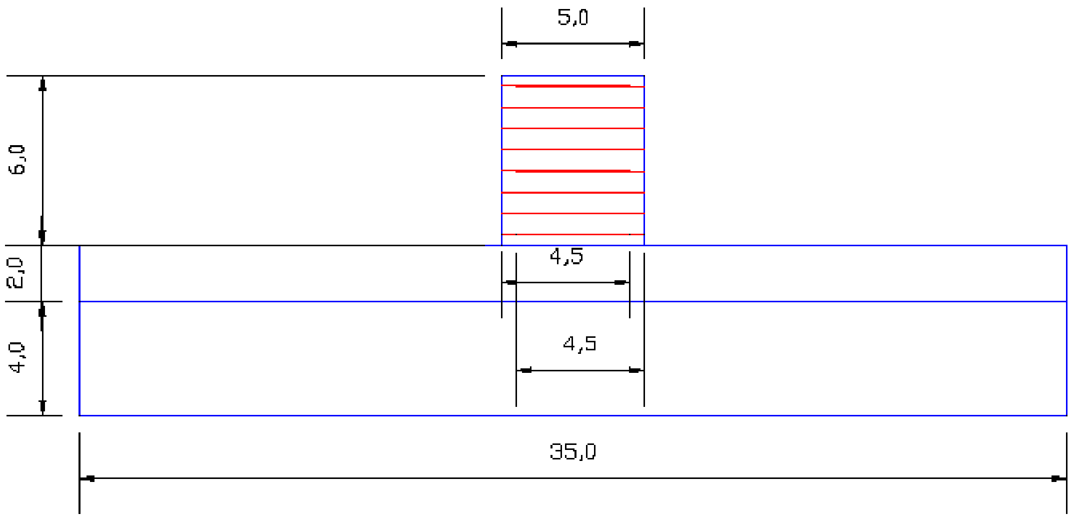


**Figure 9: Geometry of Model.**

| | Foundation Soil | Reinforced Backfill Soil | Ballast | Rail |
|---|---|---|---|---|
| Type | Mohr-Coulomb | Mohr-Coulomb | Mohr-Coulomb | Elastic |
| Young 's modulus(MPa) | 25 | 50 | 100 | 1000 |
| Poisson's ratio | 0.3 | 0.3 | 0.3 | 0.2 |
| Density (kg/m $^3$) | 2000 | 2200 | 2200 | 2500 |
| Cohesion (kPa) | 0.001 | 0.001 | 0.001 | - |
| Friction angle (°) | 34 | 35 | 45 | - |
| Dilation (°) | 0 | 0 | 0 | - |
| Tension | 0 | 0 | 0 | - |

**Figure 10: Material Properties.**

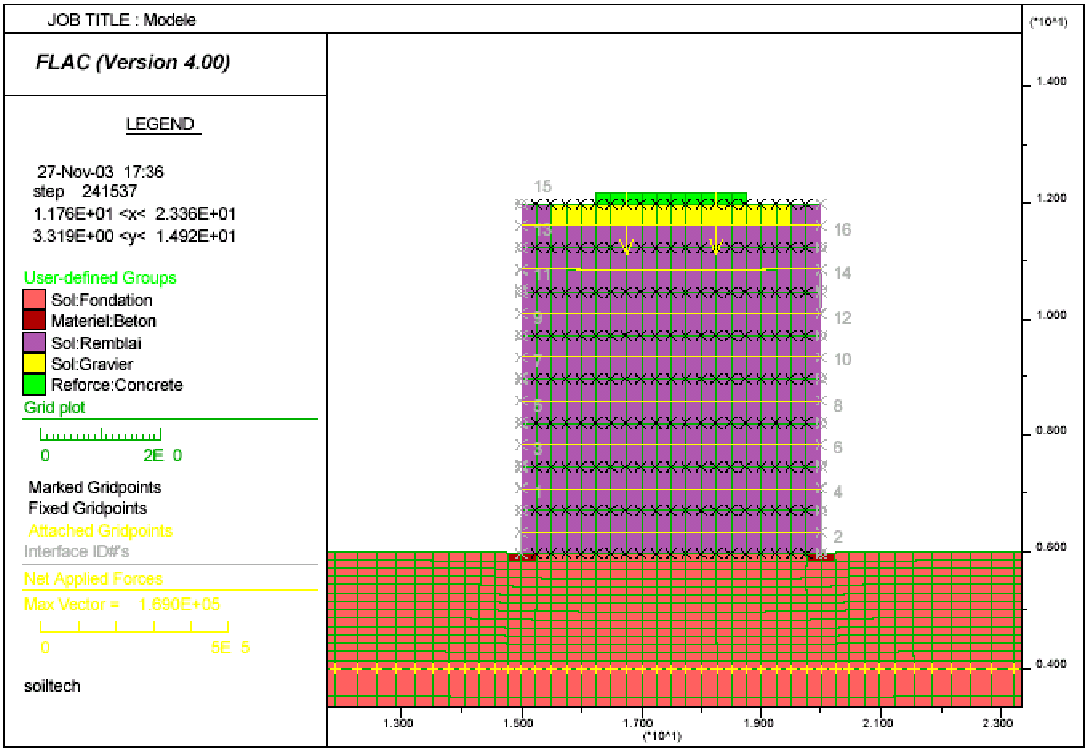


**Figure 11: Elements of Model.**

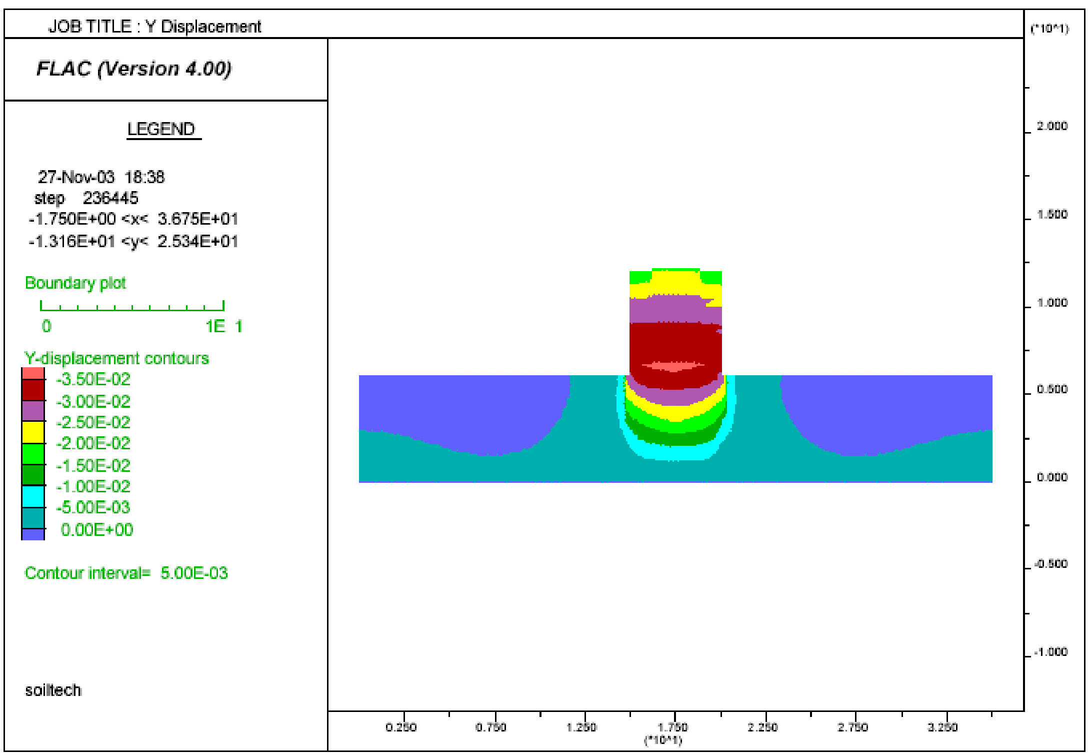


**Figure 12: Vertical Displacements.**

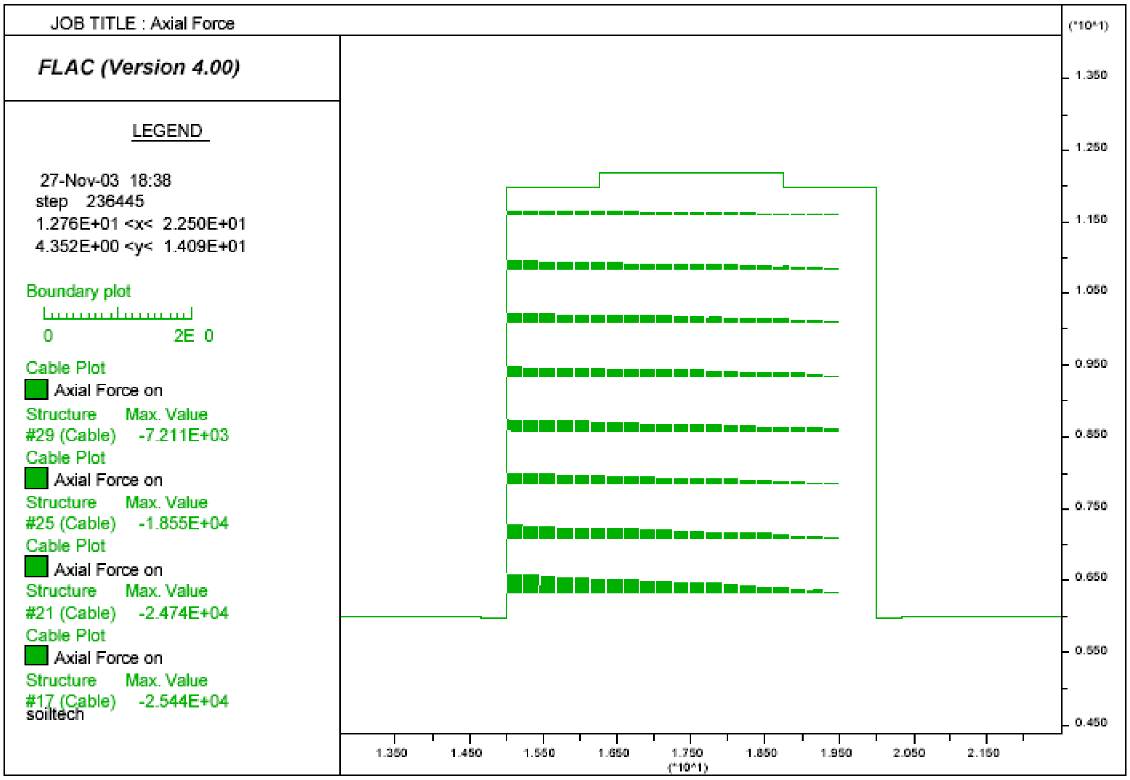


**Figure 13: Tensile Force in Strips.**

| | Axial Force per Strip (kN) | |
|---|---|---|
| Layer - Depth (m) | Single Precision - FLAC | Valdez |
| 0.375 | 4.33 | 12.49 |
| 1.125 | 11.13 | 14.16 |
| 1.875 | 12.37 | 15.19 |
| 2.625 | 12.72 | 16.78 |
| 3.375 | 13.63 | 18.23 |
| 4.125 | 14.00 | 19.51 |
| 4.875 | 14.63 | 17.69 |
| 5.625 | 20.95 | 18.79 |

**Figure 14: Comparison of Tensile Forces**

**Photo A:** **Installation of initial panel course next to CP mainline. Note the array of closely spaced timber bents in this photo.**

**Photo B:** **The panels approach the underside of timber deck and construction headroom becomes limited. The overhead Millennium line is shown on the left. Wall construction is immediately adjacent to CP line. An Eastbound "Rocky Mountaineer" tourist train passes overhead.**

**Photo C:** **Westbound CN freight train is just passing over the new deck structure as it Proceeds over the narrow back-to-back MSE walls. The wall is complete at this point with panels, coping, and handrail complete.**

**Photo D:** **Looking westbound along the MSE approach ramps leading onto the rail / road deck at Front Street. The millennium line is seen on the left. Fraser River Swing bridge is seen in the distance.**

**Photo E:** **Looking along CP line at the newly completed approach walls, and false abutment walls.**