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ANCHORED DEEP SOIL MIXED CUTOFF/RETAINING WALLS FOR LAKE PARKWAY PROJECT IN MILWAUKEE, WI

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ANCHORED DEEP SOIL MIXED CUTOFF/RETAINING WALLS FOR LAKE PARKWAY PROJECT IN MILWAUKEE, WI

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Abstract.

The new Lake Parkway had to be depressed below the U.P. RR tracks and St. Francis Ave., which required a cut and cover tunnel/bridge and retaining walls leading into the tunnel section in an area of relatively high groundwater table. An innovative retaining wall solution was designed and constructed utilizing a combination tiedback soldier beam/deep soil mixed (DSM) cutoff wall system with an architectural concrete facing. The RR bridge abutments were value - engineered for a continuation of this same solution, with the pile-supported abutment wall footing carrying the vertical bridge loading and the tiedback soldier beam/DSM cutoff wall supporting all of the lateral loading.

Introduction

The proposed Lake Parkway (STH-794) alignment will extend a distance of approximately 4.8 km from the existing terminus of Interstate Highway 794 to E. Layton Ave. along north side of General Mitchell International Airport. The roadway is designated a limited access urban arterial and will be a four-lane divided highway with an intersection or interchange at each 1.6 km. The project will follow an existing railroad corridor.

Wisconsin D.O.T. Contract I.D. 1300-04-82 is for a cut and cover tunnel at St. Francis Ave. in the City of St Francis, as part of the construction for the Lake Parkway project to allow for the Parkway to be depressed below the at grade crossing of St. Francis Ave. and the Union Pacific Railroad Kenosha branch line. Retaining walls are necessary along each side of the parkway in this area to maintain the U.P. RR on the west side and the residential properties on the east

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side along South Ellen St. The walls will be approximately 7.6 m high at St. Francis Ave. and approximately 0.9 m high, 458 m north and 305 m south of St. Francis Ave.

In this area, the ground water table is only about 2.4m below the existing ground. Therefore, in order to construct and maintain the tunnel and prevent any draw down on the adjacent properties, the ground water has to be permanently cut-off from entering the roadway.

The entire 824 m project length and perimeter will be enclosed with a continuous permanent ground water cut-off wall (total 1723 m). The five permanent tied-back retaining walls (total 1391 m) will serve the dual purpose of both retaining and cutoff walls. Conventional RR Bridge abutments (total 180 m) supported on driven pipe piles were intended to be utilized for the tunnel.

Subsurface Conditions

The site is underlain by layers of silt, silty clay, clean or fine sands, to depths of 4.6 to 18.3 m below existing grade. Underlying these upper layers are stiff to hard silty clay/clay silt with interbedded layers of medium dense to dense silty sand and silt. Groundwater is typically at a depth of 2.4 m. below the ground surface.

Contracting Procedures

The project was let in August 1996 with the tiedback cutoff/retaining walls on a design-build basis by preapproved specialty contractors. Preliminary designs were submitted and approved by WI DOT. A driven steel sheetpiling system was not allowed because of concerns about noise and vibrations affecting adjacent residential areas.

Design

In order to satisfy the project requirements, it was decided to use a deep soil mixed (DSM) wall as the groundwater cutoff system, with tiedback or cantilevered steel soldier beams with a cast-in place reinforced concrete facing for the permanent retaining wall system. Figure 1 is a typical cross-section.

Structural Design

The lateral earth, water and surcharge pressures for the temporary and permanent conditions were generated using the soil parameters in Table 1.

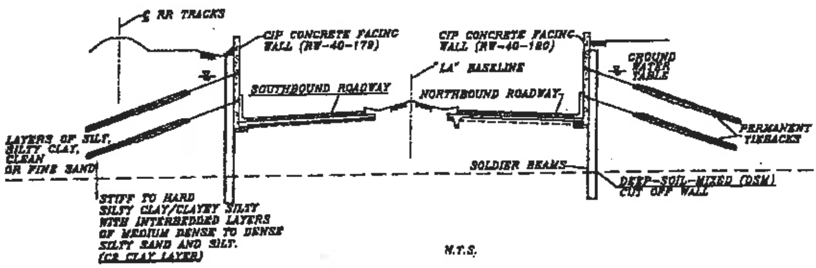

Figure 1 - Lakeway Parkway Section @ Sta. 168 "LA"

Active Rankine earth pressures were utilized for the temporary condition while at rest (K_o based on 1-sin Ø) pressures above subgrade were used for the permanent condition. For all conditions, a factor of safety of 1.5 was applied to the passive earth pressures.

The method of analysis for the cantilever, one tier and two tier walls were as follows:

1. <u>Cantilever Walls</u> - Moments are taken about the toe of the wall assuming different embedment lengths until the sum of the moments equals zero. The maximum moment was determined at point of zero shear.

Stratum No.	Stratum Description	Total Unit Weight (kN/m3)	Friction Angle Ø	Undrained Shear Strength (c) (kPa)	Lateral Earth Pressure Coefficient			Permeability cm/sec
					K_A	K_P	K_O	
S1/F	Loose Sand/Fill	18.3	28°	0	0.35	2.77	0.53	$1X10^{-3}$
S2	Med. Dense Sand	19.1	30°	0	0.33	3.00	0.50	$1X10^{-2}$
S3	Dense Sand	19.9	32°	0	0.31	3.25	0.47	$1x10^{-3}$
C1	Stiff Clay	19.9	0	48	NA	NA	0.5	$1X10^{-7}$
C2	Very Stiff Clay	20.7	0	72	NA	NA	0.5	$1X10^{-7}$
W	Water	9.9	NA	NA	NA	NA	NA	NA

TABLE I

Table 1. Soil Parameters

2. One Tier Walls - Moments are taken about the tieback level to determine the depth of embedment to satisfy moment equilibrium. The horizontal forces are then summed to determine the tieback force. Then, the maximum moment is determined at the point of zero shear and compared to the cantilever moment above the tieback level.

3. Two Tier Walls - In order to make this a determinate problem, hinges are assumed at the brace levels and at the subgrade level. The depth of embedment is determined by summing moments about the lowest brace level in order to satisfy moment equilibrium. Reaction forces and moments are determined for each span, along with the cantilever moments for the top span and embedment span at the bottom. For each span, the maximum moment is calculated at the location of zero shear.

For the cantilevers and one tier walls, the more critical of results for soil design profiles with C2 clay layer at 10.1 m and 14.3 m were used. Soil design profiles with C2 clay layer at 12.8 m was utilized for the two tier walls. For the two tier design the temporary stage excavation for the 2nd tier tiebacks controlled the design loading for the top tier tiebacks due to the essentially triangular loading diagram.

The results of the analyses for the various temporary design heights from 2.3 to 9.9 m are summarized in Table 2. An external double channel waler was used to connect the tiebacks to the steel soldier beams.

			TB TIER NO. 1					TB TIER NO. 2		
H_{TEMP} (m)	SB SIZE	SB LENGTH (m)	H1 (m)	TB SPACING (m)	DL @20° (kN)	WALER	H2 (m)	TB SPACING (m)	DL @20° (kN)	WALER
2.3	W610X92	10.8	–	–	–	–	–	–	–	–
3.8	W410X38.8	7.3	1.5	4.1	498	2MC310X52	–	–	–	–
5.3	W460X60	10.5	1.8	3.4	601	2MC310X52	–	–	–	–
6.9	W610X113	13.9	2.1	2.1	561	2C310X30.8	–	–	–	–
8.4	W610X101	15.1	2.1	2.7	538	2C310X45	3.1	3.4	587	2MC310X52
9.9	W610X125	10.6	2.1	2.1	512	2C310X30.8	3.9	2.1	534	2C310X30.8

Note: All steel is GR 345 MPa

Table 2. Tiedback wall design summary.

The vertical capacity of wall system was checked for the vertical component of the tieback load. For the temporary condition, the DSM soilcrete also functioned to support the lateral pressures from the soil, water and surcharge between the steel soldier beams. For the maximum cut depth, a minimum unconfined compression strength of 518 k Pa was required for the DSM soilcrete.

The permanent cast-in-place reinforced concrete facing was designed as a one way slab spanning between the vertical soldier beams. In order to fully encapsulate the external continuous double channel waler with minimum cover requirements, a 0.6 m thick facing was utilized. In addition, WI DOT required an 38 mm architectural rope type treatment for all exposed retaining walls. The concrete facing was structurally connected to the tiedback soldier beams using welded shear stud connectors. The concrete face was supported on a footing, which also served as a leveling pad for the concrete form work. Further, in order to provide a drainage path on the back side of the concrete facing for any seepage thru the DSM soilcrete or the tieback penetrations, a prefabricated wall drain was placed on the trimmed face on the DSM soilcrete from edge to edge of the steel soldier beams. The wall drains were connected to a collector drain at the toe of the wall by PVC sleeves at the base of the concrete facing. Figures 2 and 3 show a typical plan and section through the tiedback cutoff/retaining wall.

The retaining walls were required to be designed for a 75 year design life. Double corrosion protection was provided for all tieback tendons. Since the steel soldier beams are fully encased in the soil-cement mixture and the walers are fully encased in the concrete wall facing, no corrosion protective coatings or allowance for sacrificial metal thickness was necessary. The issue of frost protection of the tieback walls is addressed by providing 1.2 m of cover (0.6 m of concrete

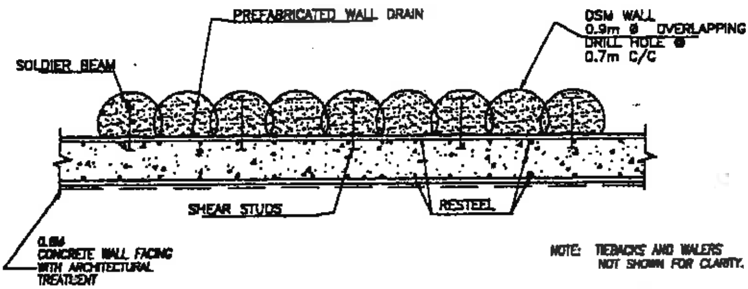

Figure 2 - Typical wall plan.

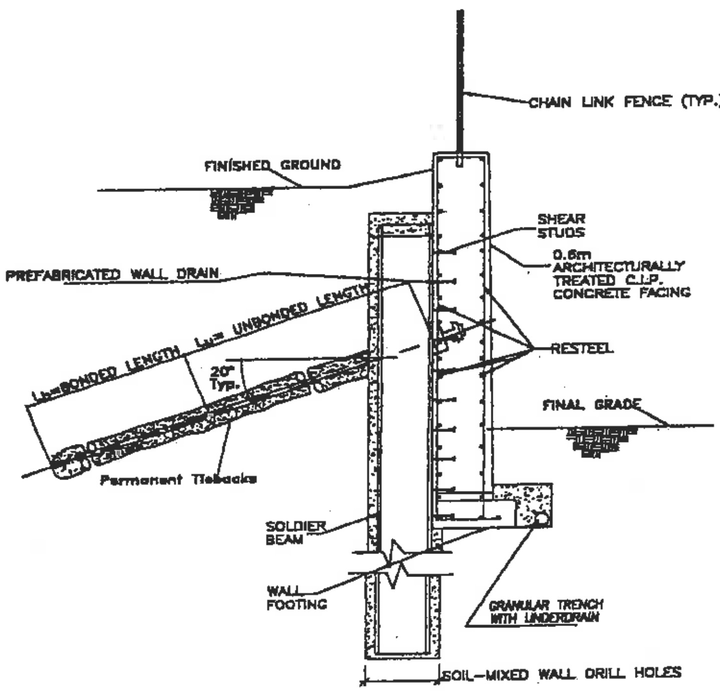

Figure 3. Typical permanently tiedback retaining wall section.

wall facing and 0.6 m thick DSM Wall), where the walls extend below the ground water level at a depth of 2.4 m.

Cutoff Design

The design criteria for the cutoff wall were as follows:

Maximum water inflow = 6.2 m3 /day/m of wall
Maximum draw down = 150 mm. at 9.2 m. behind wall.

To determine the cutoff depth requirements, the various subsurface conditions were modeled with the SEEPW computer program. The analysis began with the cutoff wall depth at 3.0 m below the excavation with the depth increased until both of the above design criteria were satisfied. The resulting cutoff wall depth varied from 7.6 to 16.8 m. It should be noted that the soil pemeabilities were assumed to be isotropic, even though the horizontal permeability was significantly higher than the vertical permeability due to the horizontal stratification. The required minimum permeability of the DSM wall to meet the above criteria is approximately 1×10^{-5} cm/sec.

In order to meet the minimum confined compressive strength of 518 kPa, the mix design required slightly less than 15% cement addition to soil by weight utilizing a soil unit weight of 16.7 $^{kN}/_{m^3}$.

Construction

The construction work had to be staged to maintain traffic. All the DSM cutoff walls were constructed first. Then, UP RR traffic on the Kenosha Branch was detoured on a runaround track and traffic on St. Francis was shifted onto the Cora Ave. detour to allow construction of the cut and cover tunnel/bridge. Once the bridge/tunnel is completed and RR and St. Francis Ave. traffic relocated on top of the structure, the remaining work will be completed in the second stage.

The DSM wall consists of a set of four overlapping vertical columns, with maximum and minimum widths of 0.9 and 0.6 m (see Figure 4). As the augers penetrate the in-situ soils to design depth, cement bentonite slurry is injected and blended with the in-situ soils. Upon withdrawal of the mixing shaft, a fluid "soilcrete" is left in place. The completed DSM wall is a homogenous mixture of bentonite slurry, cement, and in-situ soils. Overlapping of one shaft with the previous shaft guarantees continuity within the wall. Mixing is controlled by the mixing shaft speed, penetration rate, and rate of application of cement-bentonite slurry. Generally, the slurry injection rate is approximately 80% while the augers are moving downward and 20% while moving upward.

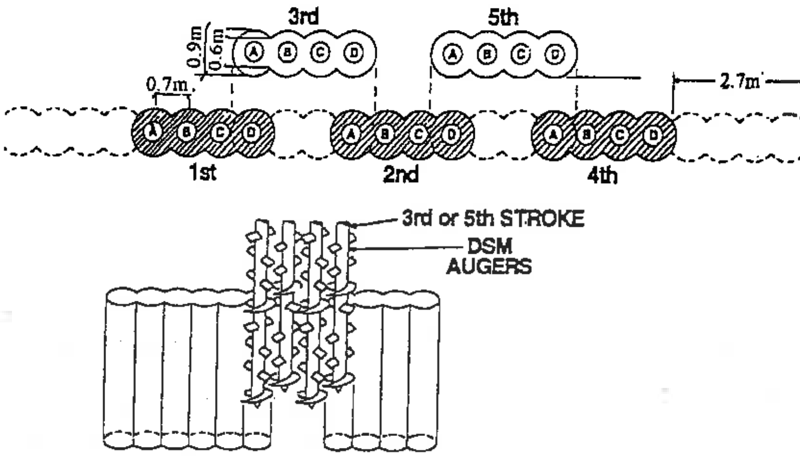

Figure 4. DSM installation sequence.

The DSM wall was constructed to the deeper of the depths derived from the cutoff and structural wall designs. In excess of 20,900 m^2 of DSM cutoff wall was installed on the project. The steel soldier beams were installed within the freshly mixed DSM soilcrete using a guide template.

The fluid DSM was sampled in the field every 75 m of wall for unconfined compressive strength testing and every 150 m for hydraulic conductivity testing. Typically, the minimum unconfined compressive strength of the samples was 620 kPa in 3 days, while the hydraulic conductivity was less then 5 X 10 $^{-7}$ cm/sec.

The tiebacks were installed using the hollow-stem-auger method. The 300 mm diameter tiebacks were constructed by first installing a pre-grouted encapsulated strand tendon inside the anger. A slip-fit point is attached to the end of the auger. Next, the tieback hole is drilled to desired depth (generally 18.3 m) and upon completion grout is pumped down the auger as the auger is extracted. All of the tiebacks were either performance or proof tested to 133% of the design load. In addition, a number of creep tests were performed to evaluate the tieback's long term load carrying characteristics and to verify that the tiebacks would carry the required design load without excessive movement.

Figures 5 to 8, respectively, show the installation of the DSM cutoff wall, tieback installation, construction of one sided formed wall facing, and completed retaining walls at north end.

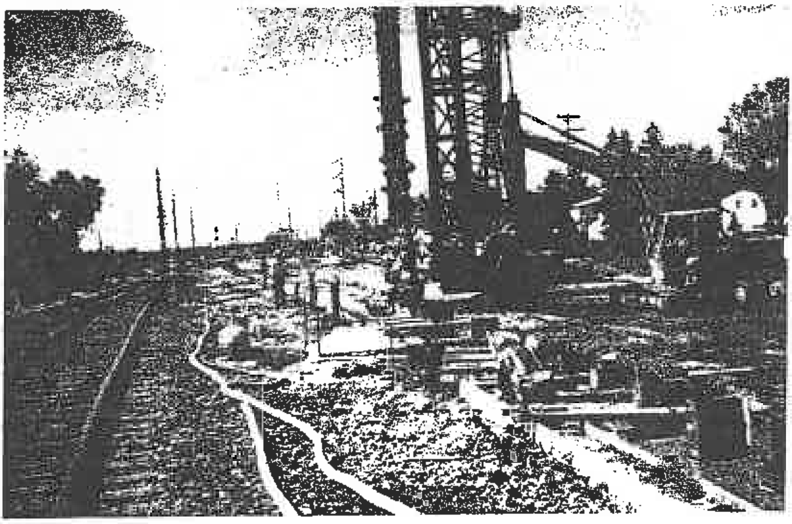

Figure 5. DSM wall installaltion.

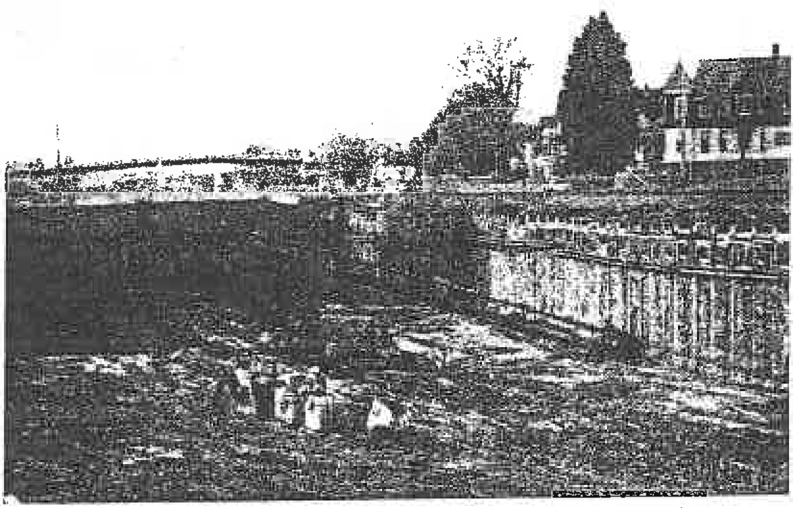

Figure 6. Tiedback installation for bottom tier at bridge abutement.

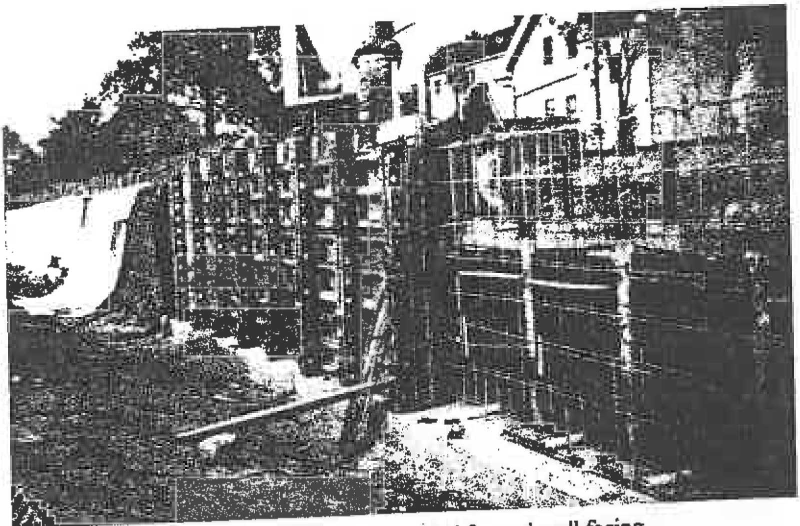

Figure 7. Construction of one sided formed wall facing.

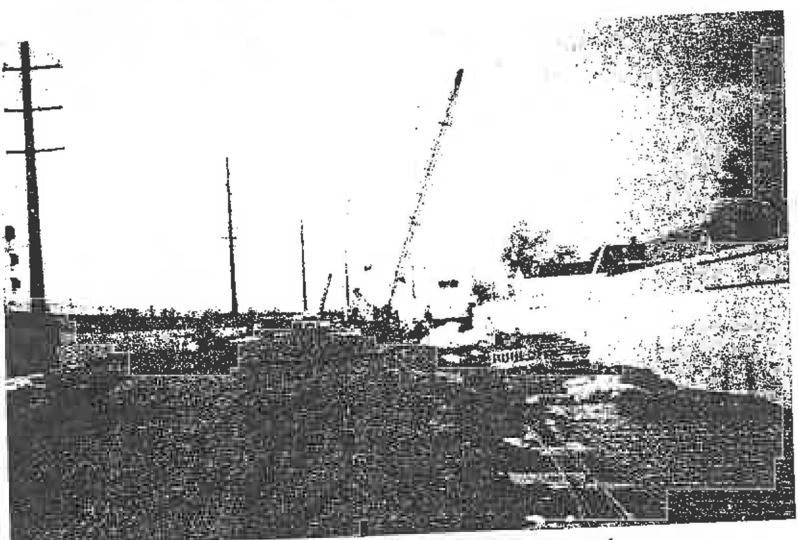

Figure 8. Completed retaining walls at north end.

Special Issues

Jet Grouting around Underground Utilities

Several large utilities crossed the DSM Cutoff walls including the 2.3 m MMSD Sludge line, 0.9 m MIS line in St. Francis Ave. and the 2.7 m storm sewer and 2.1 m water main in Morgan Ave. The retaining walls were designed to span over these lines and jet grouting was used to seal around these utilities (see figure 9).

The jet grouting was performed using a single jet rod advanced to the required depth. A check valve seated at the end of the jet rod initiated lateral flow through the jet nozzles located on the sides of the jet rod. As grout is pumped through the rod and forced through the jet nozzles, the jet rod is slowly rotated and extracted in precise increments, thus creating a jet grouted column.

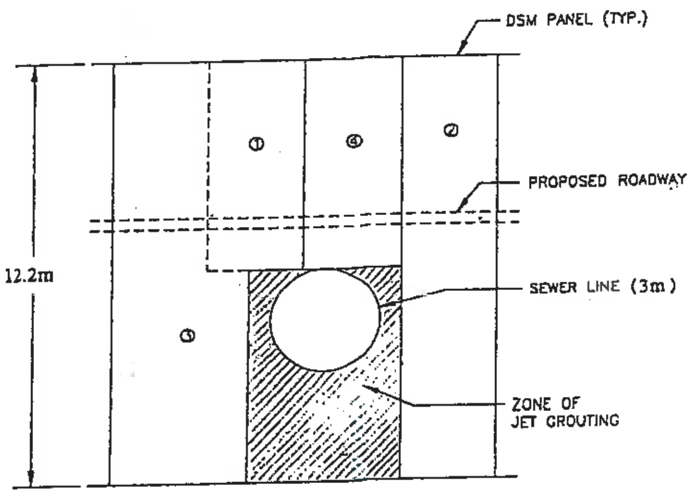

Figure 9. Typical utility blockout.

Freeze-Thaw Action

Some of the DSM soilcrete walls, especially in the vicinity of the bridge abutments were exposed throughout the excavation depth during the winter months. The surface of these walls experienced continual deterioration by small pieces flaking off the wall due to freeze thaw action. In the worst case, there was a loss of 100 to 200 mm of material, which did not jeopardize the integrity of the DSM cutoff wall. This problem requires further study as to how minimize the freeze thaw effects in cold climates.

Value Engineering for RR Bridge Abutments

Originally, the RR bridge abutments were designed to be free standing pile-supported retaining walls with the permanent groundwater cutoff walls located at some distance behind the abutment footing. These bridge abutments were value engineered to be permanently tiedback cutoff/abutment walls similar to the adjacent retaining walls to the north and south (see Fig 10). This was accomplished by eliminating the pile-supported footing projection on the back side of the abutment wall, reducing the stem wall thickness from 1.5 m to 1.14 m and reducing the number of pipe piles. The tiedback soldier beam system supports lateral soil, water and surcharge loads, while the stem wall on the pile-supported footing supports the vertical bridge loads. The soils below the skewed bridge approaches at the NW and SE corners were also stabilized by DSM method.

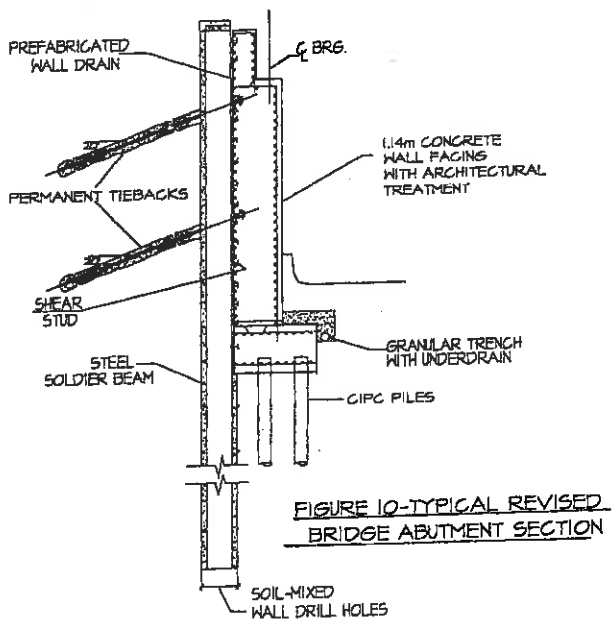

Figure 10. Typical revised bridge abutement sections.

Monitoring and Instrumentation

Ground water monitoring wells were installed at spacing of roughly 120 m. at a distance of 9 m behind the walls. These wells are showing just normal seasonal fluctuations in water level to date. No measurable seepage has been observed through or from below the DSM cutoff walls.

Three inclinometers were installed within the DSM wall to monitor lateral movement at the critical locations. To date, a maximum of 15 mm of lateral movement has been recorded on RW-40-179 near Morgan Ave. In addition, load cells were installed on the tiebacks at the location of the inclinometers. No significant change in tieback load since lock off has been recorded for these locations.

Summary and Conclusions

An innovative solution consisting of a combination permanent tiedback/DSM cutoff wall system was utilized for the retaining walls and bridge abutments on the Lake Parkway project. The successful performance of these walls to date indicate that the system was a good solution for the project requirements.

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