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Performance of Mechanically Stabilized Earth walls over compressible soils

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ABSTRACT: Two projects have recently been completed in New Jersey implementing the use of Reinforced Earth® walls over soft, compressible foundation soils. With differential settlements predicted to be in excess of the standard 1% allowable maximum, portions of a 3,000 square meter project near New York City and a 7,000 square meter project near Atlantic City were designed using an innovative two-stage construction technique. This involved construction of a flexible wire-faced MSE wall that accommodates differential settlement during consolidation of the foundation soils. Following the foundation settlement, standard precast facing panels were connected to the wire facing using a newly developed adjustable connection to complete the finished wall.

1 INTRODUCTION

Two large projects have recently been completed in New Jersey implementing the use of Reinforced Earth walls over soft, highly compressible foundation soils. Two different wall designs and construction techniques were used, depending on the amount of differential settlement expected. Conventional Reinforced Earth walls, with precast concrete facing panels and steel soil reinforcements directly attached to the panels, were used in areas where the anticipated differential settlements were within the tolerable limit for the precast panel system (i.e., less than 1%, or 1 meter of differential settlement along a 100 meter wall length).

In areas with greater differential settlements, a more flexible, two-stage, Reinforced Earth wall system was developed, which consisted of an initial wire-faced reinforced earth wall and a final precast facing panel attached to it. A 600 millimeter separation is maintained between the two facings during construction and is later filled with gravel. Temporary earth surcharge was placed on top of the wire-faced wall to consolidate the foundation soils and to achieve most of the anticipatded settlement prior to constructing the final concrete facing panels. The advantage of the wire-faced wall is its ability to tolerate more differential settlement than the conventional precast panel system.

Due to the extremely low initial shear strength of the foundation soils, some of the walls had to be constructed in several vertical stages to allow the foundation soils to consolidate and gain strength as the fill was being placed. Also, some conventional ground improvement techniques (e.g., vertical wick drains, dynamic deep compaction, high strength geosynthetics, etc.) were utilized to improve the foundation soils below the walls.

Successful performance of these structures documents the economic advantage of incorporating specialized mechanically stabilized earth structures in place of traditional cast-in-place walls supported on pile foundations for applications involving high differential settlements. Also, the use of the two-stage wall system in particular, eliminated the need for constructing, and completely removing, conventional temporary earth surcharge embankments with side slopes.

2 TWO-STAGE WALL SYSTEM

The two-stage wall system involved initial construction of a Reinforced Earth wire-faced wall, with steel soil reinforcements, to the final height of the proposed embankment. Both the wire facings and the soil reinforcements were designed for the full 75-year design life of the structure. The flexible wire facings were able to tolerate significant amount of differential settlements. The wire facings actually suffered significant deformation and distortion without any adverse impact on the structural integrity and performance of the final wall.

Following the completion of the consolidation of the foundation soils, precast concrete facing panels were connected to the wire facings/soil reinforcements with an adjustable connection system, shown in Figures 1 and 2.

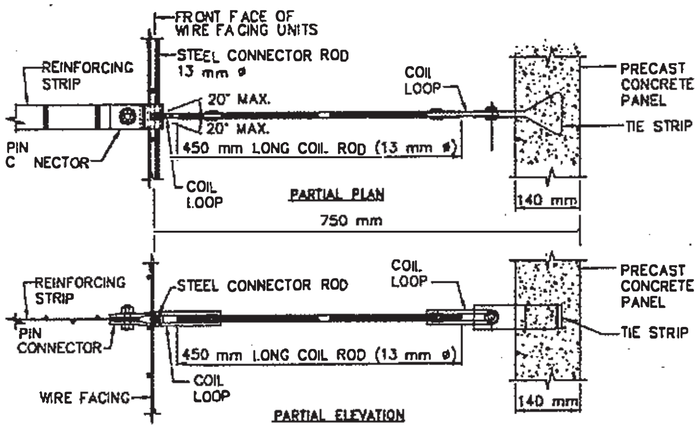

Figure 1. Two-Stage MSE wall connection detail.

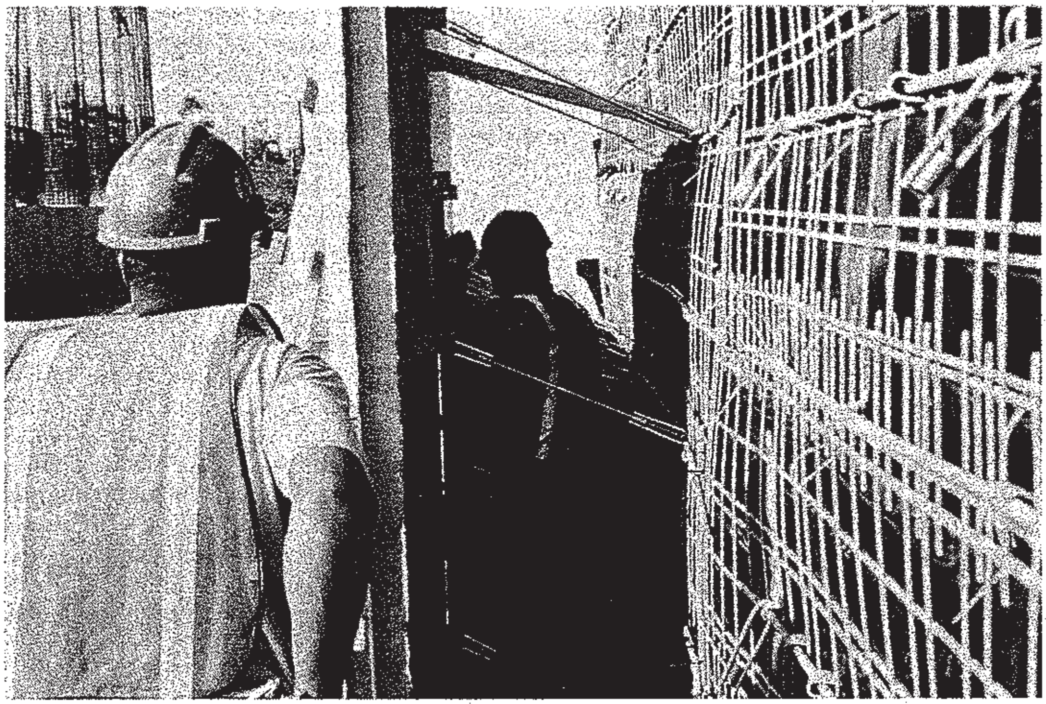

Figure 2. Connection of precast panels to wirewall.

The adjustable connection system utilized a standard steel coil rod with opposite threads on the two ends of the rod. Coil loops were attached on each end of the coil rod with the opposite threading, resulted in a turnbuckle-type connection. During the initial construction phase, one set of coil loops were slipped onto the connector bar attaching the soil reinforcements to the wire facings, in order to transfer the connection load directly to the soil reinforcements. The coil loop locations coincided with the locations of the soil reinforcements along the connector bar. During the final construction phase, the coil rods were threaded into these coil loops and into a second set of coil loops on the opposite end of the rod. That second set of coil loops were then bolted to the standard tie strips attached to the back face of the precast concrete facing panels.

Since the coil loops at both ends of the coil rod were free to rotate in the vertical direction, this connection system allowed for adjustment of the connector rod orientation in the vertical direction (i.e., in the direction of the foundation settlement). Limited adjustment was also allowed in the horizontal direction by this connection system.

After the completion of the connection for each course of precast concrete facing panels, the 600 millimeter space between the wire facings and concrete panels was then filled with free flowing gravel to complete the structure.

3 KAPKAWSKI ROAD PROJECT, ELIZABETH, NEW JERSEY

In this project, four Reinforced Earth walls (Walls 1 through 4) were constructed along the Elizabeth Waterfront Boulevard and Jersey Gardens Boulevard to provide access from the New Jersey Turnpike to a proposed Mall Development site in Elizabeth, New Jersey, just west of New York City, NY. Walls 1 and 2 were constructed as single-stage walls while Walls 3 & 4 were constructed as two-stage walls. Temporary earth surcharge was not required for any of the walls at this project.

Walls 1 and 2 included a total of 170 lineal meters of wall with heights in the range of 3 meters to 10 meters. Geotechnical investigations indicated that the ground surface below Walls 1 and 2 was underlain by a 3 to 4 meter thick layer of waste fill materials. The waste fill materials consisted of loose to dense municipal solid waste intermixed in a matrix of silty sand soil. Underlying the waste fill material, intermittent layers of soft to medium stiff peat and medium stiff silty clay, ranging from 0.3 meters to 1.5 meters in thickness, were encountered.

The natural moisture content of the peat layer was found to be near its liquid limit, indicating normally consolidated material with very low shear strength. Total settlements ranging between 0.9 meters and 1.5 meters were estimated to occur due to the construction of the 10 meters high embankment.

Due to excessive settlements, a Dynamic Deep Compaction (DDC) technique was recommended to densify the soils/fill, followed by construction of conventional single-stage Reinforced Earth walls. Subsequent to the dynamic compaction, total settlements under the weight of the proposed embankment were estimated to be reduced to a maximum of 460 millimeters (from 1.5 meters originally). A 0.9 meter thick granular mat, reinforced with high strength polyester geogrids, was also recommended to be placed below the embankment to prohibit a possible shear failure through the peat layer and to reduce differential settlements. The objective of the ground improvement techniques was not only to reduce the potential differential settlement but also to enhance long-term global (rotational) stability of the embankment.

Actual construction settlements were up to 280 millimeters, at the maximum height of the wall/embankment of 10 meters. Within the remaining portions of the wall, actual total settlements were less than 170 millimeters. The calculated differential settlement along the wall face was less than 1%.

The cost evaluations performed by the contractor for Walls 1 and 2 indicated that the use of single-stage Reinforced Earth walls in conjunction with ground improvements was significantly more cost effective than a cast-in-place wall supported on deep foundations.

Walls 3 and 4 were planned adjacent to Spartina Marsh, an existing wetlands area. The walls reached a maximum height of 10.7 meters at the highest end of the embankment. Geotechnical explorations at the wall location indicated highly variable subsurface conditions in the vicinity of Walls 3 and 4. A 2 to 3 meter thick layer of loose to dense silty sand fill was present at the ground surface, overlying marshy soils. Below the fill materials, the borings generally encountered intermittent layers of soft to medium stiff silty clay and peat underlain by medium dense to dense silty sand soils. Bedrock was encountered below these granular layers, about 15 meters below ground surface.

Settlement analyses indicated up to 300 millimeters of total settlement but significant differential settlements were anticipated due to the high variability in the soil conditions across the site. Settlement was anticipated to take place over a period of 2 to 5 months after completion of embankment construction. Site restraints as well as the expedited project schedule dictated that the embankment be constructed on the existing ground without any ground improvements. Therefore, a two-stage Reinforced Earth wall system was deemed feasible and was selected, since it has the ability to tolerate significant amount of differential settlements. The two-stage walls were constructed using the technique described earlier in this paper.

Actual total construction settlements at the location of Walls 3 & 4 were on the order of 100 to 200 millimeters. Maximum differential settlements along the wall face were computed to be generally less than 1%, with the exception of some localized areas of soft pockets in the near surface soils, where differential settlement slightly exceeded 1%.

The reinforced fill used in the construction of the four walls for this project consisted of an open graded crushed stone (locally referred to as No. 57 stone). The particle size of this stone is 19-millime-ters.

This project was completed in the summer of 1998. To date, the four walls at this project have performed as expected, with no precast panel misalignment or distress observed due to post construction/secondary settlements.

During the initial phase of the two-stage walls, only minor bulging (less than 75 millimeters) was observed on the wire facings, with the exception of one local area where bulging on the order of 300 millimeters was observed. This was attributed to poor construction practice (high rate of fill placement and compaction, and use of compaction equipment in close proximity to the wall face).

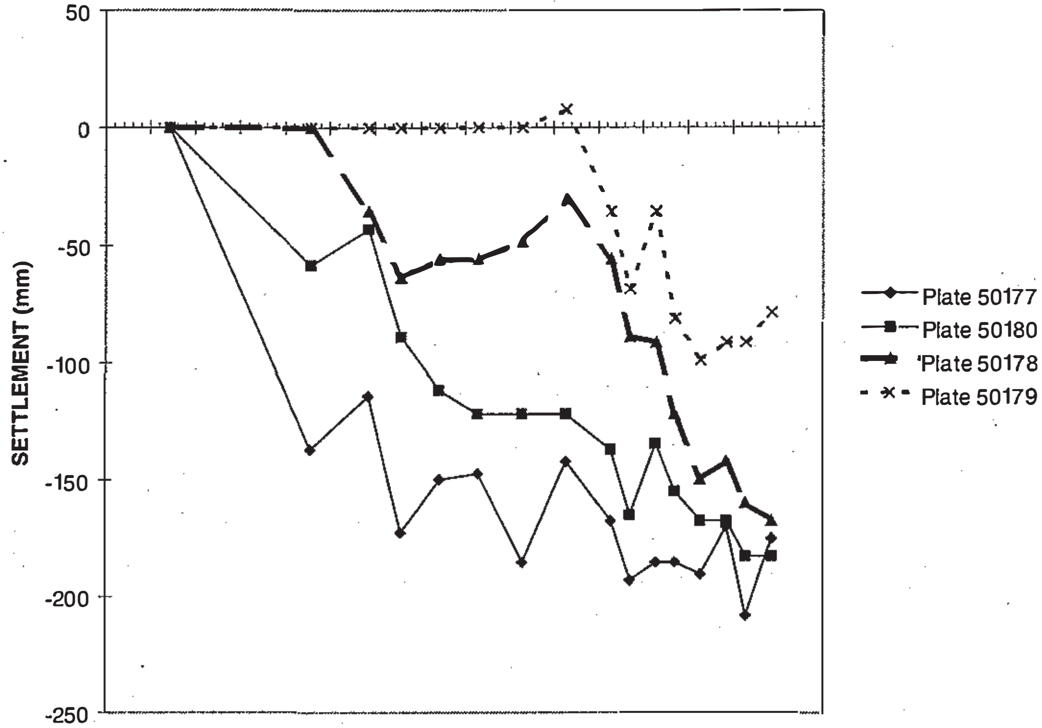

Figure 3. Settlement plate readings, Wall 3, Kapkowski Road.

4 ATLANTIC CITY-BRIGANTINE CONNECTOR, NEW JERSEY

The Atlantic City-Brigantine Connector is the largest public/private design-build highway project in the recent history of the state of New Jersey. The connector provides a link between the City of Brigantine and the marina-area casinos in Atlantic City, NJ.

This project included construction of over 7,000 square meters of Reinforced Earth walls up to 10 meters in height, at 9 proposed bridge locations.

Figure 4. Temporary surcharge on wirewall, Atlantic City.

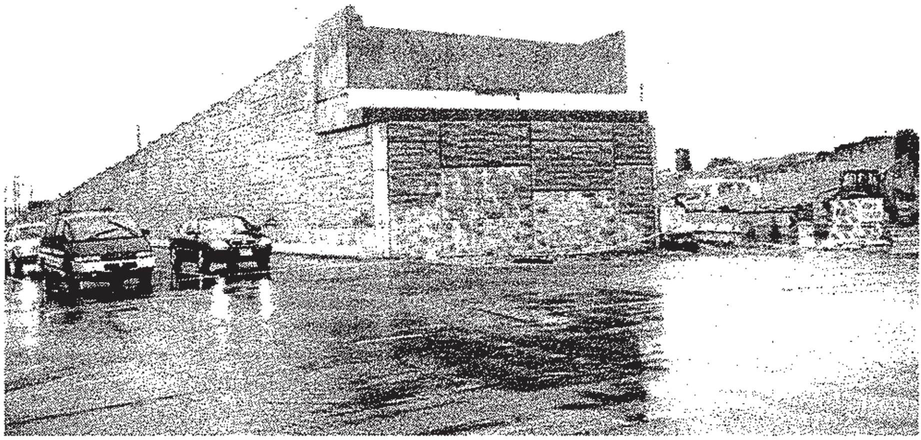

Figure 5. Complete two-stage structure, Atlantic City.

Again, both conventional single-stage walls and two-stage walls were constructed. The bridges were supported on conventional stub abutments supported by concrete filled steel pipe piles.

The geotechnical investigation indicated most of the site was underlain by highly compressible/low shear strength clayey soils with up to 1 meter of total settlement anticipated under the weight of the proposed embankments. Based on embankment heights (up to 10 meters at the bridge approaches) and the low initial undrained shear strength of the foundation soils, the roadway embankments needed to be constructed in several vertical stages to allow the foundation soils to gain strength as the fill was being placed. At several locations on the project the walls were used in conjunction with ground improvement techniques such as vertical wick drains and high strength geotextile base reinforcement. Temporary earth surcharge fills were placed on top of the majority of the walls, as required by the geotechnical design.

At four bridge abutment locations the availability of space and time allowed preloading the site with conventional earth surcharge embankments with side slopes. Single-stage wall construction was utilized at these four locations following the removal of the earth surcharge. At an adjacent bridge abutment location, where enough space for a surcharge with side slopes was not available, a single-stage wall was constructed, incorporating a 4.5 meters temporary surcharge above the top of the wall. The use of a single-stage wall was feasible at this location based on an estimated maximum differential settlement of less than 1% along the wall face. During construction of the wall, there was no evidence of panel misalignment or distress due to the settlement of the soils, confirming the ability of the conventional, single-stage, Reinforced Earth walls to tolerate up to 1% differential settlement, without showing any signs of distress.

Over 4,000 square meters of the walls (8 bridge abutment locations and one approach ramp location) at this project were constructed using the two-stage wall system due to anticipated differential settlements being greater than 1% and due to unavailability of space for placement of conventional temporary earth surcharge embankments. Actual construction total settlements along the wire-wall face ranged generally from 600 millimeters to 900 millimeters, as anticipated by the design. Maximum differential settlement exceeded 1% along the wall face, which was also anticipated by the design.

The reinforced fill used in the construction of all walls at this site consisted of a silty fine sand material, containing no more than 15% fines less than 75μm in size.

One of the interesting observations on this project was the significant bulging of the wire facings (on the order of 200 millimeters and 400 millimeters) observed in several areas during the surcharge stage of the two-stage walls. The bulging observed exceeded that observed at the Kapkawski Road project described above. The difference in the performance of the wire facings was attributed to the type of the reinforced fill used (crushed stone in Kapkawski versus fine sand in Atlantic City) and the practice used by the contractor to place and compact the fill in the two projects.

The Atlantic City project is still under construction, at the time this paper was submitted, with the majority of the precast panels already installed.

5 CONCLUSIONS

Both projects realized significant cost savings by using two-stage Reinforced Earth walls in areas of high differential settlement in place of traditional pile supported cast in place walls, or extensive foundation improvement methods. All walls are performing very well with no precast panel misalignment or distress from secondary settlement. The flexibility of the conventional precast panel system to tolerate up to 1% differential settlement was demonstrated on both projects.

The significant deformation and distortion suffered by the wire facings in the initial stage do not have any adverse impact on the structural integrity and the performance of the final wall. Visually, there is no difference in outward appearance of the single-stage or two-stage walls as the precast facing panels are identical.

REFERENCES

Abraham, A and Sankey, J, 1999. Design and Construction of Reinforced Earth Walls on Marginal Lands. *Geotechnics of High Water Content Materials, ASTM STP 1374.*