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Wall Construction and Monitoring Program of Tiebacks Walls in a Shale Stratum

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Abstract. This paper presents the results of a monitoring program in two tieback walls. Both walls were constructed to preserve the foundation of a highway bridge, to stabilize a slope and to protect an adjacent railroad. Slope deformations and wall deformations were summarized and correlated with construction activities. The construction of both walls involved backfilling and excavation activities. The walls exhibited maximum normalized lateral deformation less than average values reported in the literature. Bulging-type deformation was observed between the ground anchors. The monitoring results showed a beneficial effect of the installation of the soldier piles in a shale layer.

Keywords. Tieback wall, lateral deformation, ground response, instrumentation, bottom-up construction.

1. Introduction

Wall construction imposes significant changes in ground stresses and strains. Several studies have analyzed the behavior of anchored soldier pile walls used in excavations by means of model and full-scale tests [1-3]. More recently, some studies have shown the behavior of soldier pile walls for landslide mitigation [4]. These studies revealed the complicated interaction between wall construction and ground response. This response is affected by several factors such as construction sequence, wall stiffness, anchor prestressing, bottom heave stability, and workmanship.

Several authors have studied the pattern of wall and ground deformations during a typical top-down construction sequence (i.e. excavation in stages) in various soil types [5, 6]. However, these studies did not discuss wall response to a bottom-up construction in which the wall is backfilled simultaneously to the installation of ground anchors. In excavation, it has been observed that cantilever movements occur on top of the wall prior to the installation of the upper tiebacks. Further excavation causes the wall to bulge between the locations of the anchors with maximum lateral displacements observed in the middle of the support spans. However, this pattern of deformation may not be representative for walls constructed using both excavation and backfilling activities simultaneously.

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This paper presents the results of a monitoring program during the construction of two tieback walls. Both walls were constructed to stabilize a slope and to preserve the foundation of an adjacent bridge. The project completion involved simultaneous excavation and backfill in the unstable slope. Collected data during and after construction is presented and correlated with the construction activities. The influence of construction sequence on the pattern of wall deformation is studied. Maximum displacements are compared with typical reported values of this type of walls.

2. Project Description and Site Condition

The project site is located along the western slope beneath the State Route 82 Bridge, near Brecksville, Summit County, Ohio, USA. The two tieback walls were constructed in response to widespread slope instability. This region has been recognized as prone to slope movements in previous decades [7]. At the slope site, slumps, surface erosion, and block movements were noted throughout the area. These movements extended about 60 m to the north and 120 m south of the bridge centerline.

Figure 1 shows a plan view of the area and the tieback walls. Thirty-six soldier piles were installed in the project (HP 14x73); seventeen in the lower wall and nineteen in the upper wall. The separation of the piles was 3.1 m and 2.4 m in the lower and upper wall, respectively. Precast concrete lagging was installed between the soldier piles with a thickness of 304.8 mm. A total of 68 anchors were installed in the project with a diameter of 101.6 mm and bonded length of 4.5 m. Ground anchors were distributed in two rows of anchors in the lower wall and three in the upper wall. The inclination of anchors was 15 and 45 degrees measured from the horizontal in the lower and upper wall, respectively. The anchors for the lower wall were oriented horizontally to prevent their intersection with the piles of the upper wall. Figure 2 shows a profile view of both walls, as well as the soil profile. It can be observed that the construction of both walls implied backfilling and excavation in the front of them.

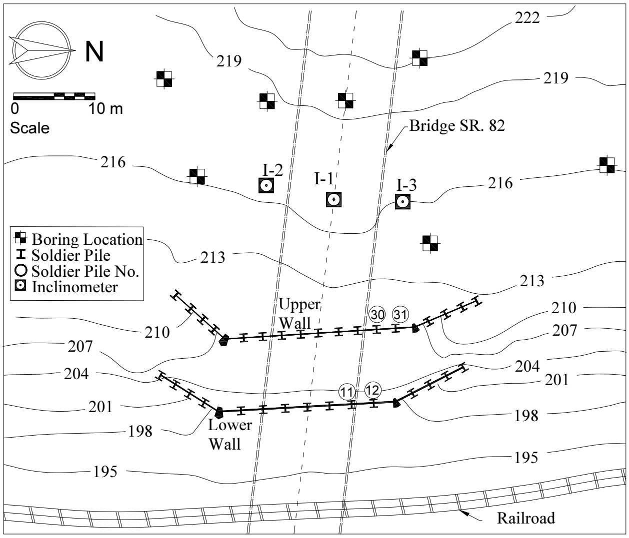

Figure 1. Construction plan and instruments locations.

Based on the subsurface investigation, three soil strata were identified on the site. The upper soil layer was composed of brown silty clay and clayey silt. These soils combined without a consistent pattern throughout the site and had some traces of loose to medium sand. Beneath this layer, the profile was composed by a soil layer consisting of gray clayey silt and silty clay. The consistency of this second layer was typically stiff to very stiff. The lowest part of the soil profile consisted of a shale stratum. Shale surface dropped to the west with a tendency north-south. Top of the shale stratum was weathered with the weathering decreasing with depth. In the slope, the natural moisture content was approximately uniform with depth and ranged between 20 and 30 percent. Blow counts increased as a function of the effective overburden stress, with a considerable increase observed near the shale layer.

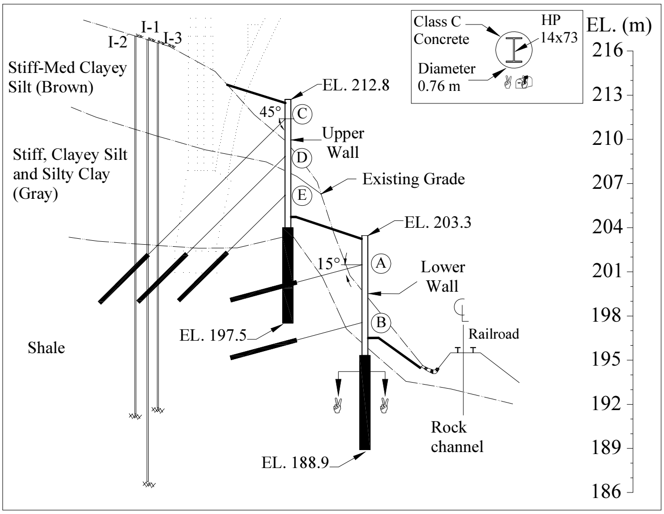

Figure 2. Lateral view of the project.

Table 1 shows the general construction sequence of the project. The soldier piles were installed in pre-drilled holes with a diameter of 762 mm and were penetrated 6.1 m into the shale stratum. The total length of the piles was 15.2 m and 14.3 m in the upper and the lower wall, respectively.

Table 1. General construction sequence.

Day	Construction activity
20	Installation of ground inclinometers.
28-41	Installation of solider piles for the upper wall.
41-51	Installation of solider piles for the lower wall.
36-61	Preproduction tests
72-106	Installation and testing of anchors in Row D in the upper wall.
106-115	Installation and testing of anchors in Row B in the lower wall.
115-132	Installation and testing of anchors in Row E in the upper wall.
132-146	Installation and testing of anchors in Row A in the lower wall.
146-177	Installation and testing of anchors in Row C in the upper wall.
157-185	Final backfilling of the lower wall.
181	Concrete lagging installation in the upper wall was completed.
181-188	Final backfilling of the upper wall, post-grouting, and construction completed.

During installation, the piles were lifted into place by a crane. Afterwards, concrete was placed using tremie techniques. Rows C and D correspond to anchors in the upper wall and Row A correspond to anchors in the lower wall. These anchors were installed under “fill” conditions. During the installation of these anchors, steel casings were drilled into the shale stratum to support the jacking system and to prevent the borehole from collapsing. The penetration depth of the casings varied between 1.8 m to 2.4 m. Rows B and E anchors were installed under “cut” conditions. In this condition, the shale stratum was excavated in front of the soldier piles to install the anchors. During anchor installation, the drill mast was supported on a crane and clamped to the flange of the soldier piles for lateral stability. Anchors were installed one row at a time. While installing a row of anchors, excavation and backfilling were conducted on the other wall.

3. Instrumentation

Slope movements were monitored throughout the project using three inclinometers (Figure 1). The inclinometers were installed at depths of 29.6 m, 25.3 m and 24.4 m. The behavior of both walls was monitored using inclinometers attached to the soldier piles. Figure 1 shows the location of the two instrumented soldier piles in each wall for a total of four in the project. The tops of the inclinometers were 3 m shorter than the soldier piles to protect them from damage during construction. The inclinometers were extended 4.6 m below the bottom of the soldier piles to monitor movement at the bottom of the wall.

4. Analysis and Results

4.1. Lateral deformation in ground inclinometers

Figure 3 presents the ground deformation measured with the slope inclinometers. Data from the Inclinometer 1 were collected until Day 154 due to its damage by construction activities. At Day 41, the observed ground movements were caused by the installation of the soldier piles of the upper wall about 30 mm. This displacement was observed in the Inclinometer 3 while the other inclinometers showed displacements with a magnitude less than 5 mm. The difference in ground movements was attributed to the location of the haul road of the project. Major excavations and ground disturbances were generated during the installation of the piles adjacent to the Inclinometer 3. According to the inclinometers, the lateral deformation of the slope was restricted to the uppermost 5 m of the profile with the maximum displacement at the surface. During the installation of the soldier piles of the lower wall and preproduction tests, between Day 41 and Day 51, slope movements showed a slight variation as seen at Day 63 around 2 mm in the inclinometers 1 and 2. However, Inclinometer 3 measured a maximum increased in the lateral deformation of 19 mm (Figure 3c). Slope movements suggested that the installation of the piles in the lower wall did not alter the movement of the slope significantly.

Installation of the steel casing for the Row D of anchors was finished around Day 84. During this activity, maximum lateral displacement was about 100 mm in the inclinometer 3. While the Inclinometer 2 showed displacements of about one-fifth of Inclinometer 3, the displacements in the Inclinometer 1 was negligible. Between Day

106 and Day 115, the drill mast was moved to install the anchors of Row B. Simultaneously to the installation of these anchors, the ground was excavated in front of the upper wall to install the Row E of anchors. During these activities, the pattern of deformation was consistent with those observed previously. Maximum deformation of the slope was registered in Inclinometer 3 as 133 mm. Although movements increased in the three inclinometers, these tended to concentrate more in the upper portion of the soil profile. The installation of the anchors and the backfilling of both walls were completed between Day 120 and Day 208. During this period, the maximum variation of the ground displacement was only 25 mm. From Figure 3, it is observed that as the construction activities progressed, the vertical extent of lateral deformation reduced from an initial value of 7 m to approximately 5 m. From the end of construction until Day 310, the ground movements developed in Inclinometer 3 with an increment of 55 mm. This variation was concentrated in the uppermost portion of the soil profile. The vertical extent of lateral deformation decreases continuously until the last day of measurement (Day 310). Inclinometer 2 did not show significant variation in the measured deformation. Based on the rate of displacement observed, both walls effectively contributed to the stability of the slope. Based on Figure 3, ground deformation was mostly limited to elevations between 211 m and 215 m approximately. This area was approximately the interface between the brown clayey silt and the gray silty clay deposits.

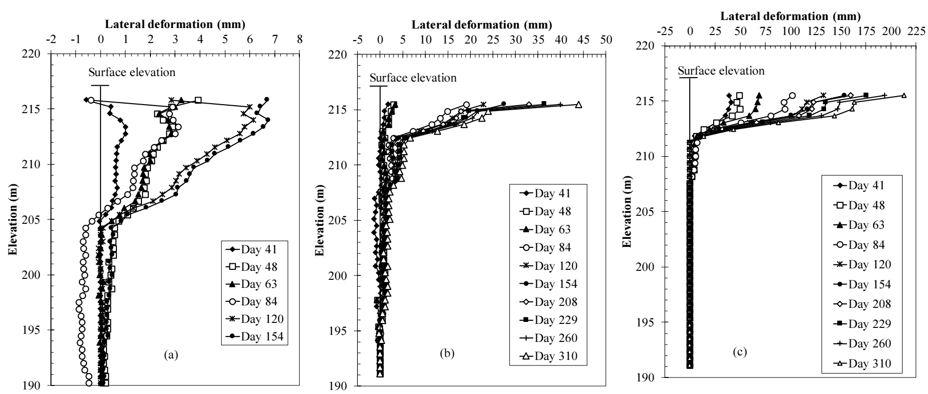

Figure 3. Lateral deformation of the slope; (a) Inclinometer 1; (b) Inclinometer 2 and (c) Inclinometer 3.

4.2. Lateral soil deformations observed in the wall inclinometers

Soldier Piles 30 and 31 were monitored in the upper wall. Soldier Piles 11 and 12 were monitored in the lower wall. The locations of the monitored piles are shown in Figure 1. As stated, the construction of both walls involved excavation and backfill. Figure 4 shows the backfill elevation during construction. In the figure, the lowest elevation of the backfill in corresponds to the installation of the drainage behind the walls. The installation of the anchors in the upper wall was longer given that it used platforms to install and tension the anchors. Figure 5 shows the measured deformation in the lower wall. Data at Day 183 in Soldier Pile 12 appears to be an erroneous measurement given that the adjacent soldier pile did not show that type of movement and there were not significant construction activities at this location at this day.

During the installation of the Row A anchors, the backfill was at 200.7 m. The installation of these anchors produced a localized effect in the lateral deformation measured by the inclinometers. As seen in Figure 5, the inclinometer casing moved towards the slope approximately 6 mm. Between the ground anchors, a bulging deformation was observed with maximum lateral movement of 3 mm. This bulging deformation represents the wall response to backfilling before and after installation of the upper anchors (Row C). Soldier Pile 12 exhibited a maximum lateral deformation of 10 mm above the upper anchors. However, this value is doubtful due to the localized effect during upper anchor installation.

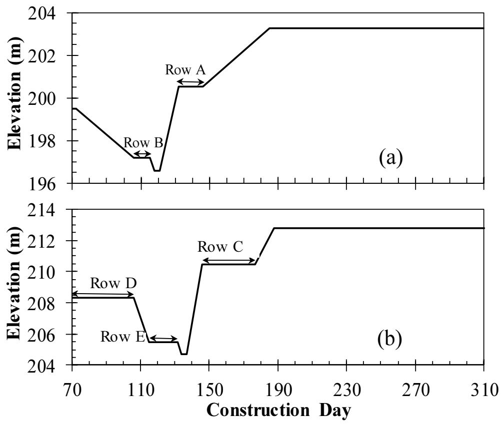

Figure 4. Backfill Elevation: (a) Lower Wall; (b) Upper Wall.

At Day 208, the construction of the lower wall finished. After completion of the backfill, lateral deformation of the wall was invariant with respect to the deformations measured previously during the installation of the Row A anchors. Long-term monitoring until Day 310 revealed that further movement of the slope was restricted. Both soldier piles showed similar behavior below the upper anchors; movements concentrate approximately 7 m below the top of the wall in the backfilling area.

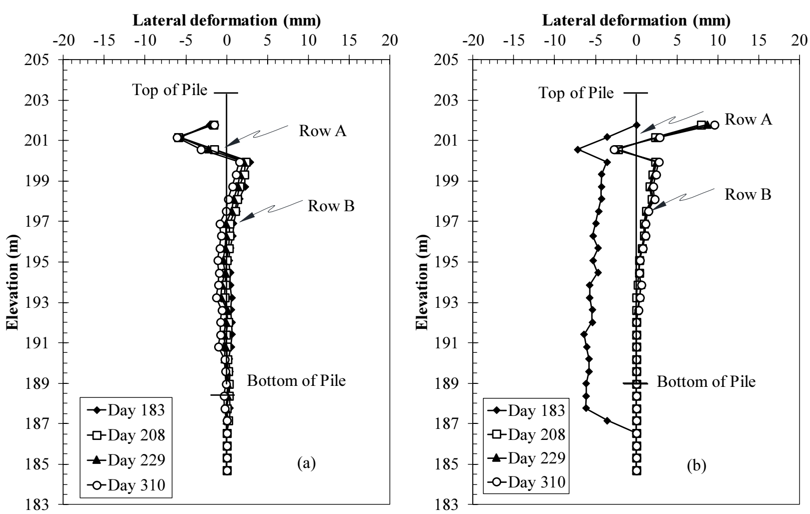

Figure 5. Lateral deformation measured in the lower wall; (a) Soldier Pile 11 (b) Soldier Pile 12.

Figure 6 presents the measured response in the upper wall. Although the ground anchors were installed at Day 183, the backfill of this wall was incomplete. Below the Row C anchors, the maximum deformations were observed between the anchors in a bulging type profile. The maximum lateral deformations were 8 mm and 4 mm in the Soldier Piles 31 and 30, respectively. At Day 208 construction and backfilling of the upper wall was completed. Post grouting of anchors around this day attenuated the lateral deformation profile in the Soldier Pile 31. Measurements after construction showed an insignificant increase in the wall deformation around 2 mm by the end of the monitoring period. As in the lower wall, the upper 7 m of the upper wall exhibited lateral deformation. Consequently, the lateral deformation was concentrated only in the areas of backfill in both walls. In the excavated portion of the walls, the lateral deformation was nil because of the installation of the piles in the shale stratum. The deformation profile at Day 310 confirmed that both walls successfully improved the stability in the slope given the cease of the ground deformation.

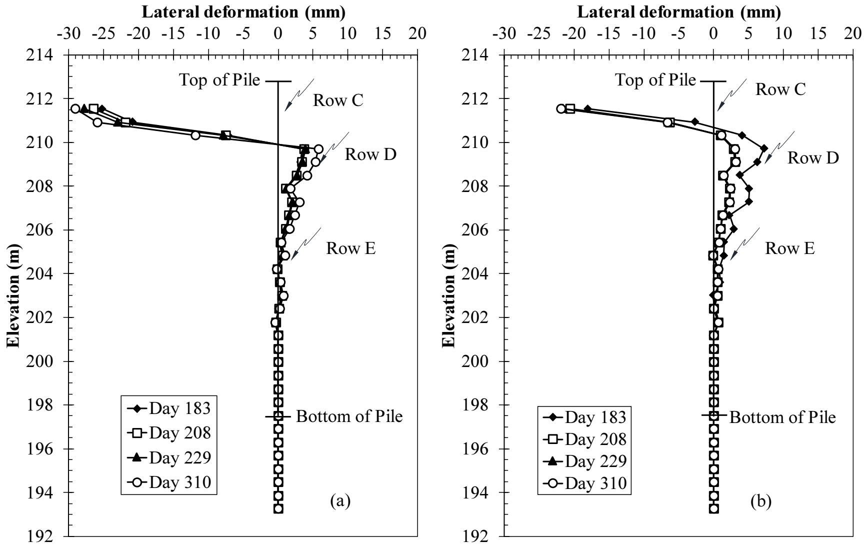

Figure 6. Lateral deformation measured in the lower wall; (a) Soldier Pile 30 (b) Soldier Pile 31.

Figure 7 shows the maximum lateral deformation (Day 310) in the walls compared with typical values reported in the literature for this type of walls. In both walls, the measured movements were less than the limit values reported by Clough et al. [9] and closer to the Yoo [8] average. Normalized deformation in both walls was similar even though both walls differ in height and soldier pile separation. In the upper wall, it was 0.06 percent while in the lower it was 0.07 percent. Walls installed in soils overlying rock tend to exhibit smaller lateral movements due to the lateral restriction of the wall toe. These small values of deformation can be attributed to the embedded of the piles in the shale stratum. As reported by other researchers [8, 10, 11], the presence of bedrock may have a significant influence on wall deformations. In this project, the magnitude of the lateral displacements was somewhat limited compared to the 0.4 percent reported by Ma et al. [11] for a wall installed in a gneiss stratum.

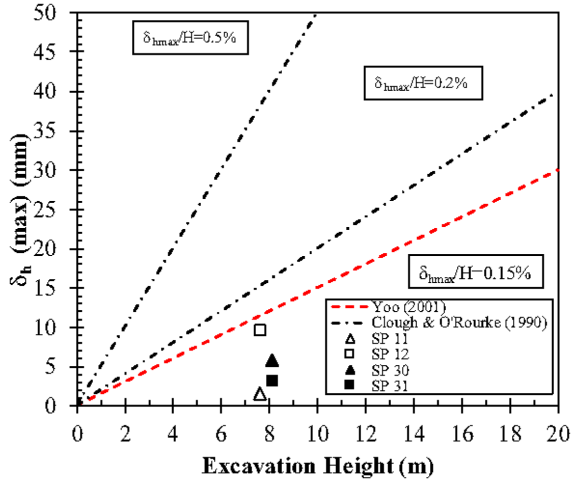

Figure 7. Maximum lateral movement.

5. Conclusions and Recommendations

Monitoring results showed that the two soldier-pile walls significantly improved the stability in the slope. Measured lateral deformations were smaller than average values reported in this type of walls. It was recognized that the installation of the soldier piles in the shale had a beneficial effect in controlling the lateral deformations. Lateral deformation concentrated in the upper portion of both walls in the backfill area. Bulging between anchors was observed similarly to typical top-down construction sequence. Although both walls were close to each other, it seemed that the upper wall construction activities were more correlated with the slope response. Long-term data showed that the two walls effectively control the stability problems in the area and preserve the bridge foundation.

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