Effects of Pile Driving Through a Full-Height Precast Concrete Panel Faced, Geogrid-Reinforced, Mechanically Stabilized Earth (MSE) Wall

R. Berg, F.ASCE[1], and C. Vulova, M.ASCE[2]

[1] President, Ryan R. Berg & Assoc., Inc., 2190 Leyland Alcove, Woodbury, Minnesota 55125, PH (651) 735-7622; FAX (651) 735-7629; email: ryanberg@att.net
[2] Application Technology Manager, Tensar Earth Technologies, Inc., 5883 Glenridge Drive, Suite 200, Atlanta, GA 30328; PH (404) 250-1290; FAX (404) 250-9185; email: cvulova@tensarcorp.com

Abstract: Geogrid-reinforced mechanically stabilized earth (MSE) walls are used for bridge approach/abutment applications. The bridge structure is typically supported on pile foundations constructed through the reinforced mass. The common construction technique is to build the MSE wall after the piles or the pile sleeves are installed. An alternative construction technique is to drive the piles through the constructed reinforced mass. This alternative offers significant construction advantages over the traditional approach.

Full-scale demonstration/testing was conducted to investigate the feasibility of this alternative construction technique. The constructability of driving steel H piles through an HDPE geogrid reinforced MSE wall was demonstrated.

This paper documents the wall construction and materials, instrumentation, and monitoring results of the full-scale demonstration/testing. The design implications and the advantages of this proposed construction technique are summarized.

INTRODUCTION

Geogrid-reinforced mechanically stabilized earth (MSE) walls are used for bridge approach/abutment applications. The bridge structure is typically supported on pile foundations constructed through the reinforced mass. The common construction technique is to build the MSE wall after the piles or the pile sleeves are installed. This technique results in some difficulty during the fill placement/ compaction and geogrid installation around these obstructions. An alternative construction technique is to drive the piles through the constructed reinforced mass. This alternative offers significant advantages over the traditional construction. The fill placement and geogrid installation are not hindered by pre-installed piles or pile sleeves. The backfill is readily compacted with heavy equipment minimizing the possibility of under-compacted zones. Driving the piles through constructed reinforced mass eliminates the use of hand operated compaction equipment and special construction techniques to hold pre-installed sleeves in vertical position during fill placement and compaction.

Full-scale testing (Figure 1), to investigate the feasibility of this alternative construction technique for the Colorado E-470 project, was conducted in November 2000. The effects of pile driving on wall behavior were investigated on an instrumented 4.6-m (15-ft) high, 8.2 m (27 ft) long wall, with full-height precast concrete face panels, silty sand wall fill, and HDPE geogrid soil reinforcement. Four steel HP12 x 74 piles, were driven through the MSE wall, 0.8 to 1.4 m (31 to 54 in) behind the full-height precast concrete wall facing. This paper documents the wall design, construction, materials, instrumentation, and monitoring results of this full-scale demonstration/ testing. The design implications and the advantages of this proposed construction technique are summarized.

TEST WALL

A mechanically stabilized earth (MSE) retaining wall with full-height precast concrete panels and uniaxial high density polyethylene (HDPE) geogrid soil reinforcements was selected for the test, see Figure 1. An elevation and a plan view of the structure are shown in Figure 2.

Figure 1. Pile diving through a full-height precast concrete panel faced geogrid-reinforced MSE wall.

Piles and Driving Equipment. Four steel HP 12 x 74 piles were driven through the abutment reinforced mass after the wall was backfilled to the top. The piles were driven at a distance from the back of the panels varying from 0.8 m (31 in) to 1.4 m (54 in) (Figure 2b). Each pile had identical drive points fillet-welded to the toe (Figure 3). A Manitowoc 222 pile driver was used to install the piles. A hydraulic pile hammer, Junttan HHK6 (Figure 1), with a maximum energy of 72 kN-m (53 ft-kip). One of piles was installed through a 0.6-m (2 ft) sleeve extending 2 m (7 ft) beneath the top of wall.

Wall Design. The design of the test wall was based on the National Concrete Masonry Association (NCMA) design guidelines. The soil reinforcement was under-designed to exaggerate the effect of driving piles through the reinforced fill on the face panels. The geogrid elevations are noted on Figure 2c. A typical cross section is shown on Figure 4.

Two different reinforcement layouts were used for the center and the wing sections of the wall. The center panel used lower strength geogrids than the two outer panels. The lower strength reinforcements were used to exaggerate potential panel face movements caused by pile driving. The tensile strength and connection strength safety factor ranged from 1.29 to 7.7 for the five layers of reinforcement, as listed in Table 1, and based upon design strengths for temporary loadings. The two outer panels used higher strength geogrid compared to the center panel. The heavier, higher strength reinforcements were used to maximize reinforcement resistance to pile driving. Two layers of geogrid in the center panel were instrumented. The full length of these layers was cast into the panels to eliminate any possible effect of the joints on geogrid strain readings. All other layers were connected with HDPE connectors (bodkin bars) to short tabs of geogrid wet cast into the panels.

Instrumentation. Locations of the instruments to monitor the abutment during construction and pile driving are noted in Figure 4. Also noted in Figure 4 are the geogrid soil reinforcements used in the center and outer panels and the location of the 10-foot deep sleeve used with the one pile. Instruments and measurements are discussed below, under Observations During Pile Driving.

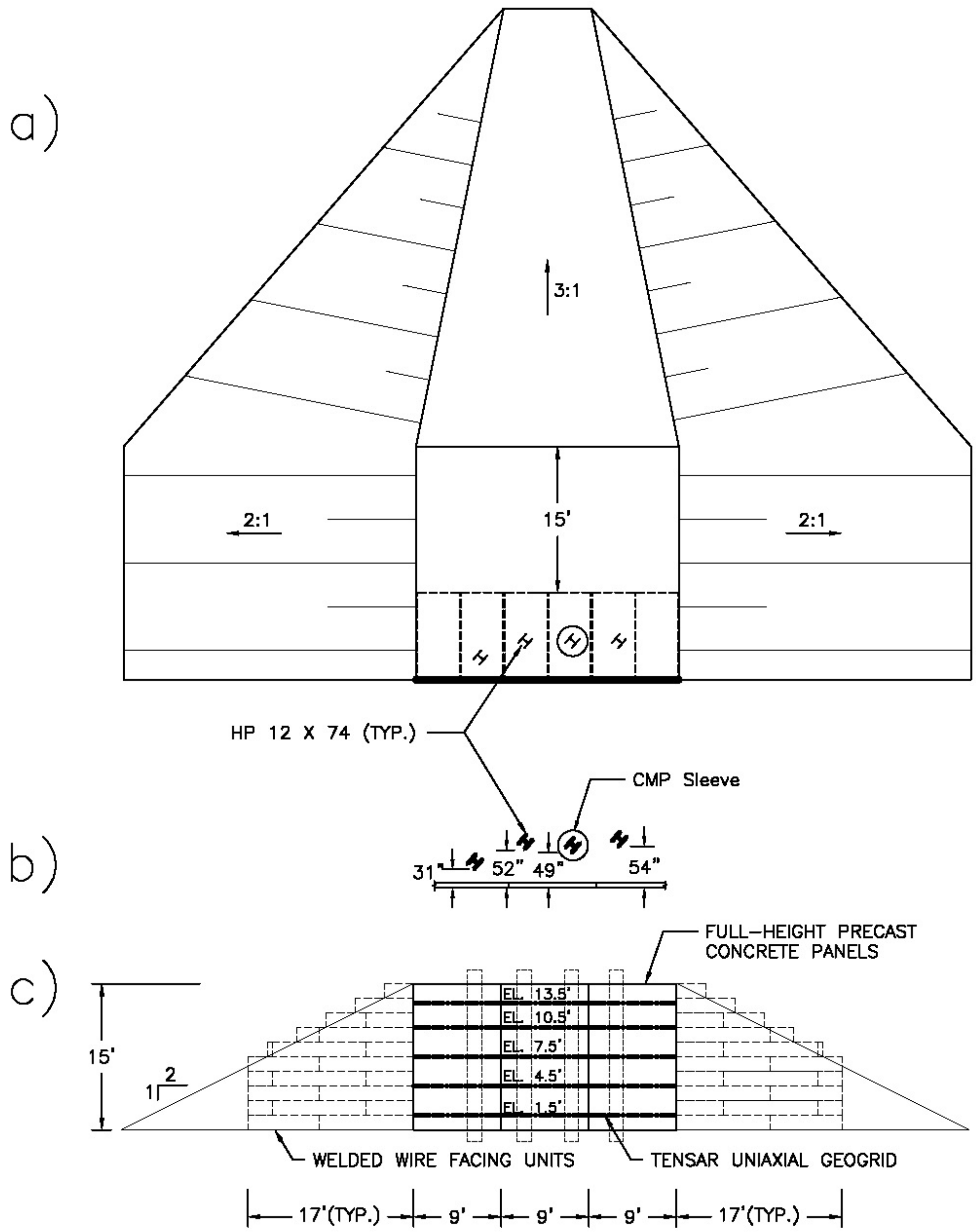


Figure 2. Field-scale test bridge abutment structure: (a) plan view; (b) pile location in plan view; (c) elevation view.

Table 1. Wall Design: Factors of Safety for Connection and Geogrid Strength, Based Upon Temporary Loading Condition.

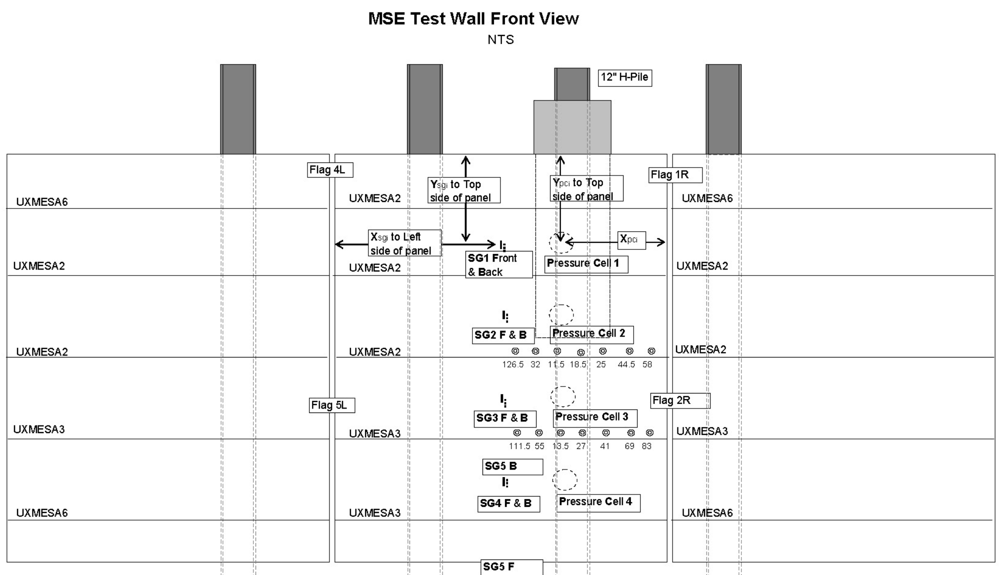
Geogrid Layout: Elevation Above Leveling Pad, m	(ft)	Type	Factor of Safety for Connection Strength	Factor of Safety for Geogrid Strength
Center Panel				
0.46	(1.5)	UXMESA3	1.29	1.29
1.4	(4.5)	UXMESA3	1.66	1.66
2.3	(7.5)	UXMESA2	1.82	1.82
3.2	(10.5)	UXMESA2	3.21	3.21
4.0	(13)	UXMESA2	7.74	7.74
Outer Panels				
0.46	(1.5)	UXMESA6	3.27	3.27
1.4	(4.5)	UXMESA3	1.66	1.66
2.3	(7.5)	UXMESA2	1.82	1.82
3.2	(10.5)	USMESA2	3.21	3.21
4.0	(13)	UXMESA6	25.1	25.1

MSE WALL CONSTRUCTION

Wall construction was completed on 7 November 2000. Piles were driven through the reinforced soil abutment on 14 November 2000. Location of piles relative to the wall face and approximate orientation are illustrated in Figure 5. Abutment dismantling and inspection started on 14 November, after completing pile driving and after applying a lateral load to one pile.

Figure 3. Pile drive point attachment.

Construction of this demonstration abutment wall consisted of the following steps: (1) Low strength concrete leveling pad is cast. (2) After curing, holes are drilled near the front edge of the leveling pad and panel alignment pins were inserted to provide minimum (versus typical construction technique) lateral restraint and maximize potential panel movements due to pile driving. (3) The precast concrete, full-height facing panels are set on the leveling pad. (4) The panels were set with an initial batter of approximately 4 mm per 0.3 m (5/32 in./ft). (5) Panels were braced at the top point, until backfilling was completed, to maximize potential panel movements due to pile driving. (6) Panels were clamped to adjacent panels, to prevent differential rotation of adjacent panels during backfill placement and compaction. (7) Wall fill was placed and compacted, to the respective elevations of the geogrid soil reinforcement. (8) Reinforcement lengths were bodkin-connected to the tabs extending from the precast facing panels, tensioned to remove the slack in the bodkin joint by leveraging back on the tail of the reinforcement with a pitch fork, and tension was held until fill was placed on and anchored the geogrid. The instrumented geogrid layers on the center panel were full length and cast into the panel. (9) Fill placement and compaction, and reinforcement placement and tensioning continued until abutment fill reached the top of the wall panels. (10) One 0.6-m (2-ft) diameter corrugated metal pipe pile sleeve was placed vertically in the fill and extended to a depth of 2 m (7 ft) below top of facing panel. One of the piles was driven within this sleeve.



Instrumentation Positions:

	X_{sg} to Left	Y_{sg} to Top		X_{pc} to Right	Y_{pc} to Top	Y_{pc} to Bot
SG1 F	52.5"	38"	PC1(33965)	40.5"	38	11.83
SG1 B	51.75	38.25				
SG2 F	52	73.75	PC2(33962)	39.5	70.5	9.13
SG2 B	51.75	71.5				
SG3 F	52.5		PC3(33963)	39	107	6.08
SG3 B	53.5					
SG4 F	51.25	144.5	PC4(33964)	40	144.5	2.96
SG4 B	55.5	144.5				
SG5 F	Center	On Ground				
SG5 B	55.5	144.5				

Note: The two insturemented layers in the center panel were full length grids cast into panels. All other layers were bodkin connected to short tabs of grid cast into the panels.

Figure 4. Instrumentation and geogrid layout.

OBSERVATIONS DURING PILE DRIVING

Pile Driving. The four steel HP 12 x 74 piles were driven through the reinforced mass in a sequence right-to-left looking at the front elevation view of Figure 4. The centerline of the project piles are detailed to be 1.6 m (10.3 ft) back from the front face of the wall panel. The first three demonstration piles were installed at approximately the project design distance behind the wall panel. The fourth pile was installed at a distance of 1.0 m (3.3 ft) back from the front face of the wall panel. This pile was driven closer to increase the effect of pile driving on the facing panel.

Piles were easily driven through the 4.6-m (15-ft) thick reinforced fill, at about 1 blow per 0.3 m (1 ft) foot and a hammer stroke of approximately 0.30 to 0.41 (12 to 16 in). The first three piles were driven near vertical. The fourth pile, closest to the facing, was driven with a slight outward batter. Skew of the piles varied somewhat, as the pile driver remained stationary for the driving of all four piles, and rotated around its set up point. Instruments were read after panel erection, during backfilling, prior to driving piles, after driving piles, and after applying a lateral load to one of the piles.

Measurements. *Contact Earth Pressure Cells.* Four pressure cells were used to measure and monitor total stress lateral soil pressure against the backside of the center facing panel. The cells are illustrated on Figure 4 as dashed-line ovals and are labeled Pressure Cell 1 through 4. The four cells were mounted to the back of the center precast concrete facing panel in a vertical line, and in front of the planned location of one of the piles to be driven. Design and measured pressures before and after pile driving are summarized in Table 2. Only small variations in pressure (-3.5% to +13.5%) were noted after pile driving. Measured pressures were significantly less than design pressures, except at PC2. Pressures at PC2 were likely effected by the adjacent corrugated metal pile sleeve.

Table 2. Measured and Design Earth Pressures at Back of Face Panel.

Cell:	PC1		PC2		PC3		PC4	
Design Pressure, kPa (psf)	5.0	(105)	10.0	(210)	15.1	(315)	20.1	(420)
Measured Pressure, kPa (psf)								
Before Driving Piles	1.8	(37)	8.8	(184)	1.4	(29)	3.6	(75)
After Pile Driving	2.0	(42)	8.8	(183)	1.3	(28)	4.0	(84)

Panel Survey Flags. Four measuring tape lengths, or flags, were mounted to the facing panels at the adjacent panel joints. These flags extended perpendicular to the facing panels and were used to measure and monitor batter of the panels. The four flags are labeled Flag 1R through 5L and their locations shown on Figure 4.

The average facing panel batter as erected, after backfilling and after pile driving are illustrated in Figure 5. The facing rotates during backfilling, as expected, and only a small rotation was observed due to pile driving. A small translation of the toe, approximately 6 mm (¼-in) was recorded.

Strain Gages. Ten strain gages were used to measure and monitor stress on the front and back face of the precast concrete, full-height facing panel. These gages were mounted to the surface of the precast panel. Maximum measured strains of 0.15% were measured in both faces, for both wall backfilling and for piling driving activities.

Soil Reinforcement Extensometers. Telltales constructed from threaded metal rods and PVC pipe sleeves were used to measure the extension of the geogrid reinforcement along its length. The telltales were installed on two layers of geogrid at El. 1.4 m (4.5 ft) and El. 2.3 m (7.5 ft). The telltale locations are shown on Figure 4.

The soil reinforcement telltale readings were used to calculate the change in the length for different conditions and the average strains in the geogrid. The computed average strains in the geogrid for different stages of the construction are shown in Figure 6 for the 2.3-m (7.5-ft) elevation. The telltale readings that were within the accuracy tolerance of 2-3 mm (1/"-1/16") were ignored.

The average strains measured in the geogrid generally did not exceed 0.9%, which indicates significantly less tensile load on the reinforcements than the design loads. The average strain induced by the pile driving was 0.31 %, and the maximum average strain induced by the lateral loading on the pile was 0.16 %. The maximum average strain due to fill placement, pile driving and lateral loading was measured at the 58-inch-long tell-tale at elevation 2.3 m (7.5 ft). Maximum average strain of 0.6% due to fill placement and effects of fill freezing was measured at the 25-inch-long tell-tale at elevation 2.3 m (7.5 ft), which seems to indicate increase of loads at the connection. However, the measured changes in the length of the shorter tell-tales were very close to the accuracy of the measurements and the results are somewhat misleading. This is confirmed by the trend of the measured average strains accumulated throughout the experiment from fill placing to lateral loading of the piles.

The fourth pile driven through the reinforced soil fill was only about 1.0 m (3.3 ft) from the front side of the facing panel. And the pile was driven at a slight batter. The pile translated outward, towards to the wall face, 63 mm (2½ in) as measured at the top of the fill. These two conditions should increase load on the facing panel, versus the other three piles. However, response of the facing adjacent to this panel was similar to the other three piles.

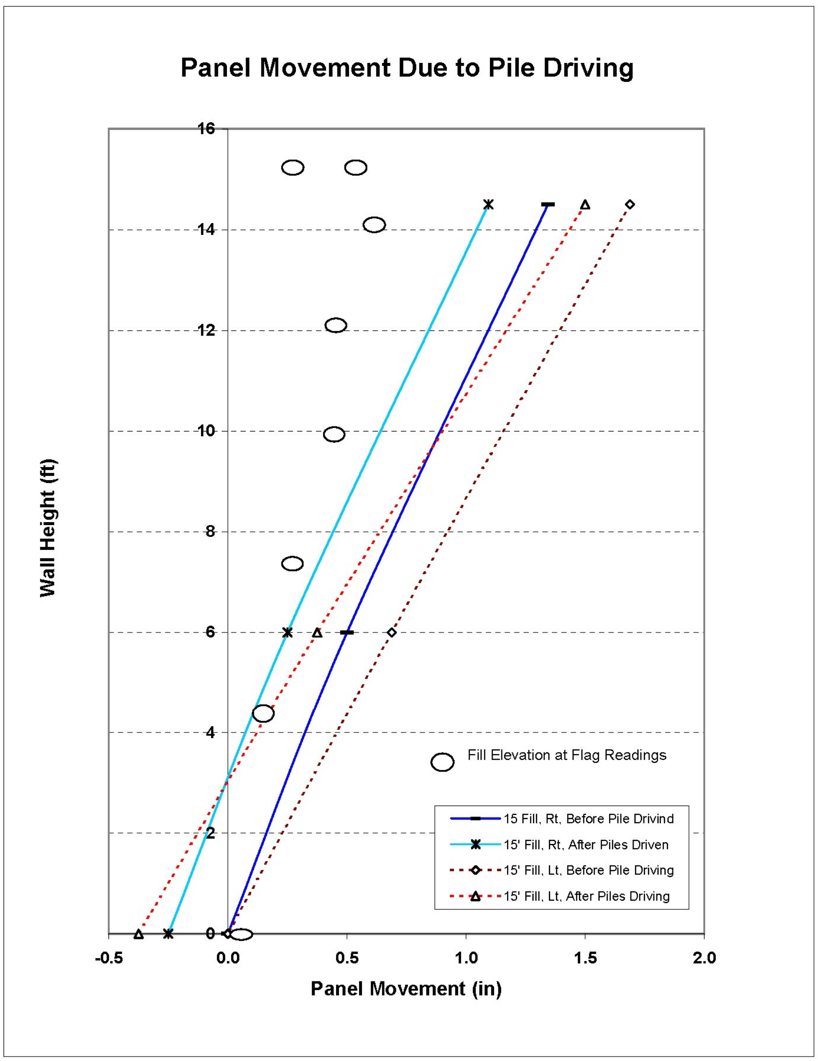


Figure 5. Measured lateral rotations and toe translation.

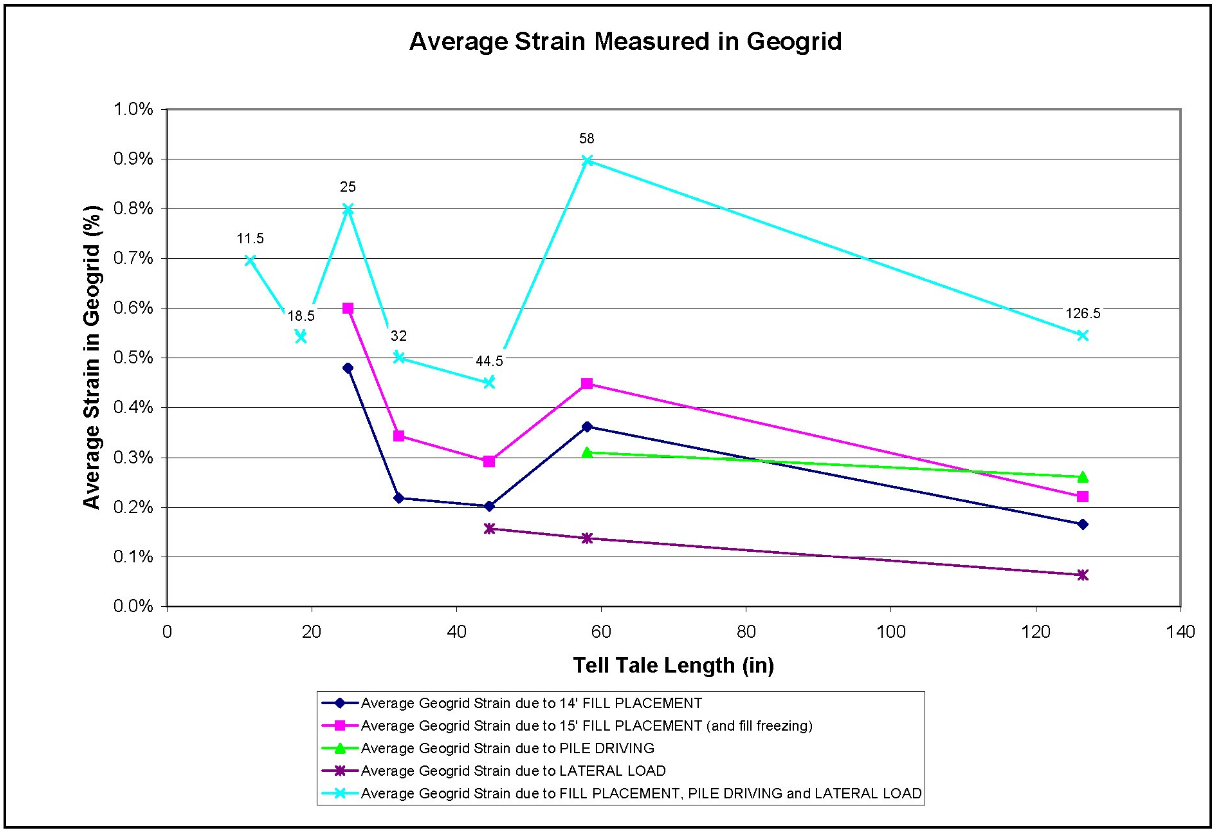


Figure 6. Average geogrid strain at 2.3 m (7.5 ft) for different construction stages.

OBSERVATIONS AFTER PILE DRIVING

After installing the four piles, a large lateral load was placed on the first pile (Figure 7). This loading was applied to observe response of the facing panel, and to investigate possible elimination of the 3-m (10 ft) long sleeves. The loading pushed the pile 75 mm (3 in) outward. The load was released and an additional rotation of 6-mm (¼-in) at the top of wall was measured. No visual affects on the wall face were noted.

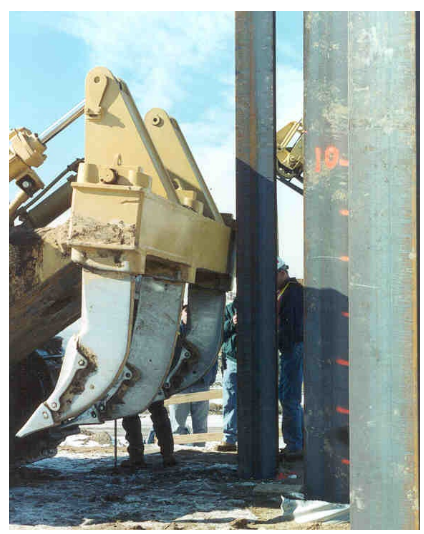


Figure 7. Applying lateral load to pile.

The soil fill was carefully removed after testing to reveal the HDPE geogrid soil reinforcement. The steel H-piles with pile toe attachments. The soil fill was carefully removed after testing to reveal the HDPE geogrid soil reinforcement. The steel H-piles with drive points were cleanly driven through the geogrid (Figure 8). The geogrid was not damaged outside of the pile footprint. Neither excessive rotation nor excessive lateral movements were observed during the driving of all four piles. Nor was damage to the full-height concrete facing panels observed.

Figure 8. Penetration of pile.

DISCUSSION

This demonstration/test wall was constructed as part of the Colorado E-470 project. The following questions were to be answered by this demonstration/test wall: (1) Can piling be effectively driven through an HDPE geogrid reinforced wall system? (2) Does pile driving cause excessive rotation or lateral movement of wall face panels? (3) Does pile driving damage the face panels? (4) How are layers of geogrid reinforcement affected by the pile penetration? (5) Does lateral loading on uncased piling cause excessive rotation or lateral movement of wall face panels?

(1) The construction of the test wall used conventional construction techniques and equipment. Outside the 0.9 m (3 ft) area next to the facing panel, the reinforced fill was compacted with heavy compaction rollers minimizing the potential for water migration and future settlements due to under compacted fill. The piles were easily driven through the 4.6-m (15-ft) thick reinforced fill at about 1 blow per 0.3 m (1 ft) while at depths four or more blows per 0.3 m (1 ft) were necessary. The presence of the HDPE geogrid reinforcement did not hinder the driving of the piles.

(2) Excessive rotation and/or lateral movement of the facing panels were not observed during backfilling, pile driving and lateral loading on one of the piles. The instrumentation readings indicated significantly lower lateral loads and reinforcement forces relative to values used in design.

(3) Distress to the full-height concrete facing panels was not observed during backfilling, pile driving and lateral loading on one of the piles, even though one of the piles was installed with an outward batter and within 1 m (3.3 ft) from the front face of the panel.

(4) The effects of pile penetration on the HDPE geogrid reinforcement were observed at the end of the experiment. It was observed that the HDPE geogrid was cleanly cut by the steel H-piles and was not damaged outside of the pile footprint.

(5) The response of the wall facing to a large lateral load applied on the first pile and during pile driving indicated that the elimination of the casing did not cause detrimental effects on the wall performance. The instrumentation readings indicated that the casing did not alleviate the observed movements and thus it can be eliminated without compromising the wall performance.

This construction technique eliminates the placement of soil reinforcement, and the placement and compaction of wall fill around driven piles or piles sleeves. Thus, the potential benefits of not constructing around these obstacles are expedited construction and a more competent (compacted) wall fill.

This soil reinforcement was under-designed on this demonstration/test wall to exaggerate the effects of pile driving.

The constructability of driving steel H piles through the HDPE geogrid reinforced fill of a full-height panel wall was clearly demonstrated. Further research of the long term effects of this construction technique is recommended to extend the application of this construction technique to other types of MSE walls.

Although the five questions were answered with this demonstration/test wall, this construction technique was not used on the Colorado E-470 project due to project time constraints and the need for re-evaluation of the superstructure design.

Limitations. Monitoring to investigate any long-term movements was not within the scope to this investigation/test. It should be recognized that the pile casing is used in the bridge construction practice to accommodate seasonal movements of integral abutment bridges that are longer than 30 m (100 ft). The elimination of the casing and its effect on the performance of the superstructure was not evaluated with this project. Different types of wall fill or reinforcement might give different results.

CONCLUSIONS

The construction technique of driving steel H piles through the reinforced soil of a full-height panel retaining wall with HDPE geogrid soil reinforcement was clearly demonstrated. No significant loads, stresses or movements were observed during or immediately after pile driving.

Furthermore, the following answers to the five questions (see Discussion) were concluded. (1) Yes, steel H piling can be driven through an HDPE geogrid reinforced soil MSE wall in clean soil without any special equipment or techniques. (2) No, neither excessive rotation nor excessive lateral movements were observed at this demonstration project during driving of all four piles. (3) No, damage to the wall facing panels was not observed. (4) The HDPE geogrids were cleanly cut by the piles. There was no damage to the geogrid outside the flanges of the piles. The state of stress (as measured with strains) of the geogrid reinforcement was not significantly altered by the pile driving operation. (5) No, neither excessive rotation nor excessive lateral movements were observed at this demonstration project, during driving of all four piles.

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