CASE STUDY: INSTRUMENTATION OF A HYBRID MSE WALL SYSTEM WITH UP TO 2 M VERTICAL SPACING BETWEEN REINFORCEMENTS

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ABSTRACT

A "hybrid" mechanically stabilized earth (MSE) wall that is 16 m (52.5 ft) tall was recently constructed in Izmir, Turkey, which is located in a highly seismically active part of the World. The wall was constructed with gabion basket facings with double twisted wire mesh tails and geogrid reinforcements overlapping the wire mesh tails. Two sections of the wall were instrumented to evaluate the effect of vertical spacing between the geogrid reinforcements. One of the sections was constructed with 1 m (39 in) vertical spacing between reinforcements and the other one with 2 m (78 in) vertical spacing (geogrid was placed in between every other gabion basket). Both of these vertical spacing were higher than what was allowed in the U.S. by federal agencies at the time of the construction. This article summarizes the data obtained from the instrumentation program that was developed to monitor the performance of these structures.

1. INTRODUCTION

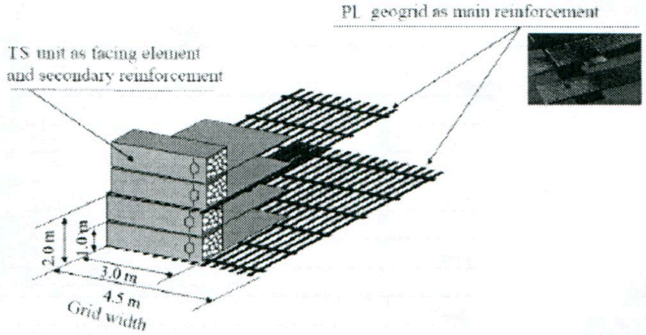
Constructing the facing of the mechanically stabilized earth walls (MSE) reinforced with geosynthetics and with gabion basket facings is not a new idea. In the U.S., these structures are historically built with reinforcements that are typically spaced vertically no more than 0.8 m (32 in) because until recently the U.S. federal regulations set forth by the Federal Highway Administration (FHWA, 2009) and American Association of State Highway and Transportation (AASHTO, 2014) had a requirement to limit the vertical spacing of the reinforcements to 0.8 m (32 in).

However, over the last five years several MSE walls have been built around the World with a newly developed hybrid system where the reinforcements could be spaced higher than 0.8 m (32 in) apart. One of these structures was built in Albania for a highway project and the other one in India for an airport project. The project in Albania involved construction of 30 composite reinforced soil structures with a total wall facing of 35,000 m2 (41,860 sy) and maximum wall height of 40 m (131 ft). Part of the terrain required the structures to be constructed with steep (84o) facing, which was accomplished by combining two different systems: a galfan (Zn-Al 5% alloy) and PVC coated double-twisted steel wire mesh unit forming the rock filled facing section (which served as secondary reinforcement), and a high strength polyester geogrid encased in a durable polyethylene sheath (which served as primary reinforcement). The primary reinforcements were vertically spaced at 1 and 2 m (39 and 78 in) apart respectively. The construction of the walls in Albania were completed in 2011 and at the time this structure was amongst the highest of its type constructed anywhere in the world. The project in Sikkim, India involved construction of MSE structures up to 74 m (243 ft) in height along a mountain near a newly proposed airport. The earth retaining structures consisted of 1 m (39 in) high gabion blocks in a near vertical configuration at the bottom of the fill and then a reinforced slope (i.e., 65o from horizontal) above. The near vertical facing was constructed at an angle of 6o from vertical and was combined with high strength geogrid reinforcement (up to 800 kN/m (590 k/ft) to create the reinforced soil mass. The geogrid reinforcements were installed typically at the same spacing as the gabion baskets at 1 m (39 in) but there were also sections where the reinforcements were 2 m (78 in) apart. The construction of this structure was completed in 2012, however during construction, in 2011, the reinforced soil structure was inundated with over 3.9 m (12.8 ft) of rain and a 6.9 magnitude earthquake without any visible signs of distress. The details of how both of these structures were designed have been previously presented by Rimoldi and Scotto (2012). Although both of these structures proved the relevancy of using the above mentioned hybrid gabion/geogrid technology with vertical spacing greater than what is typically implemented in the U.S., neither of these structures involved a detailed instrumentation program. This article is written to present an instrumentation case study, where a very similar as those described above was constructed in Izmir, Turkey.

2 CHARACTERISTICS OF THE IZMIR WALL

There were total of twenty walls constructed in Izmir as part of a large construction project. Two of these walls with similar foundation characteristics were selected for instrumentation. The purpose of the overall project was to develop leveled ground surfaces in a very hilly terrain to construct large storage tanks for a petrochemical refinery. Details of the design of the Izmir walls have been previously presented by Ozcelik et al. (2014).

The area where the instrumented walls were constructed is within a first-degree seismic zone where the peak ground acceleration (PGA) for the design had to be selected as 0.75 g. Therefore, a flexible system that could withstand larger seismic activity (with a proven record) and a free-draining facing (Izmir has long rainy seasons in fall and winter) were essential components of the selection criteria for the wall system. The hybrid gabion/geogrid technology used in Albania and India provided an opportunity to fulfill both of these requirements as there was a well-documented track record. Therefore, this system was selected by the owner as the most suitable solution for the project. The hybrid structure constructed in Izmir consisted of gabion basket facings that were 1 m (39 in) high and 3 m (9.9 ft) wide with a tail consisting of 3 m (9.9 ft) long double twisted wire mesh and high strength uni-axial geogrids. The geogrids composed of high-density polyester yarn that were coated with polyethylene sheaths. The geosynthetic reinforcement was frictionally connected in-between gabion baskets. The first 2 m (6.6 ft) of the geogrid reinforcement was overlapped with the wire mesh tail. The geogrids were designed to provide the "primary reinforcements" against the tensile forces required for the global stability; while the tails of the double twisted wire mesh were used to provide the local stability at the face against the local mechanism of direct sliding, pullout or rotational failure as they were part of each gabion basket. The vertical spacing between the geogrid reinforcements were selected to be 1 m (39 in) apart on one of the instrumented wall section (geogrid was placed in between every gabion baskets) and 2 m (78 in) apart on the other instrumented wall section (geogrid was placed in between every other gabion baskets) although the first 2m (6.6 ft) of both walls were constructed the same way with 1 m (39 in) vertical spacing between reinforcements. Figure 1 shows the schematic of the 2 m (78 in) spaced reinforcements. The transverse rebars were used to mount load cells on the surface of the wall.



Note: The circles on the facing represent the transverse rebars attached to the wire mesh on the facing.

Figure 1. Configuration of hybrid MSE wall constructed in Izmir-Turkey (after Ozcelik et al., 2014).

3 INSTRUMENTATION PROGRAM

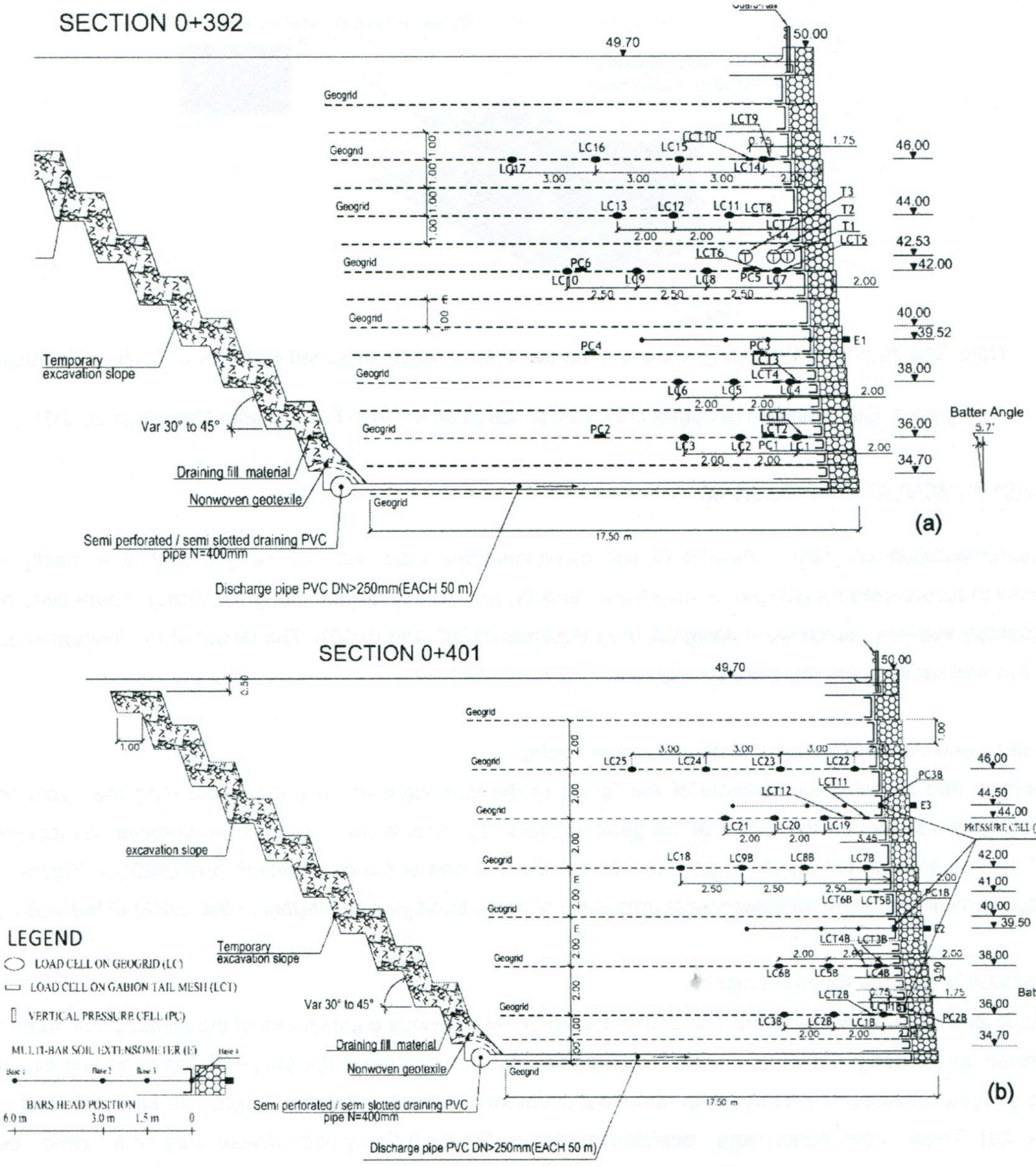
The instrumentation program consisted of soil extensometers, load cells on geogrid and wire mesh, vertical and horizontal pressure cells on geogrid, temperature sensors, and survey targets along the facing. There were two different instrumented sections, which were designated as Sections 0+392 and 0+401. The layout of the instrumentation used in these two wall sections are depicted on Figure 2.

3.1 Lateral and Vertical Displacements on Gabion Facing

The vertical and lateral displacements of the facing of the wall were monitored by recording the coordination of the survey targets installed on the facing of the gabion blocks. To date, there has been two surveys, immediately after the end of the construction (01/29/2015) and six months after the end of the construction (07/02/2015). Figure 3 shows the recorded vertical and lateral displacements from each of these surveys with respect to the height of the wall from the toe.

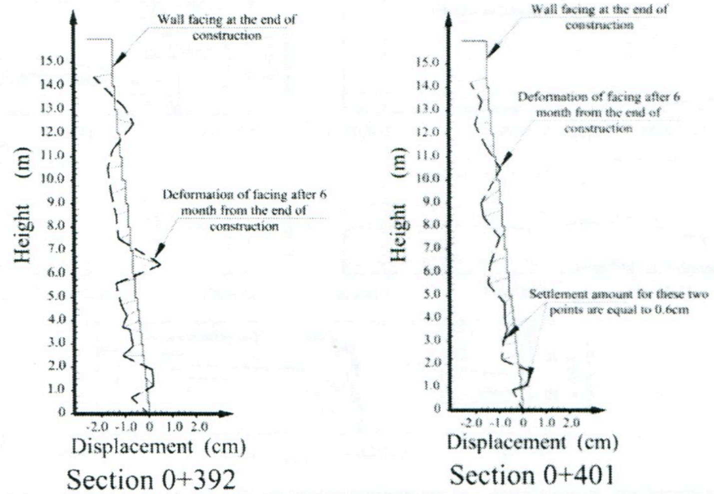
3.2 Tension in Geogrid Reinforcement

A specific load cell was designed for this project based on the previous experiences of the investigation team to measure the tension on the geogrid reinforcements. The load cell was constructed in the shape of dog bone and directly mounted on the geogrid reinforcement straps with thin steel plates on both sides that were bolted to keep the load cell in-place (Figure 4a). These instruments were depicted on Figure 2 with (LC) symbol. These load cells were designed to provide the minimum friction and passive resistance and to carry up to 50 kN (11,240 lbf) of tensile load.



Note: PCs were installed horizontally in Section 0+392. T1, T2, T3 are temperature sensors.

Figure 2. Instrumentation layout of two wall sections: wall section with primary reinforcement spacing of (a) 1 m (39 in) and (b) with 2m (78 in).



Note: - All displacements (vertical and horizontal) are in centimeter while the wall height is in meter

- Considering the undulating surface of the gabion structure, ± 1 cm is expected to be within the survey error

Figure 3. Lateral and vertical displacements of the wall facing after 6 month from end of construction

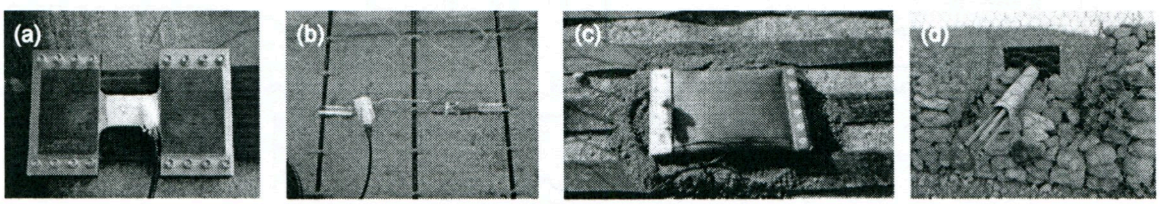


Figure 4. Instruments used in wall sections (a) load cell on reinforcement strap. (b) load cell at the facing (c) earth pressure cell, and (d) 4-bar extensometer.

There were total of 34 load cells and the distances from the facing were selected to capture the load distribution along the length of the reinforcement in order to determine the critical internal failure surface of the structure. The recorded readings from load cells installed on both wall sections are depicted on Figure 5. As can be seen from Figure 5, three of the installed load cells failed to work, which included LC3 (that never registered any data) and LC17 at section 0+392 and LC6B at section 0+401. In order to better compare the data from each wall, tension recorded at the end of construction by all load cells on geogrid reinforcement that were constructed at the same height in each wall have been graphed (Figure 6).

3.3 Tension on Wire Mesh Tail

The adherence between the gabion baskets used on the facing and the geogrid reinforcement was maintained by the frictional connection of the double twisted wire mesh tail that was extended from the bottom of the gabion basket (Figure 1). The overlap length between the geogrid and the wire mesh was 2 m (6.6 ft). This wire mesh was also enhanced with

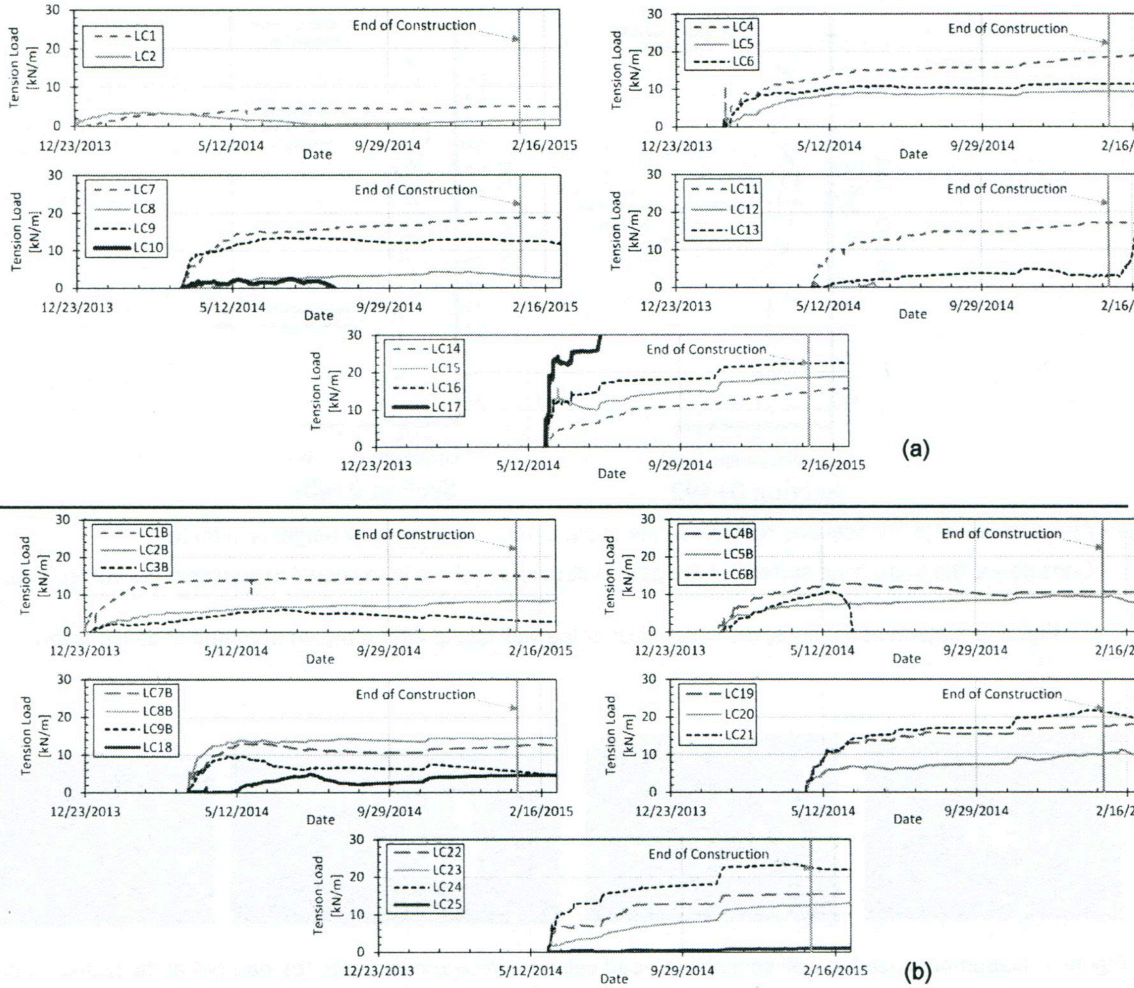


Figure 5. Data from the load cells installed on geogrid on wall sections (a) 0+392 and (b) 0+401.

transversal steel bars that were inserted parallel to the wall facing in order to contribute to the stability of the facing. As part of this investigation, sections of the wall were instrumented with a custom-made load cell that were mounted on these steel bars (Figure 4b). These instruments were depicted on Figure 2 with (LCT) symbol. These load cells were designed to be low in modulus so that their effect on the stress distribution along the steel mesh was negligible.

Two cells were installed on each steel wire system and each was calibrated separately in order to determine the deformation and modulus characteristics. The recorded data from these load cells from both instrumented sections are presented in Figure 7 Ten load cells were installed at Section 0+392 and 8 at Section 0+401. Two of the cells installed at Section 0+401 were installed at a level where there was no geogrid reinforcement (see Figure 2b at elevation +41.00 m (134.5 ft)). LCT7 and LCT8 never showed a response indicating installation damage and LCT1B stopped working after nine months. In order to better compare the data from each wall, tension recorded at the end of construction by all load cells on steel wire mesh have been graphed to show the decrease in load with distance from the wall facing and at different wall heights (Figure 8).

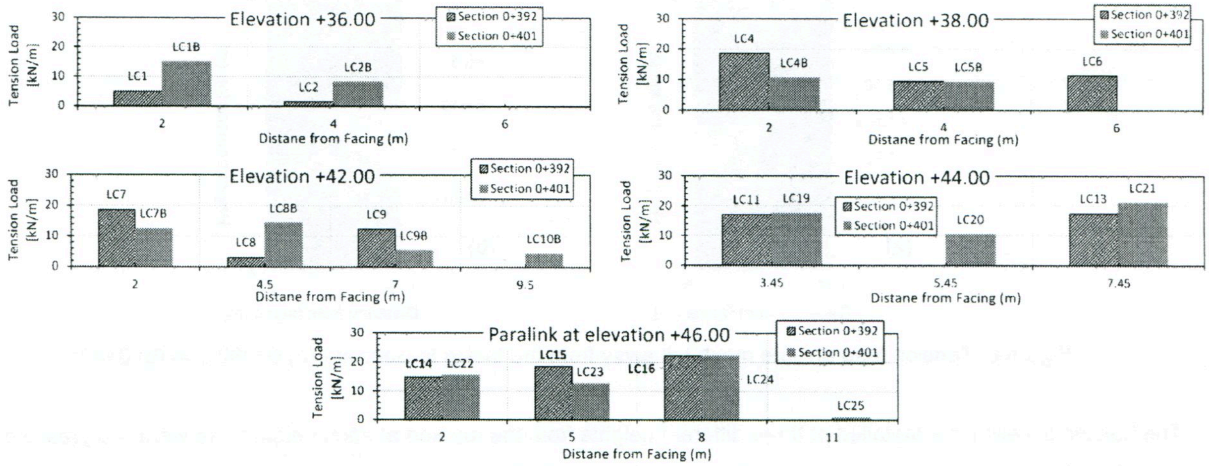


Figure 6. Tension recorded on geogrid reinforcements (at the end of construction) from both instrumented wall sections.

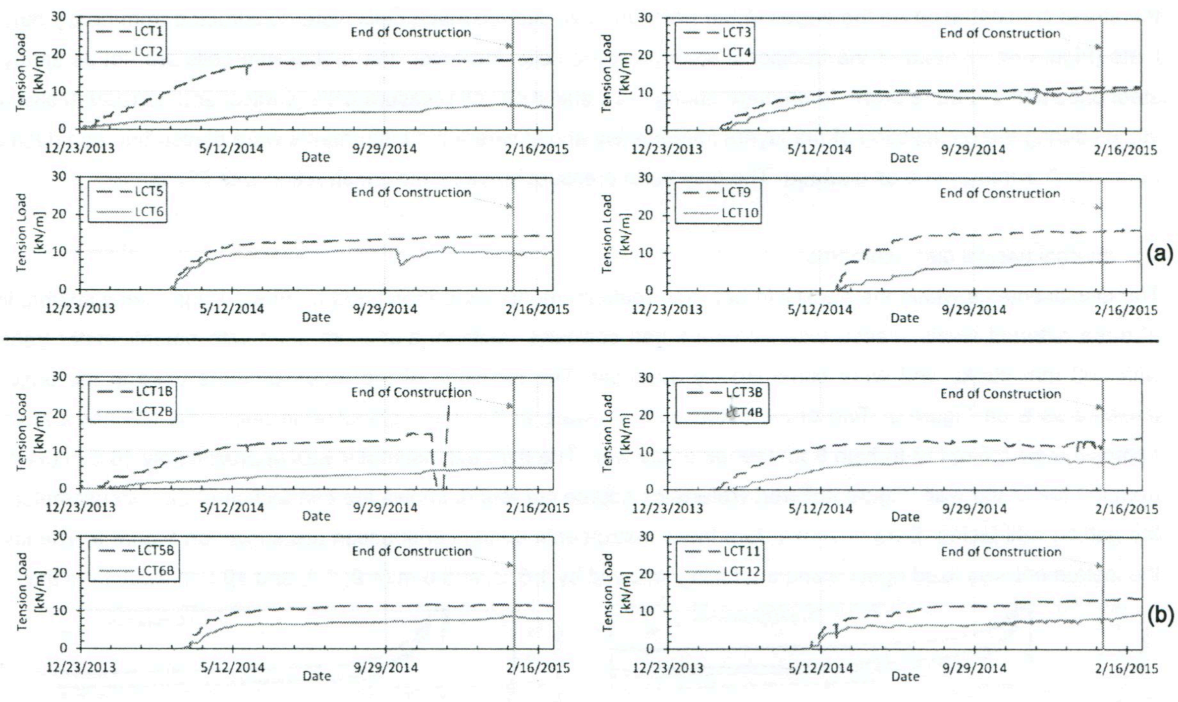


Figure 7. Data from the load cells installed on wire mesh tail on wall sections (a) 0+392 and (b) 0+401.

3.4 Horizontal and Vertical Earth Pressures

A total of 9 pressure cells (6 horizontal and 3 vertical) were installed to measure the pressure conditions within the wall. For the 1 m (39 in) vertical reinforcement spacing horizontal pressure cells were installed in order to compare with more conventional reinforcement spacing (i.e., less than 32 inches). For the 2 m (78 in) vertical reinforcement spacing, vertical pressure cells were in order to evaluate horizontal pressure at the back of the gabion baskets. All of these instruments were depicted as (PC) on Figure 2.

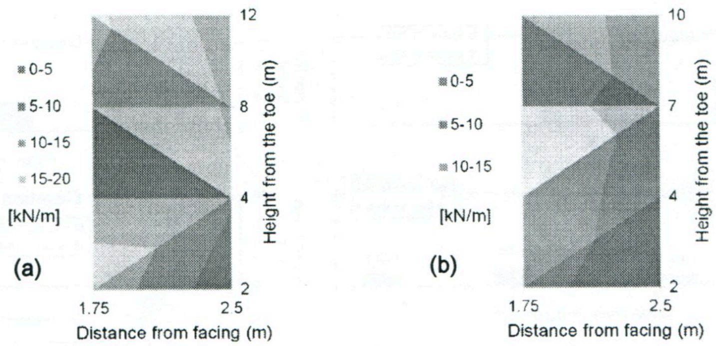
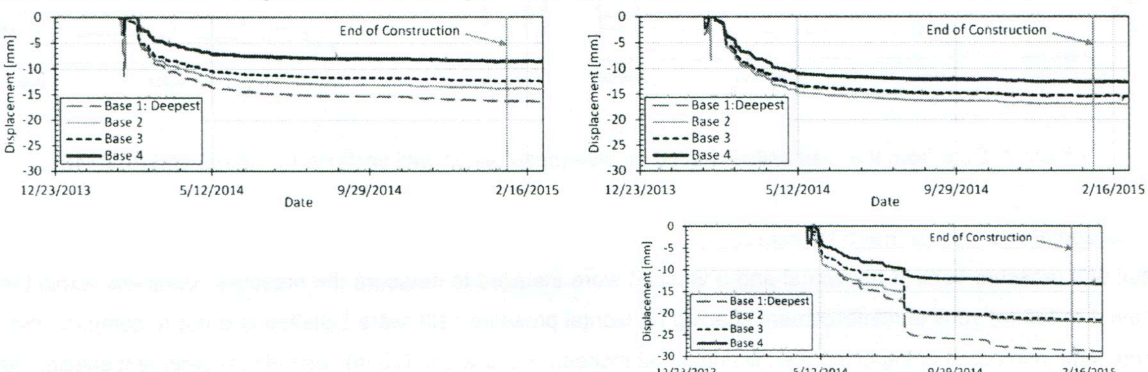


Figure 8. Tension load on wire mesh tail away from the facing in Sections (a) 0+392 and (b) 0+401.

The horizontal cells were installed at three different heights from the toe and at each height there were two pressure cells one placed close to the wall face within the twisted wire tail of the gabion and the other pressure cell was place at approximately the midpoint of the geogrid reinforcement (Figure 2a). Three vertical cells were installed right behind the gabion baskets also at three different heights from the toe (Figure 2b). In order to reduce the effect of the cell rigidity and the stress concentration on the edges of the pressure cell, custom made cells were constructed from heavy-duty rubber mats (Figure 4c) instead of the traditional steel pressure cells. However, the rubber mat cells are not as sturdy as the steel ones and are more prone to damage during the installation. All pressure cells (vertical and horizontal) showed high values during the compaction of the layers immediately above where the instruments were placed but then decreased to zero, which is interpreted as damage. The only earth pressure survived the construction was PC2B.

3.5 Internal backfill displacements

The displacements within the backfill in between reinforcements were monitored by three 4-bar extensometers installed at three different levels. These extensometers had corrosive resistant aluminum head with potentiometer transducers with 100 mm stroke and were commercially available. The locations of the extensometers used in the project were depicted as E on Figure 2. Two of the extensometers were at the same elevation in both walls (E1 and E2) and were approximately 5.5 m (18 ft) high from the toe of the wall. The third extensometer was approximately 10.5 m (34.4 ft) high from the toe of the wall. Figure 4d**Error! Reference source not found.** shows the connection of the extensometer through the gabion wall facing. Data obtained from these instruments during construction are shown on Figure 9. The first bar of the instrument was fixed right behind the facing followed by 1.5, 3, and 6 m (4.9, 9.8, and 19.7 ft) away from the facing.



Note: Negative values indicate outward displacements.

Figure 9. Data recorded from extensometers located in Sections (a) 0+392 and (b) 0+401.

4 DISCUSSIONS

The survey data showed that in both wall sections, the facing elements of the structures showed very similar behavior regardless of the differences in reinforcement spacing. In general, the movement of the facing was down and outward although there were a couple of locations that showed movements in reverse directions. The difference between the end of construction and the 6-month after survey for lateral and vertical displacements for Section 0+392 ranged from 2 mm (0.08 in) to 12 mm (0.5 in) and 0 to 8 mm (0.31 in) respectively. The same measurements for Section 0+401 ranged from 2 mm (0.1 in) to 9 mm (0.35 in) and 0 to 6 mm (0.23 in). These very small differences, within the accuracy of the survey, at the time of the second reading indicate that both structures appear to be stable and don't show any significant different in behavior in terms of internal settlement and outward movement of the facing. There were three temperature sensors placed within Section 0+392 (Figure 2a) inside the backfill (right at the facing and 1 (3.3 ft) and 2 m (6.6 ft) away from the facing). These sensors show that the temperatures within the wall section was approximately 26°C (79°F) in the summer and 8oC (46°F). In summer, the sensor that was 2 m (6.6 ft) from the facing showed approximately 2°C (3°F) colder reading and in winter the same sensor was 9oC (17°F) warmer, indicating that the temperature difference was much less than what was observed at the facing of the structure 7°C (12°F) within the backfill vs. 18°C (33°F) at the facing of the wall.

Out of 34 load cells installed on the geogrids, three failed. However, based on the remaining working load cells it can be stated that at elevations +38, +44, and +46, both walls showed very similar tension on the geogrid regardless of the differences in the reinforcement spacing (Figure 6). For elevation +36 (which is approximately 2 m (6.6 ft) above from the base of the wall), where both wall sections were constructed with same reinforcement spacing, the tension in the geogrid appeared to be at least three times higher in Section 0+401. This is possibly due to the fact that reinforcement layers in the upper portion of Section 0+401 were vertically spaced 2 m (78 in) apart, which may have created a higher magnitude dead load between reinforcement layers from the backfill of the MSE structure. However, the increased load on geogrid did not reflect on the survey results in terms of any wall facing movements. The results from elevation +42 showed conflicting results, where tension on the geogrid on Section 0+401 was much lower at 2, 7 and 9.5 m (6.6, 23, and 31 ft) away from the facing but at 4.5 m (15 ft) away from the facing it was about 4 times higher. Coupling this information with the data observed at elevation +36, it may be that the 4.5 m (15 ft) distance behind the facing could be the region where the internal failure surface is located and therefore the loads are at the highest magnitude and therefore the wall with larger reinforcement spacing showed higher tension on geogrid.

Out of 18 load cells installed on wire mesh tail, three of them failed. In general the tension on the wire mesh tail reduced with distance from the facing (Figure 8). Overall, the distribution of the tension load on the mesh that were installed at different height is fairly uniform for different distances from the facing. When the data from LCTs 5 and 6 were compared from both walls, it can be seen that overlapping the tail mesh with geogrid reinforcement reduces the tension load on the gabion tail (Figure 7). When LCT1 and LCT1B are compared, the tension on the wire line mesh in Section 0+392 is almost two times higher. This could be due to the fact that at lower elevations, due to the difference in reinforcement spacing, geogrid in the wall with 2 m (6.6 ft) spacing carries most of the load and therefore less-load is transferred on to the wire mesh. In all cases the extensometer closest to the facing showed the minimum displacement, which is most likely due to the fact of confinement provided by the wall facing. And in all cases extensometers at the furthest away from the facing showed highest displacement. At the facing, when data from E1 and E2 area compared, the extensometer placed in 1 m (3.3 ft) reinforcement spacing showed less backfill displacement than the one in 2 m (6.6 ft) spacing (8 mm vs. 12 mm respectively) but in both cases, these displacements stabilized even during construction. The extensometer

(E3) that was placed approximately 10 m (33 ft) above the toe of the wall showed similar behavior as the one placed 5 m (17 ft) above the toe until August 2014. However, in August there appears to be sudden increase in movement of up to 10 mm that may have been caused by some construction event that is undocumented (i.e., vibrations from heavy equipment, etc.).

4 CONCLUSIONS

This project demonstrated that the hybrid wall described in this article is a viable alternative to other existing wall technologies and the difference between the 1 and 2 m (39 and 78 in) reinforcement spacing did not result in significant differences in terms of tension on primary and secondary reinforcements. However, it should be noted that the results presented in this study are based on the foundation conditions, reinforcement types, and backfill used for this project.

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