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Evaluating the Effectiveness of Hybrid Geosynthetic System to Reduce Surficial Heaving Using Large-Scale Box Test

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ABSTRACT

Transportation industries encounter substantial challenges concerning ride quality and serviceability when expansive soils are encountered underneath roadway structures. These soils exhibit swell-shrink behavior with moisture variations, which cause surficial heaving on the pavement structure causing billions of dollars in maintenance and rehabilitation costs. Over the past four decades, a particular stretch of US-95 highway near the Idaho-Oregon border has exhibited recurrent pavement damages due to the underlying expansive soils. To solve this problem, the Idaho Transportation Department (ITD) has tried several different remedial measures including, lime stabilization and, vertical and horizontal barriers. However, these stabilization techniques often fall short when problematic soils are at depths greater than 1.2 m. In such cases, hybrid geosynthetic systems with geocells and geogrids were successfully used to mitigate expansive soil swelling under railroad infrastructure. However, very few studies have used geosynthetics to minimize swelling distresses for pavements and the mechanisms behind swell mitigation were not fully understood. This research explores this idea of using a hybrid geosynthetic system to mitigate differential pavement heaving and evaluate its application especially in cases where shallow chemical stabilization may not be an effective alternative. For this purpose, a large box test was developed to observe the heave due to moisture variation on pavement system with and without geosynthetic reinforcements. A highly plastic soil (PI>40) from the problematic section of US-95 was used to observe the swelling behavior. The effect of the hybrid geosynthetic system (geocell-geogrid combination) was measured and compared with the unreinforced case. The results indicate that the hybrid geosynthetic system could be used to mitigate differential heaving due to expansive soils.

INTRODUCTION

In the USA, billions of dollars are spent annually to fix the swelling related distresses on the roadways over expansive soils (Al-Qadi et al., 2009). It is usually not feasible to bypass these soils due to the widespread distribution all over the USA (Johnson et al., 1975). Typically, these soils exhibit volumetric change due to the presence of swelling mineral like montmorillonite that expands and contracts with moisture ingress and digresses, respectively (Chen, 1988). The roadways constructed over these expansive soils are subjected to surficial movement with seasonal variation and can cause upward heave and cracks on the surface of the pavements (Nelson and Miller, 1992). Several mitigation approaches including chemical stabilization, compaction, moisture barriers and pre-wetting were developed over time to overcome this issue (Woodward et al., 1968; Poor, 1979; Sebesta, 2002). However, these techniques may sometimes fall short due to the complexity of the problem and the excessive cost of implementation. For example, the authors encountered a case in Owyhee County, Idaho where a section of US 95 highway (milepost 0 to 18.5) has gone through several rehabilitation activities over the last four decades due to distresses caused by the underlying expansive soils (Islam, 2017; Tamim, 2017). Recurrent damages continued to occur in a section (milepost 16 to 18), despite the rehabilitation efforts that were satisfactory results in other parts. An extensive study by Islam (2017) revealed that the expansive soils in these problematic sections are extended to a depth greater than 1.83 m with high sulfate contents (>2000 ppm). Conventional chemical stabilizations are economically viable up to 0.9-1.2 m while Ca-based stabilizers can lead to the formation of swelling minerals like ettringite in the presence of sulfates (Puppala et al., 2012; Chittoori et al., 2016). As a solution to fix this section of the highway, the authors suggested a flexible-mechanical system using geocells and geogrids (hybrid geosynthetic system) that can mitigate the uplift pressures from the underlying expansive soils and protect the flexible pavement surface.

Hybrid Geosynthetic System (HGS) works by sharing the advantages of the component geosynthetic materials and boost the overall performance of the integrated system. The hybrid system can be comprised of geocell-geogrid, geomembrane-geogrid, geotextile- geogrid etc. based on the need of the solution (Koerner, 2012). Zornberg et al., (2012) also found that the inclusion of geosynthetics mitigated the swelling induced cracks in flexible pavements. Geocells and geogrids are very popular geosynthetic system all over the world for their reinforcing mechanism (Koerner, 2012). Geocells are known as cellular confinement systems with 3-D honeycombed structure and they have confinement, hoop stress, and horizontal frictional resistance benefits (Tsorani, 2008) whereas geogrids, consist of tensile ribs with large apertures for the interlocking mechanism and have lateral frictional resistance and membrane effect as their benefits (Zornberg et al., 2008). When both these materials are placed in a combined/hybrid system, a collective reinforcing effect is generated which not only has confinement and hoop stresses but also lateral resistance and tension effect. Figure 1 illustrates the combined effect of a hybrid geosynthetic system using geocell and geogrid combination.

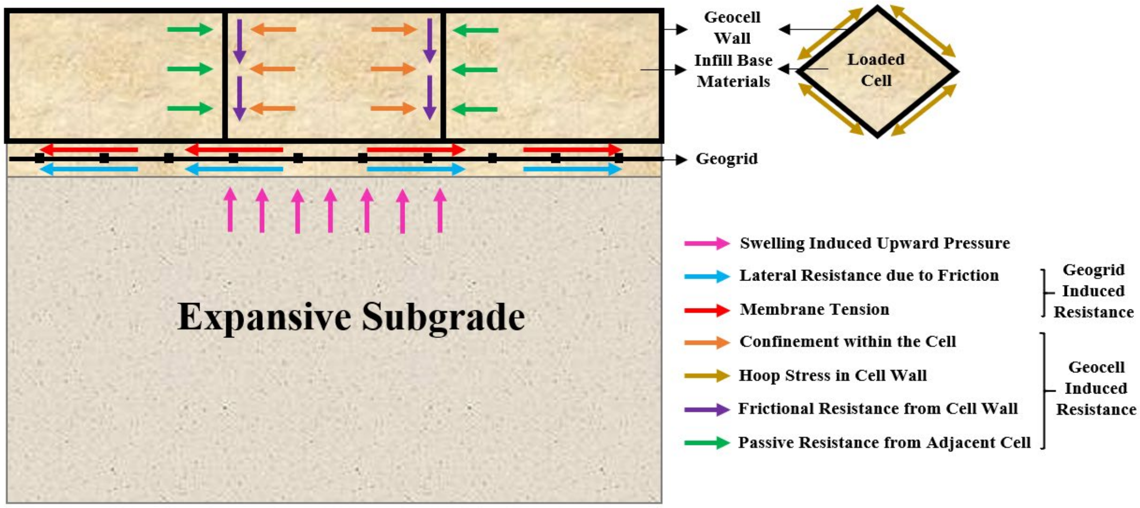


Figure 1. Illustration of the reinforcing mechanism of hybrid geosynthetic system.

HGS is not a common mitigation approach to solve expansive soils related distresses in transportation infrastructure. A few studies were conducted on railroads and embankments which demonstrated the combined benefit of the geocell-geogrid hybrid system (Sitharam and Hedge, 2013; Kief, 2015). Sitharam and Hedge (2013) investigated the performance of geocell-geogrid combination over the soft settled red mud in embankments and found that the hybrid geosynthetic system increased the bearing capacity by four to five times that of the control case. The interconnected cells formed a panel mattress and transferred the load to a larger area decreasing the contact pressure thereby leading to better overall performance. Their results also indicated that the combination of the geocell and geogrid was more beneficial than geocell alone. It was noted that the inclusion of geogrid mobilized extra support in clay bed and resisted the settlement of the footing. Another study by Kief (2015) revealed the potential of a hybrid geosynthetic system in mitigating volume changes in a railroad overlaid on expansive soils. Kief (2015) used a stiff biaxial geogrid located at the subgrade/pavement interface was used in combination with a stiff geocell layer embedded in the unbound granular layer. The stiff geogrid provided a working platform for the stiff geocell layers, which act like an 'I' section; this combined shape generated a unique composite strength which surpassed the sum of individual effects. This semi-rigid composite mattress acted as a foundation which separated the weaker subgrade from the upper rail track structure and mitigated the surficial heave. Stiff geocells over weak soil act as a stable working platform and provide resistance to swelling distress (Kief, 2015). The performance of this hybrid system was verified by track monitoring measurements which showed negligible surficial distresses compared with the unreinforced section. Based on these examples it is evident that there is good potential for hybrid geosynthetic systems to strengthen the base/subbase layers and improve swell mitigation on pavement surfaces. In the current research, the efficacy of hybrid geosynthetic systems as a flexible mechanical system to mitigate the heaving distresses coming from underlying expansive soils in the problematic section of US 95 was evaluated.

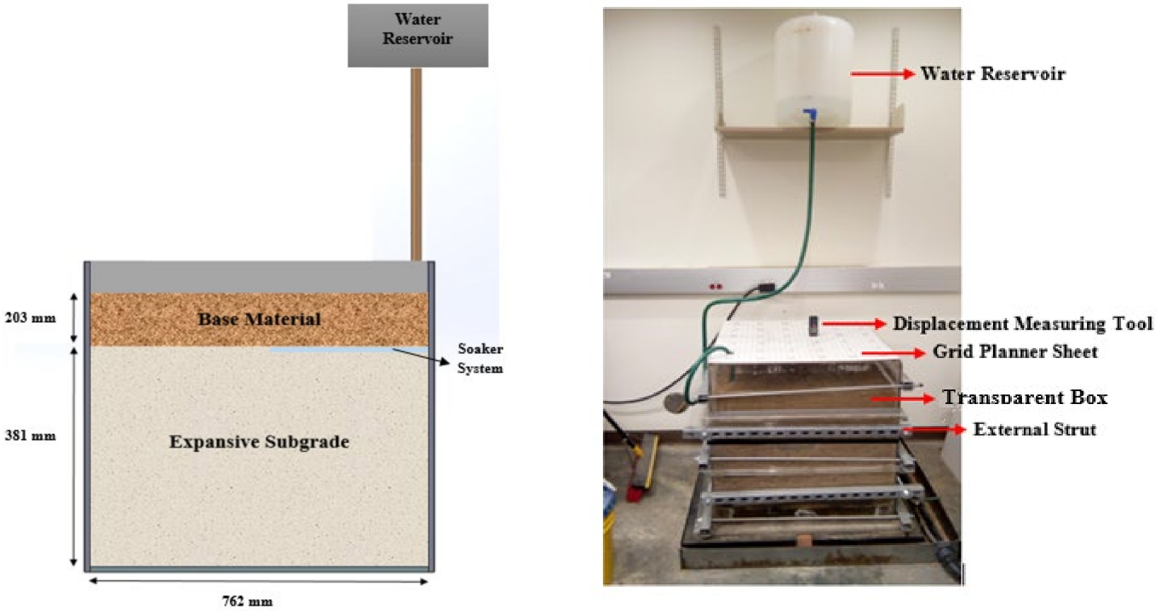
TEST PROGRAM

The primary goal of the testing program was to evaluate the use of HGS in mitigating swelling distress on the pavement surface due to the volumetric changes in the underlying expansive soils.

To achieve this goal, a large-scale box was constructed to replicate typical pavement section with expansive soils. This section of the paper details the development of the box along with the testing procedure followed for the different configurations tested in this study.

Large-Scale Box Test Set-Up. The objective of the test set-up was to evaluate the efficiency of hybrid system (geocell-geogrid) in mitigating swelling distress on pavement due to expansive subgrade. Figure 2(a) illustrates a schematic of the large-scale box set up. A 12 mm thick transparent box was used for the test set-up with inner dimensions of 762 mm (length) × 762 mm (width) × 762 mm (height). Expansive soil from Marsing, ID area was compacted inside this box at 95% of the maximum dry unit weight from Standard Proctor and mositure contents equivalnet to optimum moisture content ± 3%. A base layer was compacted over this layer. Asphalt layer was not replicated in this setup. The researchers acknowledge that by not placing a stiff asphalt layer above the base layer, the surficial deformations may be higher than normal. Nevertheless, since this aspect is common between the HGS and control sections any error in surface deformations would remain common in both cases. The differential heaving at the surface was measured using a laser distance measuring tool. The datum for this measurement device was a perforated planar sheet that was palced on top of the box. A total of 36 points were marked as reference points where measurements were made over time. This tool can measure vertical distance up to 30 m with the accuracy level of 1.5 mm. These heave measurements can give a three-dimensional picture of heave of the test section with time. A complete test set up is shown in Figure 2(b).

Differential Heaving Method. Since the focus of this experiment was to mitigate heaving coming from the underlying soils, the researchers allowed the underlying expansive soil to swell by giving access to moisture. Typically, expansive subgrades are generally exposed to moisture during rainfall event, where the water percolates through base layers and deposits on the expansive subgrades. The soil then absorbs the moisture and starts to swell resulting in cracks and heaves on the pavement surface. The deposition of water at the interface between the base and subgrade layers was replicated using a garden soaker system placed at that interface which allowed the moisture access to the undelying expansive soils. Soaker tubes were chosen to avoid any clogging issues when delivering water. This soaker system (see Figure 3b) was connected to a water reservoir placed six feet above the top of the box to offer hydraulic gradient and enhance the saturation rate of the soil. External steel struts ensured that there were no lateral movements in the box and any heaving is directed vertically to the top surface. The soaker system was placed on one half of the box to ensure differential heaving on the surface of the base layer.



(a) **(b)**

Figure 2. (a) Schematic and (b) Components of the large-scale box set-up.

Materials for the Test. A highly plastic clay soil sample obtained from the Marsing, ID area was used as subgrade for in the test program. The soil sample was collected from a real field condition where this kind of soils exhibit severe distresses on pavement surface (Chittoori et al., 2017; Tamim, 2017). A typical base course material was used over the expansive subgrade. No asphalt layer was used in the test section. Standard ASTM methods were used to determine the basic characterictics of the subgrade and base materials. Table 1 illustrates the properties of subgrade and base materials.

The HGS comprised of a geocell and a geogrid layer. A high-density polyethylene (HDPE) geocell was used as a part of the hybrid system. The depth and the thickness of the geocell were 152 mm and 1.5 mm respectively. There were 8 cells in the sample and the expanded cell size is 370 mm by 250 mm. The basic properties of geocell sample can be found in Tamim (2017). A biaxial geogrid was used with the geocell in the hybrid reinforced system. This material is composed of polypropylene resin which was extruded into grid pattern (TenCate, 2017). This material is inactive to most biological processes and resistant to naturally encountered chemicals such as alkalis, and acids. Grid aperture size of the sample was 25.4 mm in machine direction (MD) and 33.0 mm in cross machine direction (CMD). The thickness of the geogrid was 1.5 mm. Mechanical properties of the geogrid sample can be found in Tamim (2017).

Test Configurations and Test Procedure. The test program comprised of two configurations that include one control section and one hybrid reinforced section or the HGS section. The ***control section*** without reinforcement (HGS) provided a baseline for the heave potential of the expansive subgrade under the base layer. Figure 3(a) shows a schematic of the control section. A 203 mm of base course material was placed over 381 mm of the expansive subgrade. The base course material was compacted at 90-95% of MDD with 6±1% of moisture content and subgrade was compacted at 95-98% of MDD with 25±3% of moisture content. Soaker system arrangement was embedded at the top of the subgrade (half portion) shown in Figure 3(b) to initiate differential heaving. Base compaction was done in such a way that the soaker system placed above the subgrade soil (see Figure 3b) was not disturbed.

Table 1. Physical properties of the test materials.

Physical Properties	**Expansive Subgrade**	**Base Material**	**Test Standard**
Maximum Dry Density (kg/m^3)	1095	2315	ASTM D698
Optimum Moisture Content (%)	32.5	8.5	
Gravel Content (%)	-	39.6	ASTM D6913
Sand Content (%)	-	59	
Silt Content (%)	19	-	ASTM D7928-17
Clay Content (%)	76.5	-	
Liquid Limit (%)	111	Non- Plastic	ASTM D4318
Plastic Limit (%)	40.4	Non- Plastic	
Plasticity Index (%)	71	Non- Plastic	
Soil Classification	Fat Clay (CH)	Poorly Graded Sand with Gravel (SP)	USCS

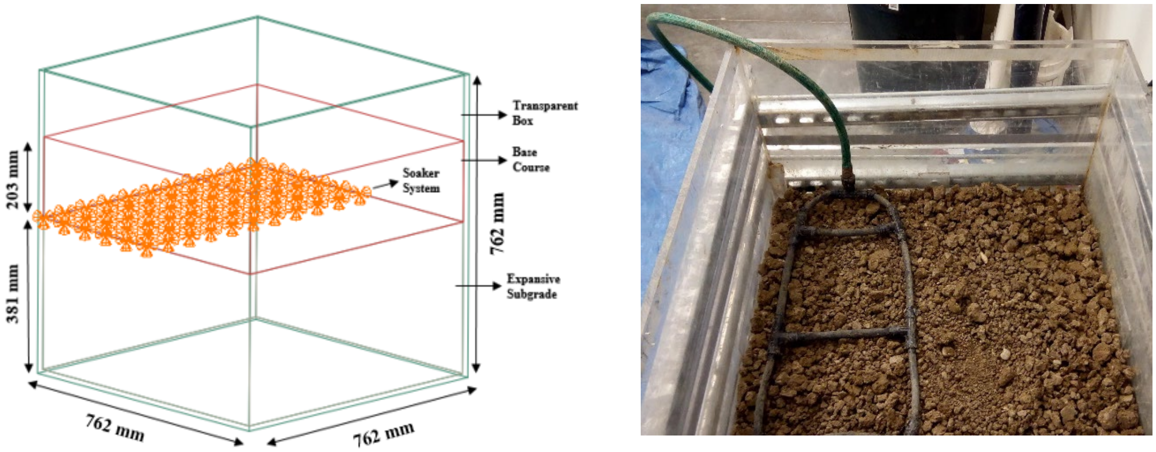


Figure 3. (a) Schematic of control section and (b) Placement of soaker system at the top half of the subgrade.

A water reservoir was connected with the soaker system to provide sufficient moisture with a six feet water head. When the complete set up was done, the outlet valve of water reservoir was opened to supply moisture. Initially, surrounding soils near soaker system started swelling. Water then percolated through the voids and saturated the adjacent soils over time which resulted in differential heaving on the base layer surface. The surface deformations were measured using the grid sheet and the laser tool explained earlier. The soil is allowed to swell for 15 days. It was found that the heaving with time plot was almost asymptotic after 15 days. Figure 4 shows the control section after compaction.

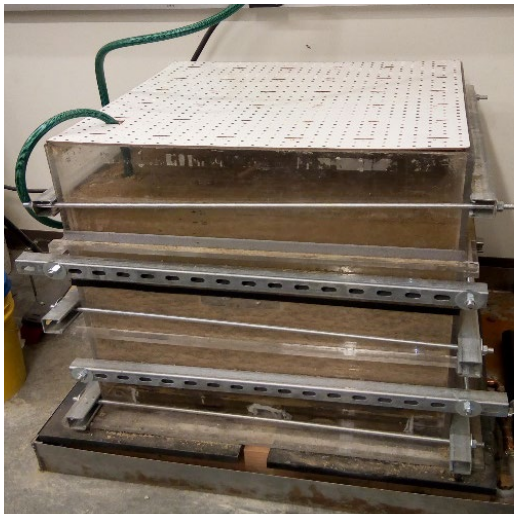


Figure 4. Complete large-scale box set-up for control section

After establishing the baseline heaving potential of subgrade for the control section, ***HGS section*** was constructed by excavating the control section completely and re-compacting. A schematic of the HGS section is illustrated in Figure 5. Identical procedures were followed to prepare the subgrade layer in the HGS section. Soaker system was embedded in the top half of the expansive soil section similar to the control section. One geogrid layer was placed at the bottom of base layer and anchored at the sides to ensure the development of tensile forces with soil swelling. Figure 6(a) shows the placement of geogrid in the box. Galvanized steel pegs were used to anchor the geogrid to the subgrade layer (as shown in Figure 6(b)). All the outer sides of the geogrid sheet were anchored into the soil with 5 pegs on each side with a total of 20 pegs. A small layer (50 mm) of base layer was placed at the top of geogrid and compacted for interlocking.

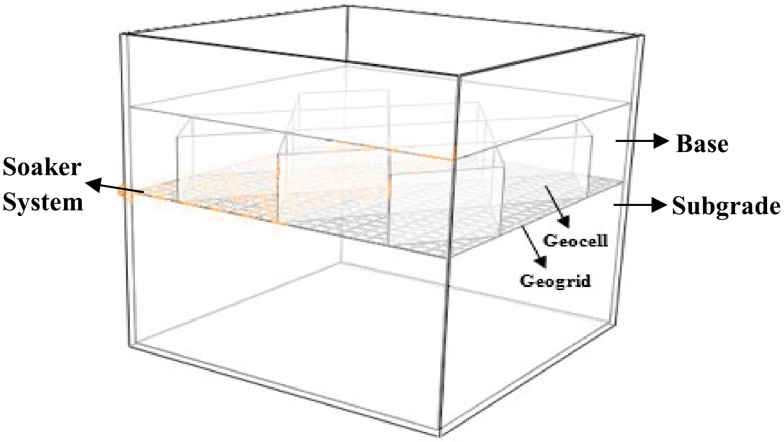


Figure 5. Schematic of HGS section.

(a) (b)

Figure 6. (a) Geogrid placement in hybrid test section and (b) Anchoring of geogrid using steel peg.

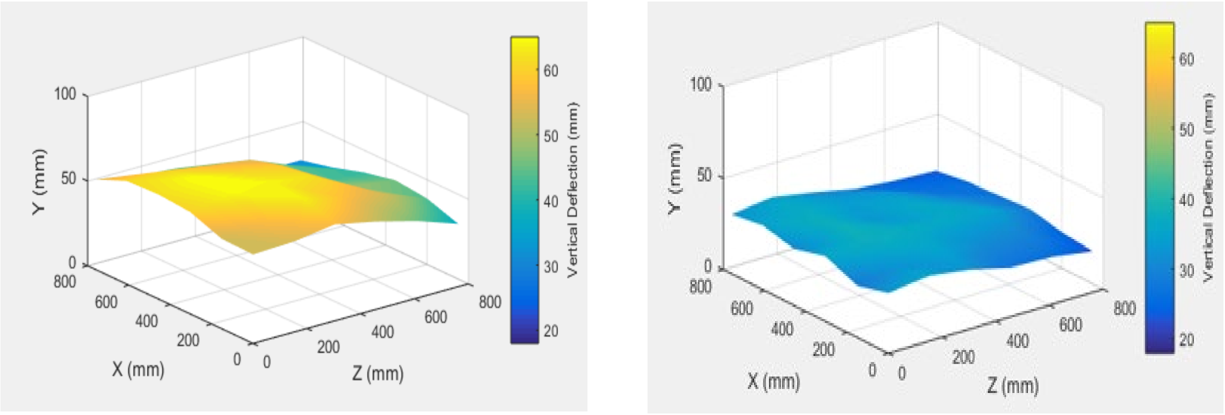
After that, a geocell layer with 152 mm cell depth was placed on top of the geogrid reinforced layer and filled and compacted with the base layer as shown in Figure 7(a). Density and water content of both subgrade and base materials were maintained similar to the control section. The water reservoir was connected with the soaker system with similar water head and allowed to swell for the same amount of time as in case of control section. Figure 7(b) shows the reinforced section after compaction.

(a) (b)

Figure 7. (a) Geocell placement in hybrid reinforced section and (b) Complete hybrid reinforced section after compaction.

RESULTS AND DISCUSSION

The goal of the test program was to evaluate the effectiveness of hybrid geosynthetic system to mitigate differential heave due to expansive subgrade and compare the results with the control section. Test results showed that inclusion of hybrid geosynthetic system significantly reduced the maximum heave of the test section compared to the control section without reinforcement. Figure 8 shows the three-dimensional contour plot for maximum surficial heave after 15 days for both unreinforced and reinforced section.



(a) (b)

Figure 8. Maximum vertical deflection for (a) unreinforced section and (b) Hybrid reinforced section after 15 days.

It can be noted from Figure 8(a) that the heave between Z = 0 and Z = 400 mm is higher than that between 400 and 800 mm. This shows that the use of soaker system on one side of the box was able to produce differential heaving. Figure 8(b) shows that both the maximum heave and the differential heave was reduced considerably. It was found that the hybrid geosynthetic system reduced the maximum surficial heave by 42% and the differential heave (the difference between highest and lowest heave) by 62% with hybrid geosynthetic system. Comparison of maximum and differential heaves is shown in Figure 9. When the expansive subgrade started swelling and pushed the bottom of the base layer, geogrid layer offered lateral resistance and membrane effect by grid-aggregate interlocking mechanism against swell pressure. In addition to the geogrid induced resistance, geocells within base layer triggered additional strength by confinement of base course materials within the cells along with the cell-base materials frictional resistance. Both of these layers acted as single unit hybrid system resulting in a composite layer with higher strength and reduced the vertical deflection in the experimental section.

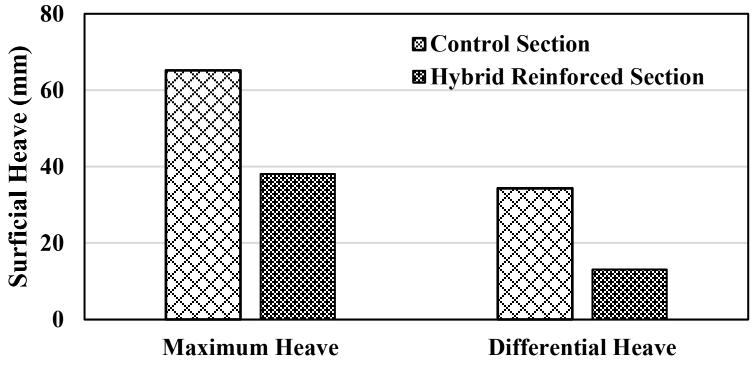


Figure 9. Comparisons of maximum and differential movement on pavement surface.

CONCLUSION

The main focus of authors research effort was to evaluate the performance of hybrid geosynthetic system (geocell-geogrid combination) experimentally to mitigate heaving problems due to expansive subgrades as a candidate remedial measure. Test results illustrated the evidence of improvement for the hybrid system to mitigate swelling in the test section. This research effort is solely based on the vertical swelling in the test section. Additional instrumentation for swell pressure and moisture measurement within the test set-up can increase the reliability and applicability of hybrid geosynthetic system in pavement industries. In addition, a full-scale field study on pavement section can give a more realistic overview of hybrid geosynthetic application.

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