Landmarks in Earth Reinforcement, Ochiai et al. (eds),
© 2001 Swets & Zeitlinger, ISBN 90 2651 863 3

Reinforcement of soft sub-grade for high-speed railroads using geocell

S.D. Cho, J.M. Kim, M. Chung & S.H. Yoon
Korea Institute of Construction Technology, Koyang, Korea

Y.Y. Kim
E&S Engineering, Seoul, Korea

ABSTRACT: This paper presents the results of field plate loading tests and laboratory dynamic loading tests carried out to evaluate the performance of geocell where it is used to reinforce soft sub-grade for high-speed railroads. The factors selected in the tests include the type of infill material, the number of geocell mattress layers, the thickness of cover soil, the stiffness of the original foundation soil, and the presence of geotextile separating the geocell mattress and the neighboring foundation soil layer. The results of the tests confirmed the effect of geocell mattresses in improving load-bearing capacity of soft soil. The settlement rates of geocell reinforced railroad structure subjected repeated loadings were revealed from the dynamic loading tests.

1 INSTRUCTION

Geocell or geocell mattress is referred to as a three-dimensional soil confinement system consisting of a series of interlocking cells. Geocell may provide a practical means to reinforce soft foundation soils for the construction of high-speed railroads, in cases where the conventional soft ground improvement techniques are not favored due to time and cost constraints. Reinforcing soft ground with geocell mattresses is easy and fast. Geocell mattresses, first, are positioned on a surface in their stretched form. Then, each of cells is filled with coarse grains or concrete that is selected in such a way to better serve the purposes of its application. When geocell mattresses are used in load support applications, cover soil is usually applied on the top of the geocell mattresses.

Improved load bearing capacity of a soft ground with an aide of geocell is a combined result of the hoop strength of the cell walls, the passive resistance of adjacent cells, and the frictional interaction between the infill and the cell walls (Presto and Intersol Engineering Inc. 1997). The performance of geocell reinforcement, therefore, is influenced by factors such as: raw material, shape, and size of a geocell; type of infill and compacting effort for infill; and applied load. Some literatures report on the use of geocell: geocell made of woven and non-woven geotextile (Rajagopal et al. 1999); large scale model tests on polymeric geocell mattress (Barthusrst & Jarrett 1988); and reinforcement of embankment using geocell mattresses (Bush et al. 1990; Cowland & Wong 1993). However, more researches are yet to be needed to better understand the efficiency of geocell with many different influencing factors.

This paper deals with field plate loading tests and laboratory dynamic loading tests designed to investigate the performance of geocell when it is applied to soft sub-grade for high-speed railroad. The relative efficacy of geocell was compared with the reduced thickness of reinforced roadbed of sub-ballast and aggregate layer.

2 EXPERIMENTAL PROGRAM

2.1 *Field plate loading tests*

The site for plate loading tests was situated near the Inchon international airport where its construction was ongoing. For all the tests, the shallow surface soil was excavated to a depth where the underlying silty clay layer was exposed. A deposit of silty clay is typical in this region and exists with the thickness of 3 to 10 m. The shear strength of this silty clay layer measured at its near-surface depth from vane shear tests was in the range of 5.9 and 12.7 kPa.

A series of plate loading tests were performed with the combination of influencing factors. The factors selected were the type of infill material, the number of geocell mattress layers, the thickness of cover soil, the stiffness of the original foundation soil, and the presence of geotextile separating the geocell mattress and the neighboring foundation soil layer.

Geocell mattresses used were made of textured high-density polyethylene and provided by its local agent. The dimensions of a geocell mattress in its expanded position were approximately 2.4 m in width, 6.1 m in length, and 0.2 m in thickness. The dimensions of an individual cell were 406 mm in length and 488 mm in width and the area was 991 cm^2. The infill materials used were crushed stone and sandy soil. For each of the plate loading tests, the same cover material as the one for infill was employed. The crushed stone was classified as GW by the unified classification system with the maximum size of 60 mm. The maximum dry density was 2.06 Mg/cm^3. The sandy soil was classified as SW and its maximum dry density was 2.06 Mg/cm^3. The infill and the cover material were compacted at its relative density of 90% and 95% respectively.

2.2 *Laboratory dynamic loading tests*

Dynamic loading tests were carried out using a test setup simulating the real field conditions. A schematic of the test setup is shown in Figure 1. In a 1.0m wide, 1.4m long, and 2.0m deep chamber, there were, from the bottom, a 0.5 m thick silty clay layer, a 0.2 m thick geocell mattress layer and 0.05 m thick cover soil, an aggregate layer of crushed stone, a 0.2 m thick sub-ballast, and a 0.35 m thick ballast. The thickness of the aggregate layer varied during the tests: 0.25, 0.35, 0.45, and 0.55 m. The combined layer of sub-ballast and aggregate layers constitutes a reinforced roadbed. A sheet of non-woven geotextile with a tensile strength of 29.4 kN/m was placed between the geocell mattress and the underlying clay for separation. The silty clay was obtained from the site where the plate loading tests were performed. Crushed stone with the maximum size of 125 mm was used as the infill for the geocell mattress and the overlying components.

The maximum sinusoidal load of 117.7 kN was applied at the frequency of 3.5 Hz as many as 80,000 times on the ballast through a 0.27m×0.8m rectangular steel plate. The loading conditions were determined from the preliminary tests reflecting the local design criteria for high-speed railroads and the limitations of the test setup.

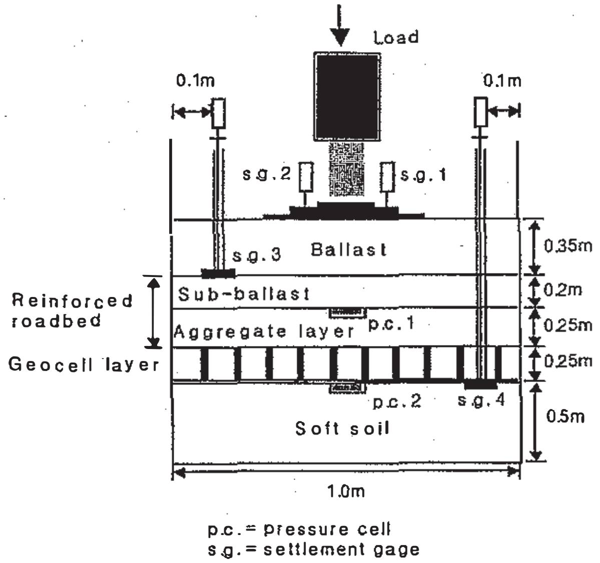

Figure 1. A schematic of test setup for laboratory dynamic loading tests.

The local design specifications require K_{30} no less than 68.6 MN/m^3. Otherwise, the original foundation soil should be reinforced using proper means. If K_{30} is between 68.6 and 107.9 MN/m^3, the required thickness for sub-ballast and aggregate layer is 0.2 m and 0.6 m, respectively.

The second series of dynamic loading tests were performed to investigate the effect of geocell reinforcement in reducing the thickness of reinforced roadbed. The loading conditions and test chamber were the same as those for the previous dynamic loading tests. Since these tests were designed to simulate the foundation soil condition of K_{30} no less than 68.6 MN/m^3, sandy soil instead of clay was placed in the bottom of the chamber and compacted to have a K_{30} value in the vicinity of 68.6 MN/m^3. Geocell mattress was not employed. An aggregate layer was placed immediately above the sandy soil foundation with the thickness of either 0.4 or 0.6 m. The thickness of sub-ballast and ballast was also 0.2 m and 0.35 m respectively.

3 RESULTS AND DISCUSSION

3.1 *Field plate loading tests*

Sub-grade reaction modulus K_{30} (MN/m^3) and strain modulus E_v (MN/m^2) were calculated from the load versus settlement curves of plate loading tests. K_{30} is obtained from the normal stress σ corresponding to a settlement of 1.25 mm. The subscript 30 means the diameter of the loading plate. E is the gradient of the secant modulus between the points $0.3\times\sigma_{max}$ and $0.7\times\sigma_{max}$ using the following equation (German standard, DIN 18134):

$$E_v = \frac{1.5\times r}{a_1 + a_2\times\sigma_{\max}} \tag{1}$$

$$s = a_0 + a_1\times\sigma_0 + a_2\times\sigma_0^2 \tag{2}$$

where r = radius of the loading plate (mm), σ_{max} = the maximum average normal stress of the loading cycle (MN/m^2), σ_0 = the average normal stress below the plate (MN/m^2), s = settlement (mm), and a_0, a_1, a_2 = factors.

Figure 2 shows the results of the plate loading tests performed with respect to a number of geocell layer (1 or 2 layers) and the type of infill with a constant cover thickness of 50 mm. The legends in Figure 2 are explained in Table 1. Without the presence of geocell mattress, the soil exhibited an ultimate load bearing capacity of 58.8 kPa at about 30 mm settlement. In cases where the geocell mattresses were placed on the same soil, the effect of geocell

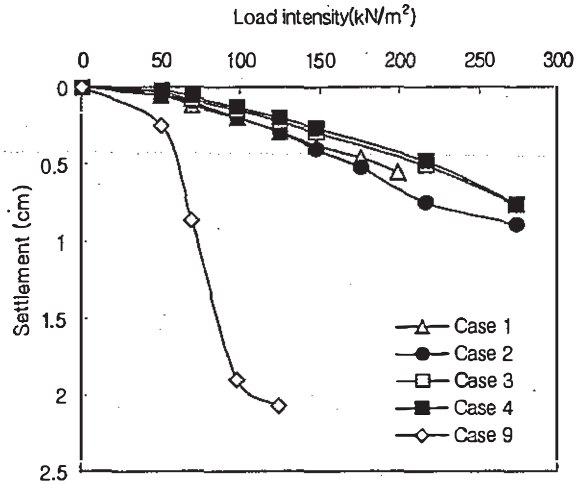

Figure 2. The results of plate loading tests as a function of the number of geocell layer and the type of infill: the thickness of cover was fixed at 50 mm.

Table 1. Description of test conditions.

Denotation	Test Description
Case 1	1 geocell layer + 5 cm cover : sandy soil*
Case 2	1 geocell layer + 5 cm cover : crushed stone
Case 3	2 geocell layers + 5 cm cover : sandy soil
Case 4	2 geocell layers + 5 cm cover : crushed stone
Case 5	1 geocell layer + 10 cm cover : sandy soil
Case 6	1 geocell layer + 20 cm cover : sandy soil
Case 7	1 geocell layer + 30 cm cover : sandy soil
Case 8	1 geocell layer + 40 cm cover : sandy soil
Case 9	without geocell reinforcement

Note: * indicates the type of cover soil

Table 2. Calculated values of K_{30} and E_v from plate loading tests.

Test Conditions	Site A		Site B	
	K_{30} (MPa/m)	E_v (MPa)	K_{30} (MPa/m)	E_v (MPa)
Case 1	62.8	7.0	56.9	4.8
Case 2	57.9	7.8	55.9	4.0
Case 3	76.5	7.9	72.6	6.9
Case 4	69.6	8.1	58.8	7.8
Case 5	73.6	9.2	68.6	7.0
Case 6	74.5	9.7	74.5	8.1
Case 7	81.4	13.9	75.5	10.5
Case 8	107.9	16.5	79.4	13.6
Case 9	20.6	1.0	16.7	2.3

mattresses in increasing load-bearing capacity was obvious as expected. The gradients of the load intensity and settlement curves did not show distinct inflection points and were almost linear in the range of the applied load intensity. The parameters K_{30} and E_v were calculated as indices of how the geocell reinforced soil behaved under the given test conditions and are listed in Table 2.

The effect of infill material can be seen from the comparison of K_{30} and E_v of Case 1 with those of Case 3: and Case 2 versus Case 4. Sandy soil, to some extent, outperformed crushed stone at both Sites A and B, which is against a general tendency of the effect of angularity of grain in load supporting mechanism. It may be because crushed stone than sandy soil was relatively easier to penetrate into the soft foundation soil during load application.

In the tests with one layer of geocell and cover soil of varying thickness (Case 1, and Cases 5~8), the load intensity and settlement curves were almost linear as observed in Figure 2. The curves exhibited increasing K_{30} and E_v as the thickness of cover soil increased. The combined effect of the densification of infill during the compaction of cover soil and the load distribution effect of cover soil itself are believed to be responsible for increased values of K_{30} and E_v. When the same material for infill and cover was used, one layer of geocell mattress with thicker than 200 mm cover soil led to better load supporting capacity in terms of the indices than two layers of geocell mattresses with 50 mm cover soil. This indicates that, in a practical sense, a cost efficient design of geocell reinforcement can be achieved by determining an appropriate thickness of cover that would meet the design requirements.

Figure 3 shows the results of the plate loading tests undertaken to investigate the improvement of load bearing capacity by means of the filling of sandy soil on soft foundation soil. The thickness of fill varied between 0.25 m and 1.00 m. No geocell reinforcement was employed in this case. The value of K_{30} was: 47.8 MN/m^3 for a 0.25 m thick filling; 63.6 MN/m^3 for 0.50 m; 73.1 MN/m^3 for 0.75 m; and 91.4 MN/m^3 for 1.00 m. Proportional relation between load intensity and settlement as observed in the cases of geocell reinforcement was found only when the fill thickness was equal to or more than 0.75 m. The comparison of these K_{30} values with

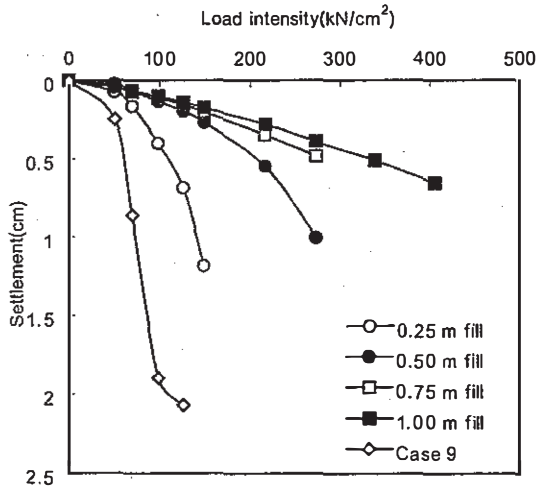

Figure 3. The results of plate loading tests with varying thickness of fill overlying soft clay foundation.

those for Site A shown in Table 2 indicates that one layer of geocell mattress with a 0.1 m cover (Case 5 in Table 1) is equivalent to a 0.75 m thick fill without geocell reinforcement. It can be said that reduction of fill thickness can result from the use of geocell mattresses, which in turn, leads to reduction of the weight of foundation structures for high-speed railroads. This will be of help in increasing the stability of the structures and in saving construction time.

When geocell mattresses placed on a soft foundation soil are subjected to dynamic loadings, infiltration of clay particles into the geocell mattresses, or mud pumping, might occur without a separator at the interface of these two layers. Geotextile is commonly used in this case as a separator. Plate loading tests under the condition of Case 5 in Table 1 were carried out at Site B with and without geotextile. The results are shown in Figure 4. Without geotextile, E_v was 7.0 MPa as shown in Table 2. In the presence of geotextile, load-bearing capacity of geocell reinforced soil significantly decreased. Strain modulus E_v was calculated to be 1.0 and 0.9 MPa. The reduction of load bearing capacity with geotextile is probably because geotextile might have prevented the infill from penetrating into the underlying soft soil during compaction. This penetration of the infill formed a replaced layer immediately beneath the bottom of the geocell mattress, producing a more resistance to the external forces during plate loading tests. The plate loading tests did not provide an information about whether this adverse effect of geotextile would be only valid for the given test conditions or not. Since the geotextile used had, however, a marginal strength, it is not unreasonable to predict that reduction of load bearing capacity is instantaneous during construction and may disappear under real loading conditions.

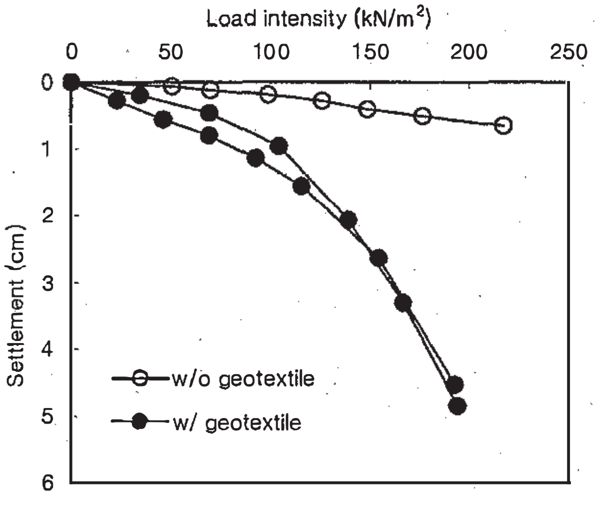

Figure 4. The effect of geotextile on the load supporting capacity of geocell reinforced soil.

3.2 *Dynamic loading tests*

During the dynamic loading tests, settlement was measured at the three different points as shown in Figure 1: on the top of and beneath the ballast layer; and on the top of the clay layer. The settlement rates with respect to the different thickness of the aggregate layer are plotted in Figures 5 to 8. Examination of the figures revealed a consistent pattern in the settlement rates, but a wide range of variations in the magnitude of settlement.

The total settlements appear to increase at relatively rapid rates until the number of load ap-

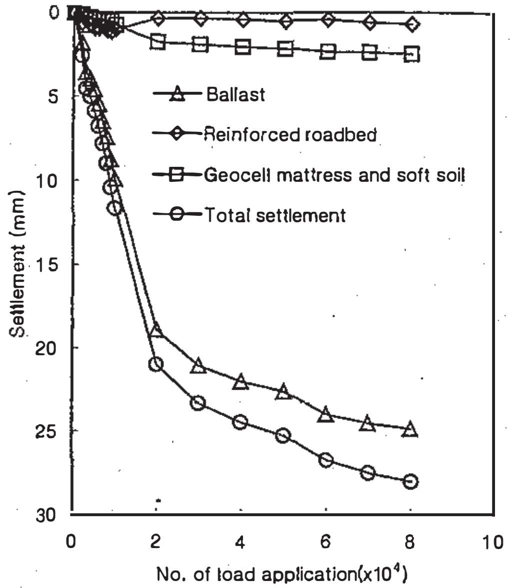

Figure 5. The results of dynamic loading tests: with 0.25 m thick aggregate layer.

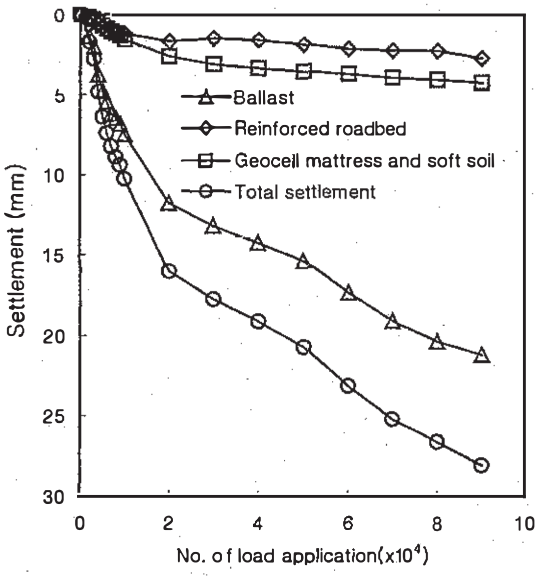

Figure 6. The results of dynamic loading tests: with a 0.35 m thick aggregate layer.

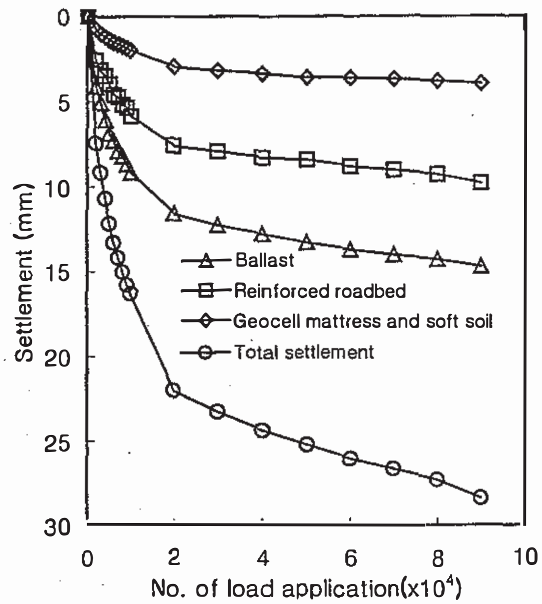

Figure 7. The results of dynamic loading tests: with a 0.45 m thick aggregate layer.

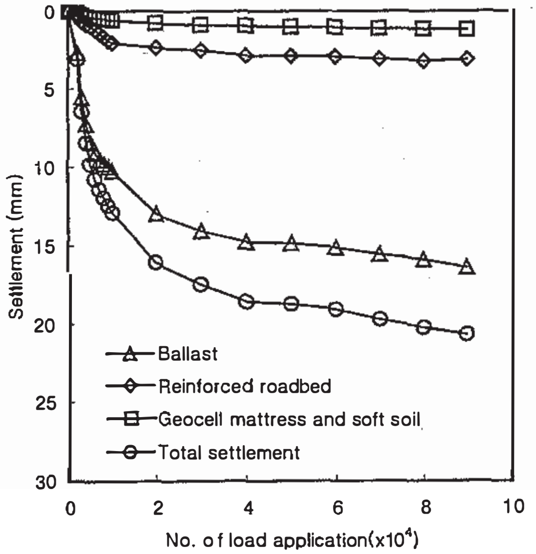

Figure 8. The results of dynamic loading tests: with a 0.55 m thick aggregate layer.

plication reached approximately 20,000 times. Then, they continued to increase monotonically with relatively slow rates for the rest of the load application. Settlement in the ballast layer constituted the vast majority of total settlement. The case of Figure 6 was exceptional, but the ballast settlement took up about a half of the total settlement. For both the subballast and the clay layer, the magnitude of settlement approached a relatively small plateau value and the subsequent increments were marginal. The sharp settlement rates of the ballast layer in the early loading stage are thought to be due to the reorientation and cracking of the grains in the geocell mattress. Anomaly in the magnitude of settlement of each constituting layer appears to be caused by inconsistency involved in the test preparation processes.

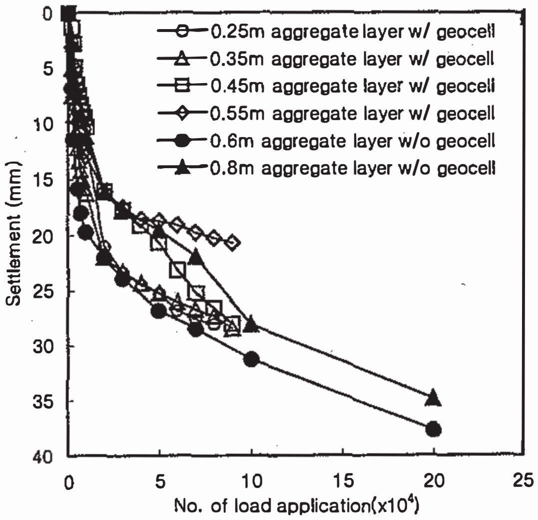

Figure 9. Total settlement versus number of load application with respect to varying thickness of aggregate layer.

The results of the second set of dynamic loading tests in terms of total settlement and number of load application are depicted in Figure 9. The data points in open symbols were extracted from the corresponding tests results in Figures 5 to 8. Closed symbols are for the tests with 0.4 and 0.6 m thick aggregate layers overlying the sandy soil foundation. Up to the load applications of 80,000 times, the magnitude and rate of total settlement for the case of a 0.35 m thick aggregate layer over a geocell mattress (Figure 6) were similar to those for a 0.6 m thick aggregate layer over the sandy soil foundation. With an aid of geocell reinforcement, replacement of soft clay with sandy soil could be spared. In other aspects, the combined layer of geocell mattress and soft clay soil in this case is equivalent to the replaced sandy soil foundation with a 0.6 m thick aggregate layer. Therefore, it can be said that geocell reinforcement resulted in reduction of the thickness of aggregate layer by 0.25 m or so.

Even in the cases where clay foundation soil was replaced by sandy soil, the total settlement rates did not reach plateau values as the number of load application exceeded 80,000 times and approached 200,000 times. There is no reason to doubt the effect of geocell reinforcement in increasing load-bearing capacity of soft soil. However, more studies with different conditions are needed to better understand the reduction of roadbed thickness under dynamic loadings.

4 CONCLUSIONS

The effect of geocell reinforcement in improving load-bearing capacity of soft foundation soil was confirmed by plate loading tests. The values of subgrade reaction modulus and strain modulus significantly increased and no inflection points were found in the load intensity versus settlement curves. One layer of geocell mattress with a 0.1 m thick cover was equivalent to a 0.75 m thick fill without geocell. The use of geotextile between the geocell mattress and the underlying soft soil foundation led to reduction in load-bearing capacity. However this adverse effect of geotextile is thought to be instantaneous during construction and overcome under real loading situations. The results of the test performed as a function of the number of geocell mattress and varying thickness of cover indicated that a cost efficient design of geocell reinforcement could be achieved by determining an appropriate thickness of cover.

Dynamic loading tests were carried out using a test setup simulating the real loading conditions of high-speed railroads. The settlement rates under dynamic loadings exhibited a consistent pattern. The total settlement increased at sharp rates up to the loading number of 20,000 times and, then, continued to increase monotonically with relatively slow rates for the rest of the load application. Settlement in the uppermost ballast layer constitutes the vast majority of total settlement.

REFERENCES

Barthurst, R.J. & Jarrett, P.M. 1988. Large-scale model tests of geocomposite mattresses over peat subgrades. *Transportation research Record* 1188: 28-36.

Bush, D.I., Jenner, C.G., & Bassett, R.H. 1990. The design and construction of geocell foundation mattresses supporting embankments over soft ground. *Geotextiles and Geomembranes* 9: 83-98.

Cowland, J.W. & Wong, S.C.K. 1993. Performance of a road embankment on soft clay supported on a geocell mattress foundation *Geotextiles and Geomembranes* 12: 687-705.

Presto Products Geosystems & Intersol Engineering Inc. 1977. Manual for the Geoweb Cellular Confinement System: General Reference Material.

Rajagopal, K., Krishnaswamy, N.R. & Latha, G.M. 1999. Behavior of sand confined with single and multiple geocells. *Geotextiles and Geomembranes* 17: 171-184.