

Effect of Geogrid Reinforcement of Crushed Aggregate Subbase Course in Permeable Interlocking Concrete Pavement System

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Abstract :

A rapid urbanization has increased the impermeable area portion that may have a great effect on hydrologic processes, surface runoff patterns, and results in disruption of water cycle system. This change leads to frequent events of flooding, drought, and urban heat island. Permeable pavement system, based on Low Impact Development (LID) concept, is presented as an alternative way for storm-water control in urban areas. Therefore,it is necessary to establish a rational design procedure for the permeable pavement system that reflects our environmental conditions. Water infiltration and percolation processes through top and subbase layer into the soil may reduce the bearing capacity of sub-layers in permeable interlocking concrete pavement (PICP) system. In this study, an effort was made to investigate the bearing performance of geogrid-reinforced crushed aggregate subbase course based on field experimental approaches along with a limited numerical analysis. The PBT result in terms of the reinforcing effect reveals that the improvement of the bearing capacity is increased from 22% to 45% compared to the non-reinforced condition. In addition, the results of light weight deflectometer test (LWDT) characteristics found in the experiment are promising for the compaction quality control of crushed-stone subbase course, focusing on construction of qualified permeable pavement systems

Key Words : LID; permeable pavement; crushed-stone subbase; geogrid; LWDT; bearing capacity

1. Introdouction

The urban development and industrialization has significantly affected hydrological water circulation system. The increased impermeable area caused by the rapid urbanization leading to various environmental problems, such as urban flooding, groundwater depletion and drought along with climate change. Therefore, a distributed basin management technology, the Low Impact Development (LID), has recently been proposed as an alternative to traditional centralized rainwater management facilities. Porous pavement is proposed to promote infiltraion and percolation raising water table of acqufer and reducing stormwater runoff, storm sewer loads (EPA, 2000).

Permeable pavements base on LID concept, known as one of the most effective counter-measures for the mitigation of urban floods, are generally applied to parking lots, sidewalks and lightly trafficed roads. However, the infiltration of rainfall through a pervious pavement system could lower the bearing capacity of sublayers because of the lack of compaction due to the open graded aggregates, which might shorten the service life of the pavement structure.

05_ Skid resistance of BP

Permeable interlocking concrete pavement (PICP) consists of impervious/pervius concrete pavers that form permeable voids or open joints between the pavers. Geogrids can be used for stabilization to improve the bearing capacity and to reduce surface deformation in PICP system,as shown in Figure 1. And Figure 2 shows the representative reinforcing mechanism of geosynthetic in flexible pavement by restraining the subbase materials and increasing the friction and tension effect between the crushed-stone infill and grid in the lateral direction (Giroud and Han, 2004; US Army).

In this study, three-dimensional lattice-like reinforcement panels (3D lattice-panels), which were improved in terms of the structureal performance compared with the existing two-dimensional geogrid, are applied to the permeable layer. A series of field static and dynamic plate bearing testswas conducted to investigate the applicability of 3D lattice-pannel reinforcement on the bearing capacity and stiffness as compared with non-reinforced subbase layer. The study also includes the effectiveness evaluation of grid-reinforced crused aggregate subbase course with respect to stiffness and deformation through experimental and numerical approaches.

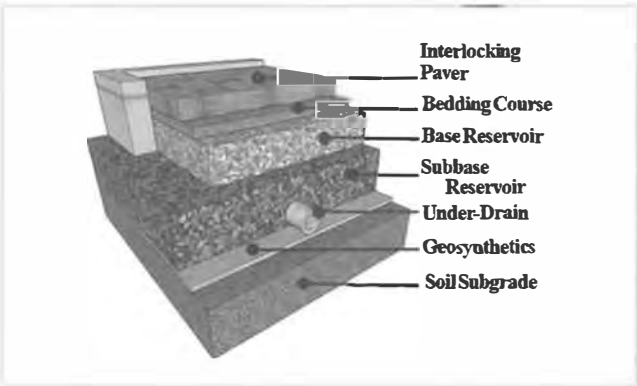


Figure 1. Typical section in PICP (FHWA, 2015).

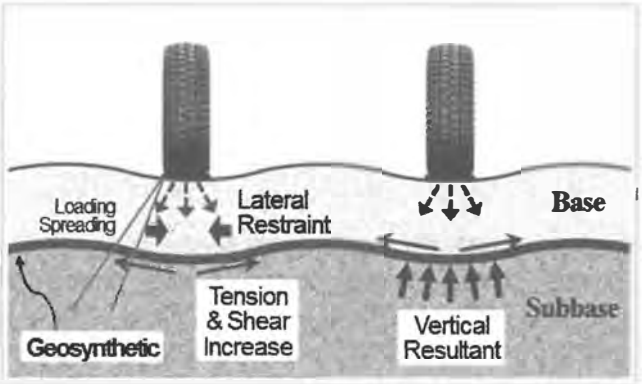


Figure 2. Mechanism overview of geo-synthetics.

2. Bearing Capacity of Subbase Course in Field Test

2.1 Field test setup

In general, 'Plate bearing test (PBT)' has been mostly conducted to evaluate the bearing capacity of in situ pavement layers, and 'Repetitive plate bearing test (RPBT)' can be carried out to obtain modulus of subgrad reaction and/or to examine whether sufficient compation has occured. In addition to PBT and RPBT, 'Light weight deflectometer test (LWDT)', which is now widely used in engineering practice to manage rapidly compaction or elastic stiffeness evaluation as simple and convenient methods.

The PLT apparatus consists of a circular load plate with a radius of 150mm, which is in close contact with the surface of the compacted subbase to be tested. Incremental static loading steps are applied to the subbase layer through the loading plate and the vertical displacements are measured, and this test precedure is repeated upto a given level of stress (KSF 2310: KSA, 2000).

From the relationship between the average normal stress and the settlement of the plate, the tiffness of the soil is determined. The subgrade reaction modulus (when using 300mm dia. plate) K_{30} is calculated using Equation (1), where σ is the average normal stress at the reference settlement s=1.25 and 2.5mm for concrete and asphalt pavement respectively:

$$K_{30} = \frac{\sigma}{s} \quad (at\ s = 1.25,\ 2.5mm) \tag{1}$$

A road construction standard specifies that K_{30} of subbase layer need to be higher than 196 MN/m^3 and 294 MN/m^3 for a concrete rigid pavement and asphalt flexible pavement respectively (MOLIT, 2016).

RPBT uses the same circular plate as the PBT test. However, there are differences in the number of loading cycles, as RPBT usually has a series of four to five loading/unloading cycles that are repetitive load stages with each increment in short loading time, whereas PBT has one loading cycle. Figure 3 (a) and (b) show the schematics of PBT and LWDT devices. LWDTs (ASTM E2835-11) are performed on the test surface after the construction of the subbase and subgrade. The instantaneous resilent modulus can be calculated by dropping a 10 kg weight from a given height onto a 300 mm-diameter loading plate applying an impact load of around 100 kPa. Figure 4 (a) and (b) show schematic subgrade reaction curves after PBT and LWDT.

2.2 Field Test

For the reinforcement performance assessment in this study, the tests were applied to four sites. The test sites were a parking lot of the research center of Kyonggi University (TS_GP), a parking lot of the GI-LID Center (TS_BPL) and that of the earthquake-center (TS_BPE) of Pusan National University, and a temporary test site in Hwaseong-city, Gyeonggi province (TS_HS), which were all located in South Korea. Figure 5 shows the scheme of pavement cross-sections.

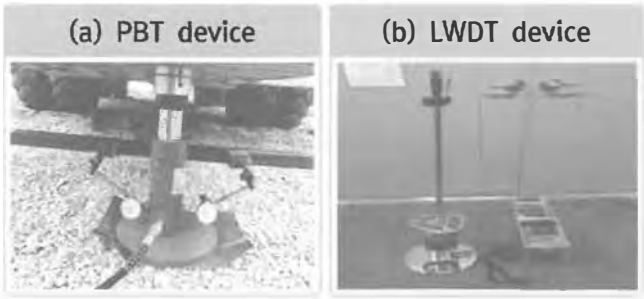


Figure 3. Scheme of PBT and LWDT devices.

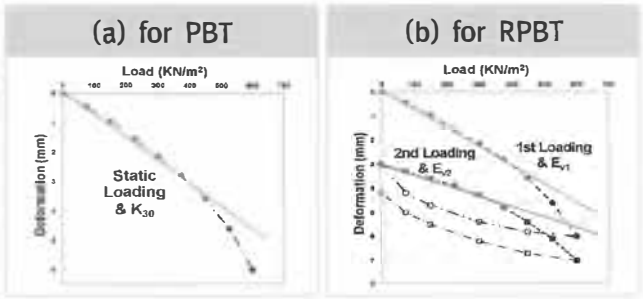


Figure 4. Schemamtic 'load vs. deformation' curves of PBT and RPBT.

Four types of crushed-stone subbase layer with the maximum particle size of 3050 mm were used and those soil types are classified as GP (poorly graded gravel) group in USCS system. Figure 6 shows the particle size distributions of the four types of subbase layers applied to each site. The 'Base Layer' represented by the dotted line in the legend of the Figure 6 shows the upper and lower-limit particle size distributions of the crushed-stone layers used in the permeable base layer specified in Seoul, Korea.

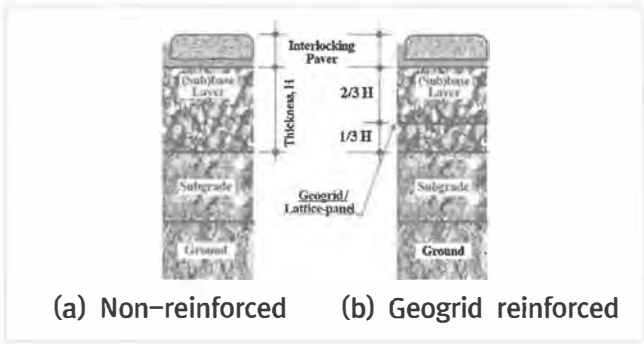


Figure 5. Scheme of pavement cross-sections.

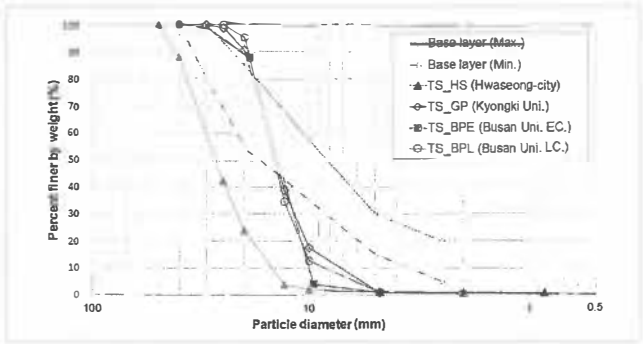


Figure 6. Particle size distributions of the site appliedcrushed-stone layers

05_ Skid resistance of BP

This study involved performing experiments under the non-reinforcement conditions to the subbase layer with 300, 350 mm thickness(H), where a set of 3D lattice-panels with studs and ribs and the general 2D plane-type geogrid are installed at 1/3 level from the bottom of the layer.

In analyzing the mechanical behavior of the geogrid used in the pavement layer, confinement, increased bearing capacity, and the tension effect are the major geosynthetic reinforcement mechanisms (Giroud & Han, 2004). The sub-structure of pavement with 3D lattice reinforcement with studs and ribs can more effectively provide the lateral friction and the triaxial compression-confinement pressure to the infill layer aggregates.

The 3D lattice-panel performs as 'a supporting mat foundation' with the interaction of the reinforced subbase to reduce the subgrade soil from moving upward and provide the vertical and lateral interlocking to aggregate material and the subbase. Therefore, these mechnismscan reduce the deformation and movement of the PCIP structure ensuring its bearing capacity performance and the road surface flatness. When thease mechanisms of the reinforced pavement structure is applied to the PCIP system, it is possible to reduce the settlement and deformation, to encure the improvement of the bearing capacity and the pavement surface smoothness.

2.3 Result and discussion

In-place density testing can be performed to evaluate the compaction of the subbase layer in the construction phase for general road pavement. In the permeable pavement layer, however, the field density can not be measured using in-place density testing method because the base and subbase layers are composed of crushed-stone aggregates so that it is difficult to estimate and exact volume of excavated portion.

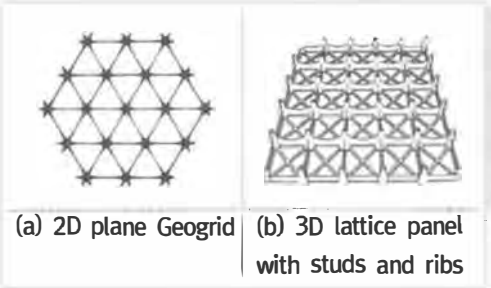


Figure 7. Scheme of grids for reinforcement.

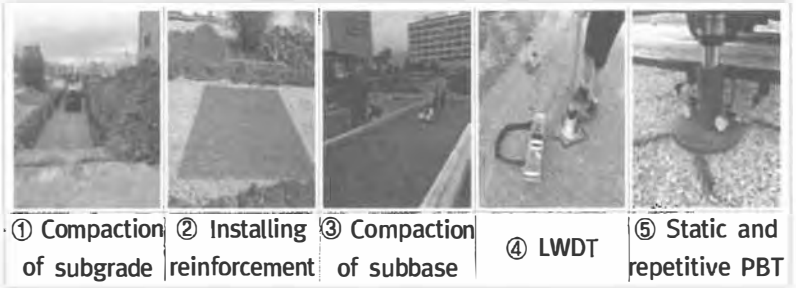


Figure 8. Procedures of construction and field test procedures.

In DIN regulations, the minimum dynamic modulus value obtained from LWDT corresponding to 97% of the degree of compaction is estimated to be equal to or greater than Evd = 35 Mpa for the GW material similar to the crushed-stone material. In this study, thedegree of compaction was verified through LWDT for each site based on this dynamic modulus for the compaction management of the permeable subbase layer.

Since the pavement surface material can use flexible and rigid permeable pavement, such as PICP , asphalt and concrete, the K_{30} value of the base layer was calculated for each surface condition, as shown in Table 1. Figure 9 shows the results of the plate bearing test performed at four sites. The reinforced effects in Table 1 indicate the degree of improvement of bearing capacity in terms of K_{30} before and after reinforcement treatment.



The K_{30} values calculated from the experimental results were estimated to be less than 168 MN/m^3 for the concrete surface layer and 160 MN/m^3 for the asphalt surface layer condition in most cases. This result reveals that K_{30} value does not satisfy the general construction standards in Korea when using crushed stone as a pavement support layer. This finding could be attributed to the grain sizedistribution of crushed stone material which has a relatively uniform paricle size. However, the experimental results in terms of the reinforcing effect show that the improvement of the bearing capacity is increased from 22% to 45% compared to the non-reinforced condition in the case of reinforcing with the grid in the crushed-stone layer. In particular, from the results of the TS_HS field test using the maximum aggregate size of 50 mm of aggregate, the result shows reinforcing effect from 67.9% to 80.1% compared to the non-reinforced base layer when applying 3D lattice-panel, while it shows about 10% increase in subgrade reaction modulus when 2D plane-type geogrid is applied.

Table 1. Results of static PBT of permeable crushed-stone layer

Category		Rigid pavement		Flexible pavement		Subbase layer thickness H (mm)
Site	Reinforcement	K_{30} (MN/m^3)	Reinforcement effect (%)	K_{30} (MN/m^3)	Reinforcement effect (%)	Subbase layer thickness H (mm)
TS_GP	No reinforcement	128	-	106	-	350
	3D grid (h_{gr} = 50 mm)	156	21.9	132	24.5	
TS_BPL	No reinforcement	112	-	104	-	300
	3D grid (h_{gr} = 50 mm)	148	32.1	132	26.9	
TS_BPE	No reinforcement	168	-	160	-	300
	3D grid (h_{gr} = 50 mm)	240	42.9	232	45	
TS_HS	No reinforcement	76.2	-	62	-	300
	2D grid (h_{gr} = 2 mm)	84	10.2	68	9.6	
	3D grid (h_{gr} = 50 mm)	128	67.9	112	80.1	

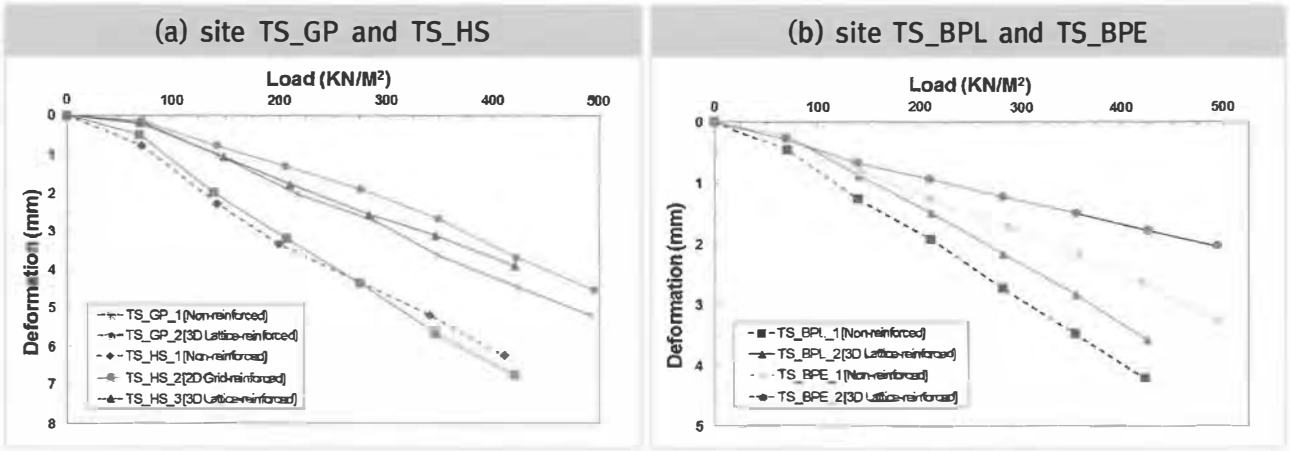


Figure 9. Static PBT results of bearing load vs. deformatin curve at test sites: (a) site TS_GP and TS_HS (b) site TS_BPL and TS_BPE.

05_ Skid resistance of BP

Repetitiveplate bearing tests were carried out at the site of TS_GP and TS_BPL. The results of the primary and secondary deformation moduli (E_{v1} and E_{v2}) are shown in Table 2 and the load vs. settlement graphs are shown in Figure 10. From the experimental results, it is shown that the secondary deformation modulus (E_{v2}) is 1.66 and 3.93 times higher in non-reinforced condition, and 2.79 and 3.34 times higher in reinforeced condition, respectively, than the first deformation modulus (E_{v1}). These results, as one of characteristics of RPBT, show that the secondary deformation modulus (E_{v2}) increases as the interlocking effect increases in the reinforcement grid and aggregate after the first plastic deformation is removed and the permeable base layer is compressed through the first pressure loading.

Table 2. Comparison of Ev1 and Ev2 from RPBT

Site	Reinforcement	E_{v1} (MN/m^2)	Reinforcement Effect (%)	E_{v2} (MN/m^2)	Reinforcement Effect (%)	E_{v2}/E_{v1}	Layer thickness H (mm)
TS_GP	No reinforcement	21.92	-	36.28	-	1.66	350
	3D grid (hgr = 50 mm)	23.43	6.9	65.43	80.4	2.79	
TS_BPL	No reinforcement	25.4	-	99.77	-	3.93	300
	3D grid (hgr = 20 mm)	37.94	49.4	126.66	27	3.34	

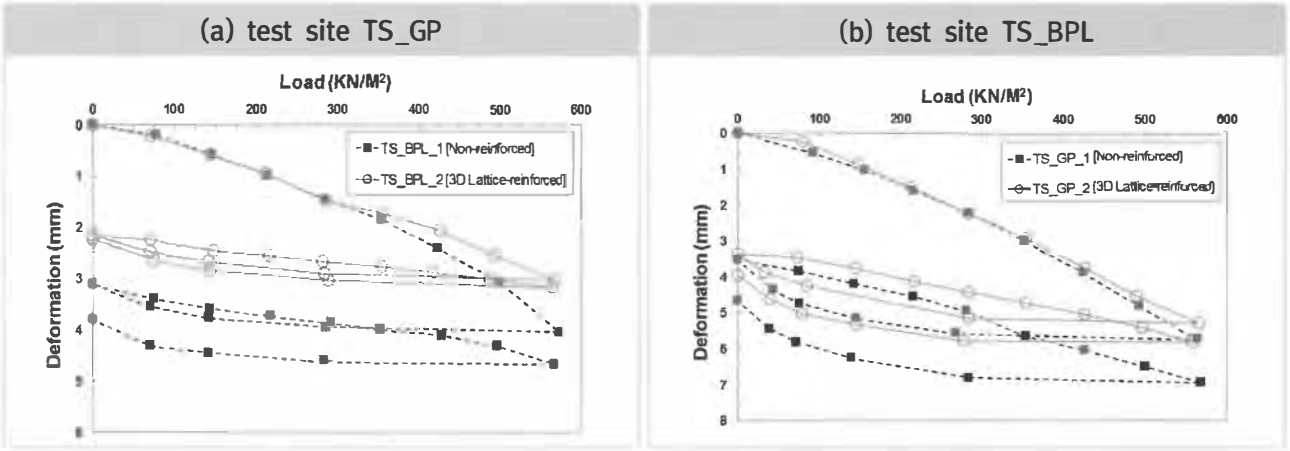
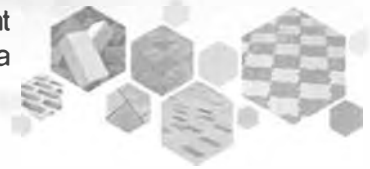


Figure 10. Static RPBT results of bearing load vs. deformatin curve at test sites of TS_GP and TS_BPL.

2.4 Reinforcement effect through a numerical analysis approach

In order to verify the geogrid reinforcement effect in 2D through the numerical analysis, the elasto-plastic analysis model was used using finite element software, PLAXIS (Brinkgreve et al., 2006), to simulate subbase layer including geogrids, subgrade and natural ground. Table 3 below shows the material properties used for the analysis.

Loading was applied as uniformly stressed on circular area with a plate-radius of 150 mm, upto a maximum pressure of 350kPa. And the geogrids applied to the 1/3 position from the bottom of the crushed-stone subbase layer. The geometry of the numerical model consists of two 300mm thick aggregate subbase and subgrade layers that lies above ground, and the analysis was conducted for no reinforcement cases and reinforcement cases. As shown in Table 3, the



saturation unit weight, modulus of elasticity, adhesion, and internal friction angle were set in the modelling for the subbase/subgrade layer and ground characteristics, where the MohrCoulomb model was used for subgrade ground while the hardening soil model for the crushed-stone layer. Figure 11shows the results of numerical analysis results for the two cases of non-reinforced and reinforced condition at the position of 1/3 from the bottom level of the subbase. And the graphs reveal that the displacement did not converge due to plastic failure under the non-reinforced condition, while showing that the reduction of displacement without plastic failure behaviour as the vertical pressure increases to 350 kPaunder the geogrid reinforced condition.

Therefore, the results indicate that the geogrid reinforcement is an important factor affecting the improvement of bearing capacity when geogrid is installed in the crushed-stone layer in-situ. From the numerical analyis, the deformation reduction of the pavement sub-structure also prove that the maximum vertical and horizontal displacements are 2.97, 0.43 mm under the non-reinforcement condition, while being 2.48, 0.28 mm respectively under the reinforcement condition.

Table 3. Properties of materials in PLAXIS

Layer	Ground	Subgrade	Subbase
$\gamma_{unsat.}$ (kN/m^3)	18	19	15.3
$\gamma_{sat.}$ (kN/m^3)	19	20	15.3
E (kN/m^2)	1.20E+05	1.30E+05	
ν	0.3	0.3	
C (kN/m^2)	5	5	0.1
φ	32	35	45

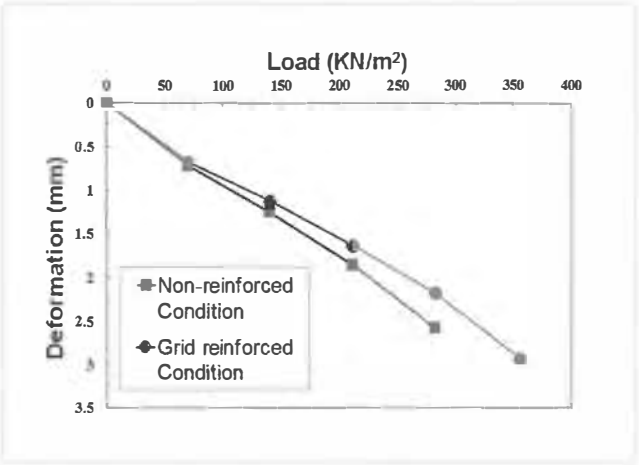


Figure 11. Results of PLAXIS analysis.

3. Conclusion

(1) This study was carried out to investigate the bearing performance of geogrid-reinforced crushed aggregate subbase course based on field experimental approaches along with a limited numerical analysis. The result of plate bearing test (PBT) shows that subgrade reaction modulus (K_{30}) value does not satisfy the general construction standards in Korea when using crushed stone as a pavement support layer. This finding could be attributed to the grain size distribution of crushed stone material which has a relatively uniform paricle size.

(2) This study involved performing experiments using a set of 3D lattice-panels with studs and ribs and the general 2D plane-type geogrid are installed at 1/3 level from the bottom of the layer. The PBT result in terms of the reinforcing effect shows that the improvement of the bearing capacity is increased from 22% to 45% compared to the non-reinforced condition in the case of reinforcing with the 3D lattic-panel in the crushed-stone layer, while it shows about 10% increase in subgrade reaction modulus when 2D plane-type geogrid is applied.

(3) From the results of repetitive plate bearing test (RPBT), it is shown that the secondary deformation modulus (E_{v2}) is higher in non-reinforced and reinforeced condition than the first deformation modulus (E_{v1}). These results, as one of characteristics of RPBT, show that the secondary deformation modulus increases as the interlocking effect increases in the reinforcement grid and aggregate after the first plastic deformation is removed and the permeable base layer is compressed through the first pressure loading.

(4) Numerical analysis results also showed improvement effect of settlement reduction performance when the reinforcement grid is applied as in the field test case. However, it is necessary in the future to continuously verify frictional resistance between aggregates and reinforcement materials, the modeling of the interlocking effect, and the effects of reinforcement grids through many field experimental and numerical approaches, such as the FEM/FDM and DEM approaches.

(5) The light weight deflectometer test (LWDT) can be applied conveniently as a compaction management alternative to the in-place density test used for the existing general road, in terms of the method for determining the compaction of the crushed-stone layer or subgrade layer in the permeable road pavement structure.

(6) Considering that permeable pavements are mainly applied to parking lots and light traffic roads in Korea, it is necessary to review the mitigation of standards (ie, subgrade bearing modulus K_{30}, subgrade resilent modulus Er etc.) for compaction management in the field, since there is no specific standard for the beaing capacity applicable to the crushed-stone layer of permeable pavement.

Acknowledgements

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