Neoweb® 3D Cellular Confinement System for Structural Pavement Reinforcement of Roads & Railways

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ABSTRACT: Despite significant reinforcement capabilities, 3D cellular confinement systems (geocells) have not been widely used in flexible pavements due to a lack of understanding of geocell technology and concerns about their durability. Recent developments in high-strength geocell polymers as well as comprehensive research into geocell reinforcement mechanisms, influencing factors and design methodologies, reviewed in this article, can change the situation. Geocells manufactured from this novel polymeric alloy provide long-term strength suitable for structural reinforcement of roads and rails. These high-strength geocells can be installed in the base layer of heavy-duty paved roads and rails to replace high quality aggregate with lower quality materials, at the same level of performance. Novel polymer alloy geocells improve the layer modulus, reduce capital and maintenance costs and utilize on-site or recycled materials, thereby preserving aggregate resources and making infrastructure development more sustainable.

1. GENERAL INTRODUCTION

Vietnam is an example of a rapidly expanding economy investing heavily in infrastructure development. Strategic expansion of the transportation network is a central component of this program, with an emphasis on increasing the quantity and quality of its paved roads and highway system. In order to align the substantial investment with the available resources, new innovative technologies for road construction can be critical to its success.

The need for millions of cubic meters of aggregate for construction strains the ability of contractors to meet their goals, particularly where projects require high-quality and/or high qualities of quarried stone. Therefore, the utilization of locally available and/or recycled materials is therefore a development goal, if not a practical necessity for road infrastructure development in the country. In general, the local construction industry is willing to adopt innovative technologies that help meet these sustainable goals.

While geosynthetics are commonly used for base reinforcement in unpaved and paved roads, geocells have more potential reinforcement due to their 3D structure. The concept of cellular confinement by geocells, three-dimensional, interconnected honeycombed polymer cells, was originally developed by the US Army Corps in the late 1970's) to improve the bearing capacity of weak subgrade (Webster and Alford, 1977). A review of the literature by Yuu et al (2008) concluded that geocell confinement improves the properties of base courses, increasing bearing capacity, distributing stress and reducing permanent deformation. However, Yuu concluded that the widespread use of geocells for base reinforcement in paved and unpaved roads was limited due to the lack of established design methods, as well as to gaps in research and understanding the mechanisms and influencing factors for geocell reinforcement.

New developments in polymeric materials for geocells in collaboration with comprehensive research programs around the world have led to new types of geocell reinforcement. The first impetus was a novel polymeric alloy material invented by PRS, an established player in geocell field. The properties of this new alloy impart long-term strength and stiffness to geocells, thereby enabling their use in long-term critical applications. The second impetus was extensive research into the mechanisms and influencing factors of geocell reinforcement and evaluations of the performance of high-strength geocells, an iterative process, including the calibration of design methodologies (Han et al, 2011).

This article summarizes extensive research conducted by leading geotechnical researchers and institutes worldwide including plate loading box tests, moving wheel tests, and field demonstrations in the US, Germany, Holland, India, and Israel. The studies demonstrate how the Neoweb® 3D cellular confinement system is a new development in construction technology that can be used to meet the sustainable construction goals in Vietnam and other rapidly developing countries.

2 NOVEL POLYMERIC ALLOYS

2.1 Reinforcement Mechanism

Han et al (2010) summarizes the key mechanisms of geocell reinforcement as lateral and vertical confinement, beam (tension membrane) effect and load distribution at a wider angle. Geocells provide lateral confinement to infill materials, preventing movement and shearing of infill under loading. Infill stiffness is increased by transferring vertical forces to hoop stresses on the geocell walls and by passive resistance from surrounding geocells. Frictional resistance between the infill and the cell walls along with the geocell-reinforced base acting as a mattress restrains soil from moving upward outside the loading area to provide vertical confinement. (Pokharel, 2009) Aggregate movement and attrition are minimized, while the distribution of lateral and vertical stresses is maximized. These mechanisms highlight the importance of geocell stiffness for the confinement.

2.2 Conventional HDPE Geocells

The most frequent use of geocells, commonly manufactured from HDPE (High-Density Polyethylene) is for slope and channel protection, low earth retention structures and unpaved roads. The geometry of the geocell is the key for erosion control and soil stabilization functions. Stabilizers are added for environmental durability against leaching of additives, oxidation and UV exposure.

HDPE geocells are suitable for load support applications in low volume roads and where long-term confinement of load-bearing infill is not required. HDPE geocells are also installed at the subgrade-subbase interface to reinforce weak subgrades soil, but these are not subject to heavy loading from the surface and base layers.

Research indicates that the tensile strength and stiffness of HDPE based geocells – particularly in long-term performance – are unsuitable for heavy load support applications such as paved highways and railways, subject to millions of loading cycles (Han 2011, Leshchinsky 2009). Stronger and more durable geocells with a higher elastic modulus are required.

2.3 High-Strength Neoloy Geocells

Neoweb is a cellular confinement system (geocell) developed by PRS, based on Neoloy. Neoloy® is made of a nanocomposite alloy of polyester/polyamide nanofibers dispersed in a polyethylene matrix. This provides flexibility for handling similar to HDPE (High-density polyethylene) with elastic behavior similar to engineering thermoplastics.

This geocell was specifically developed as a high-strength geocell to reinforce the upper layers of structural pavements in roads and rail applications. The high elastic modulus of geocells with Neoloy improves the layer moduli of the upper pavement structural layer, which is subject to hundreds of millions of repeated dynamic & cyclical loadings, as well as elevated temperatures and thermal cycling. Geocells made from Neoloy can maintain confinement (and compaction) under such loading, even while replacing high-quality aggregate with lower quality granular material.

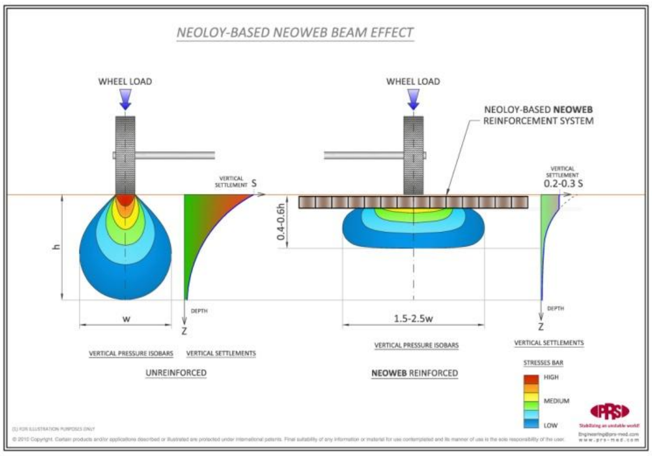

Figure 01: Neoweb beam effect on reinforced layer as compared to unreinforced layer

Strain measurements confirm the beam effect of the Neoloy-based geocells on the reinforced base (Pokharel, 2010). As shown above, the continuous semi-rigid beam produced by Neoweb reinforcement reduces the vertical stress by distributing the load to a wide area. Neoloy-based Neoweb enables durable structural reinforcement that can increase the project lifespan and reduce maintenance expenditures.

2.4 Neoloy vs. HDPE Geocells

Laboratory plate loading tests on geocells showed that the performance of geocell-reinforced bases depends on the elastic modulus of the geocell (Pokharel, et al, 2009). The geocell with a higher elastic modulus had a higher bearing capacity and stiffness of the reinforced base. Geocells made from Neoloy were found significantly better in ultimate bearing capacity, stiffness, and reinforcement relative to geocells made from HDPE (Pokharel, et al, 2009) Neoweb geocells with Neoloy showed better creep resistance and better retention of stiffness and creep resistance particularly at elevated temperatures, verified by plate load testing, numerical modeling and full scale trafficking tests (Pokharel, et al 2011).

3. REVIEW OF R&D & FIELD DEMOS

The following sections review the professional research and testing conducted on Neoweb cellular confinement systems at leading institutions worldwide and summarizes the studies, methodology and results.

3.1 Performance, Evaluation and Design of Geocell Reinforced Bases

Testing Organizations/Major Researchers:
Dr. J. Han, Dr. S. Pokharel, Dr. X. Yang, Dr. J. Thakur, C. Manandhar, et al; University of Kansas; Moving Wheel study at the Civil Infrastructure Systems Laboratory of Kansas State University, in cooperation with Kansas Department of Transportation (KDOT) and DOTs from the States of Iowa, Kansas and Missouri.

Figure 02: Installation of Neoweb and instrumentation in Accelerated Pavement Testing (APT) facility, Kansas

The objective of a comprehensive research program was to test various geocell types with different in-fill materials under real traffic on marginal subgrades. The specific goals were to:

- Evaluate the benefits of different types of Neoweb geocells as base reinforcement with different quality of infill materials through full-scale trafficking tests;
- Obtain performance data and verify theoretical solutions and results obtained from the geotechnical box testing study at the University of Kansas, and
- Develop a design method for geocell-reinforced roads considering the dimensions and mechanical properties of Neoweb and the infill quality material.

3.1.2 Laboratory Box Studies

The studies at the University of Kansas (Pokharel, 2010; Pokharel et al., 2010) subjected unreinforced and Neoweb-reinforced bases courses of different infill materials and geocell arrangements to a series of static and repeated plate loading tests in medium size boxes (60x60 cm or 80x80 cm). The tests examined the effect of infill types (Kansas River sand, quarry waste, and well-graded aggregate) on the performance of geocell-reinforced bases. The key findings for this test are summarized below (Han et al, 2011):

- Circular shaped geocell had higher stiffness and bearing capacity than elliptical shaped geocell.
- Neoweb reinforcement increased the granular base course stiffness by up to 2 times and bearing capacity by up to 2.5 times as compared to the unreinforced base course. The geocell with a higher elastic modulus material produced greater improvement.
- Under repeated loading, Neoweb reinforcement significantly reduced the permanent deformation of the granular base. The percentage of elastic deformation was higher for stronger infill material as compared to weaker fill material.
- Neoweb reinforcement significantly reduced the creep deformation of recycled asphalt pavement. It is recommended that a non-creep cover material should be used above the geocell.

Cyclic plate loading tests were performed in a large-scale testing box (2.2x2.x2.0 m high) (Pokharel, 2010; Pokharel et al., 2011; Thakur, 2011). The load actuator has a 245 kN capacity. A cyclic load at the maximum magnitude of 40 kN (corresponding to a loading pressure of 550 kPa) was applied at a frequency of 0.77 Hz on geocell-reinforced bases over weak subgrade.

Figure 03. Large-scale plate loading test in the geotechnical test box at the University of Kansas

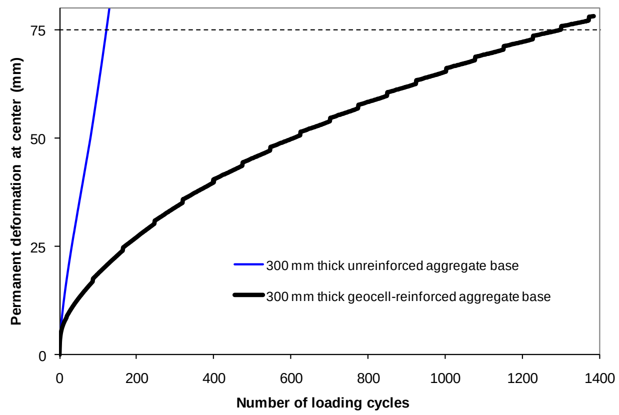

Figure 04. Comparison of permanent deformation between unreinforced and Neoweb reinforced road sections

In general, the degree of improvement depended on the geocell height and the infill material and density. The key findings for this test are summarized below (Han et al, 2011):

- Neoweb reinforcement improved the life of unpaved road sections by increasing the number of loading cycles.

- Neoweb reinforcement increased the stress distribution angle and reduced the stresses transferred to the subgrade..
- Strain measurements on the Neoweb confirmed the beam effect on the geocell-reinforced base.
- Calculated resilient moduli showed Neoweb reinforcement significantly reduced the rate of base course deterioration under cyclic loading.
- Infill density is important for the performance of geocell-reinforced bases.

3.1.3 Full-scale Moving Wheel Tests

Full-scale moving wheel tests were conducted on Neoweb-reinforced unpaved road sections over weak or intermediate subgrade using the accelerated pavement testing (APT) facility at Kansas State University (Pokharel, 2010; Yang, 2010; and Han et al., 2011, and Pokharel et al., 2011). 16 sections were evaluated utilizing: RAP well graded AB-3 limestone; Kansas River sand and quarry waste as well as an unreinforced control section. Each of the four test sections underwent wheel loading of 100,000 80-kN (18-kip) single axle load repetitions or 7.5 cm rut depth whichever came first. The testing included multiple instrumentation and performance monitoring.

Figure 05. APT facility and unpaved test sections

The key findings from these moving wheel tests are summarized below (Han et al, 2011):

- Neoweb could reduce the required base thickness to achieve the same performance of the unpaved roads over weak subgrade. The Neoweb-reinforced Kansas River sand exhibited the largest improvement over the unreinforced section.
- Neoweb reinforcement improved the life of the unpaved road sections, increased the stress distribution angle, and reduced the vertical stress transferred to the subgrade as compared with the unreinforced control section.

3.1.5 Conclusions

The laboratory experimental studies, full-scale moving wheel tests, and field demonstration in this comprehensive research have demonstrated clear benefits of Neoloy-based Neoweb reinforcement in terms of increased stiffness and bearing capacity, wider stress distribution, reduced permanent deformation, and prolonged roadway life. A basic conclusion of each type of study was that the benefit of geocell reinforcement increased with an increase of the modulus (tensile stiffness) of the geocell (Yang 2010). The study concluded with modeling and calibrating of design methodologies for roads with Neoweb reinforced bases.

3.2 Neoweb vs. Geogrids, Road Base Field Trial

Testing Organization/Major Researchers:
Van Gurp, C.A.P.M., Westera, G.E. KOAC–NPC, Netherlands, institute for testing, research and consultancy in civil engineering and road construction elements.

3.2.1 Introduction

KOAC conducted controlled field trials for geosynthetics reinforcement of road bases. Test data was based on deformation and stiffness trials of full-scale structures in controlled sites (enclosed hangars). Neoloy-based Neoweb was the only geocell in the test of 7 brands of geogrids. In addition Neoweb was also the only geosynthetic that could be tested with inferior aggregate as road base infill.

Figure 06. KOAC-NPC Enclosed Hangar Test Facility and Road Base Test Sections

3.2.2 Description

Falling Weight Deflectometer (FWD) loading created vertical deformation "footprints", which were used to assess the stiffness modulus. The results are based on the stiffness modulus of the combination of subbase and subgrade and the geosynthetic reinforcement in order to derive the road base thickness reduction factor. The design chart/method was developed by KOAC-NPC for CROW, Transport Research Knowledge Centre, Netherlands.

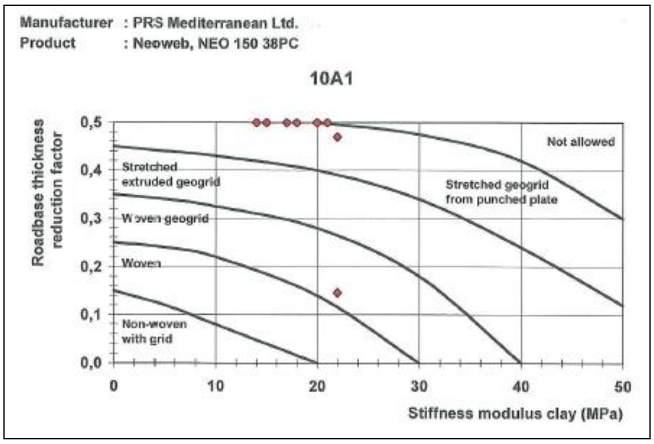

Figure 07. Roadbase Reduction Factor Neowebb (limited)

3.2.3 Results

The calculated mean road-base thickness (RF) Reduction Factor (unlimited) for Neoweb with a subgrade CBR of 1.5 was 0.73. This value off the chart, as the highest published RF for geogrid reinforcement was 0.5. Whereas geogrids RF values do not exceed 0.5, KOAC set this value as the maximum limit for the test. Even within these limitations, the mean 0.47 RF for Neoweb is higher than all other tested products.

Roadbase thickness reduction factor station 10A1

Control section	Station	Roadbase thickness reduction factor	NO LIMIT Roadbase thickness reduction factor	Stiffness clay control
(-)	(-)	(-)	(-)	(MPa)
Section 1B	1B2	0,50	0,77	15
Section 1B	1B4	0,50	0,88	15
Section 3B	3B1	0,50	0,87	14
Section 3B	3B2	0,50	0,76	14
Section 4C	4C2	0,50	0,63	18
Section 4C	4C3	0,50	0,76	18
Section 5A	5A1	0,50	0,72	17
Section 5A	5A2	0,50	0,74	17
Section 5B	5B2	0,50	0,81	20
Section 5B	5C3	0,50	0,83	20
Section 6B	6B1	0,50	0,95	21
Section 6B	6B2	0,50	0,83	21
Section 8C	8C1	0,15	0,15	22
Section 8C	8C2	0,47	0,47	22
	Minimum	0,15	0,15	
	Maximum	0,50	0,95	
	Mean	0,47	0,73	

Figure 08. Actual Roadbase Thickness Reduction Factors (limited vs. unlimited)*

3.2.4 Conclusions:

- Only reinforcement product tested with inferior infill
- Highest road base thickness RF of all tested geogrid products (limited and unlimited values)
- RF for high quality infill – avg. 0.43*
- RF for inferior quality infill – 0.31*
  (*NOTE: Maximum RF values limited to maximum of 0.50 according to test standards)

3.3. Neoweb Contribution to Load Bearing and Stress Distribution in Base Layer.

Testing Organization/Researchers:
Prof. Dr.-Ing. Norbert Meyer, Dr. Ansgar Emersleben, Institute of Geotechnical Engineering and Mine Surveying, Technical University, Clausthal, Germany.

The study evaluated the impact of Neoweb in base layer reinforcement of asphalt structural pavements via laboratory testing, field tests and long term monitoring devices to determine the load bearing capacity and stress distribution in soft subgrade:

- Phase I – static plate loading tests in 2x2x2m box.
- Phase II – in-situ road field test to verify lab results.
- Phase III - dynamic trafficking & FWD measurements.

3.3.1 Phase I – Static Plate Loading

The load settlement curve was calculated from the average values of the applied stress and the measured settlement of the load plate. The results of the dynamic plate tests showed that Neoweb reinforcement:

- Improved load-bearing capacity up to 5x
- Reduced settlement by geocell mattress up to 80%
- Reduced stresses in subgrade up to 40%

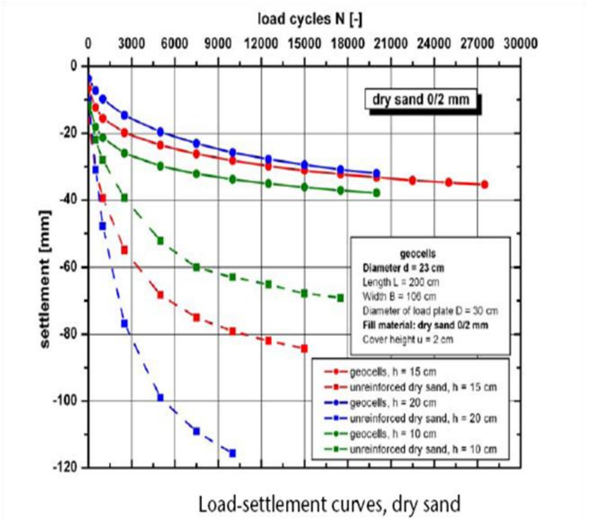

Figure 09: Plate loading tests showing load settlement of reinforced and unreinforced sand

3.3.2 Phase II – In-situ Road Field Test

The second phase involved actual field test in asphalt paved road rehabilitation. Earth pressure cells (sensors) were inserted at different locations in the support layers. Compared to the conventional solution in section 3 of 700m thick gravel infill, and a conventional resurfacing solution in section 2, the base Neoweb section 1 thickness is 47% less. (150 mm gravel + 200 mm Neoweb in base +5 mm overfill).

Installation and Infill of the Geocell (L), Earth Pressure Cells (R)

Figure 07. Installation of Neoweb and Earth Pressure Cells

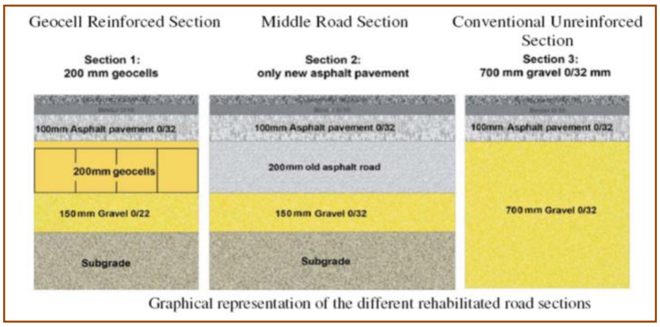

Figure 10: Cross-sections of the Neoweb reinforced and Original unreinforced secitons in Road ?

Plate loading tests carried out (before repaving of the asphalt layer) showed vertical stresses to the subgrade were reduced by 53%. Back calculation of the results showed that the modulus ratio of Neoweb is 5x that of the unreinforced layers.

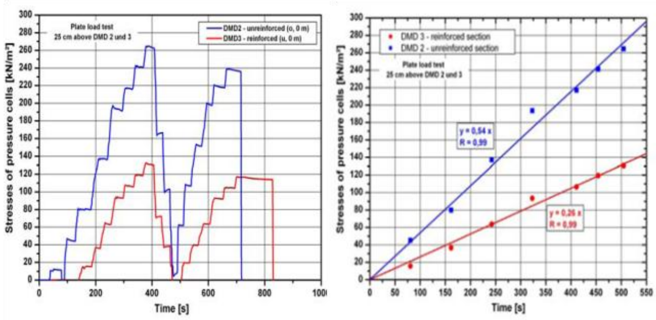

Figure 11: Vertical Stresses to Subgrade as Measured by Earth Pressure Cells

Blue lines *Unreinforced*
Red lines *Neoweb Reinforced*

Back Calculation Results
– Unreinforced vs. Reinforced Layer
Modulus Ratio: E_{sb} Reinforced 100 [MPa] / E_{sb} Unreinforced 500 [MPa] = 5

3.3.3 Phase III - Dynamic Trafficking & FWD

Dynamic Trafficking – earth pressure cell measurements of trafficking by a heavy truck showed subgrade stresses of 120 kN/m2 on unreinforced subgrade while only 75 kN/m2 were measured on Neoweb reinforced sections: **34-40% less stress** (Note: speed was incidental and showed no differences)

Falling Weight Deflectometer (FWD) Measurements – measured the influence of the Neoweb mattress below asphalt pavement and then linear-elastic modulus of layers back-calculated. Results confirmed that Neoweb increased the gravel base layer modulus and decreased deflections of asphalt surface course.

Conclusions:

- Neoweb reduced stress to subgrade by 40%.
- Field results confirmed results in lab tests.
- Back calculation confirmed field tests.

3.4 Plate Load Tests of Neoweb for Determination of Modulus Improvement Factor, India

Testing Organization/Major Researchers:
Prof. K. Rajagopal, A. Veeraragavan, S. Chandramouli, Department of Civil Engineering, Indian Institute of Technology, Madras, India

3.4.1 Phaltan Project

Plate load tests were performed on Neoloy-based Neoweb reinforced and unreinforced pavement sections on a new constructed access road at the Govind Dairy Factory, Phaltan India. Pressure-settlement data were used to estimate the Modulus Improvement Factor (MIF) for the Neoweb reinforcement.

Figure 12. Neoweb installation of access road, Phaltan, India

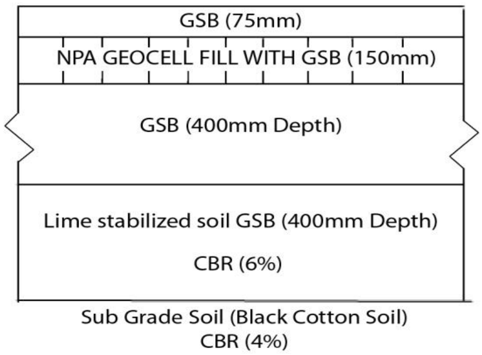

Figure 13. Section of access road

3.4.2 Determining Modulus Improvement Factor

According to the Indian Road Congress (IRC) formulas for moduli of soil layers in CBR values.

Subgrade[8]

$$E(MPa) = 10*CBR \quad \text{for } CBR \le 5 \text{ and}$$
$$= 176*(CBR)^{0.64} \quad \text{for } CBR > 5$$

Granular Sub-base and Base[7]

$$E_2 = E_3*0.2*h^{0.45}$$

Where:

E2 = composite elastic modulus of granular sub-base and base (MPa).

E3 = elastic modulus of subgrade (MPa).

H = thickness of granular layers (mm).

Poisson's ratio for granular and subgrade layer may be taken as 0.4.

3.4.3 E-Values per Structural Layer

- Subgrade (CBR 4%) =
  10*4 =40 mPa = 40000 kPa
- Stabilized subgrade (CBR 6%) =
  17.6*6^0.64 = 55.40 Mpa = 55400 kPa
- GSB (225 mm thick) =
  55400*0.2*225^0.45 = 126771.577 kPa
- GSB (75 mm thick) =
  55400*0.2*75^0.45 = 77324.53 kPa
- GSB (150 mm thick) =
  55400*0.2*150^0.45 = 105628.43 kPa
- GSB (400 mm thick) =
  55400*0.2*400^0.45 = 164235.39 kPa

3.4.4 Modulus Improvement Factor = E-Value (reinforced layer) / E-Value (unreinforced layer)

The investigators used the average settlements that from the plate load test (3.35 mm) in the field under 10T of load on the reinforced section and tested for the corresponding modulus that would yield the above settlement using the Kenpave pavement analysis program. The analysis used a load of 100 kN and plate contact radius of 150 mm (contact pressure = load/area =100/area of plate = 1414 kPa). The modulus of the Neoweb layer was selected by trial and error process to match the measured settlement at a load of 100 kN.

Table 1 – Improvement factor from E-Value/ avg. settlement

Improvement Factor	E-Value	Average Settlement
1	105628.43 kPa	4.32
2	211256.86 kPa	3.57
2.5	264071.075 kPa	3.41
2.75	**290478.18 kPa**	**3.35**
3	316885.29 kPa	3.29
4	422513.72 kPa	3.14
5	528142.15 kPa	3.03

The Phaltan section has significant results from an engineering and economic standpoint. It provides additional field test data supporting previous works on this topic and substantiates the previous calibrations for the Neoweb Modulus Improvement Factor is between 2.5 and 2.8.

3.5. Cross-Israel Highway 6 Demonstration Project

Testing Organizations/Major Researchers:
Derech Eretz road operator, National Roads Authority, Israel.

The Cross-Israel National Highway 6 (Class I grade highway) concessionaire decided to investigate the economic impact of structural reinforcement in the base layer of a new section of road with Neoloy-based Neoweb.

Figure 14. Cross Israel Highway 6

3.5.1 Design Method

Design of the solutions was based on mechanistic-empirical method for flexible pavements using the layered elastic model, based on the following parameters:

- CBR according to relative seasonal damage.
- Evaluation of the Equivalent Single Axle Loads (ESAL's) based on 18-kip single axle (W18).
- Definition of the Neoweb reinforcement properties, including the Modulus Improvement Factor (MIF) for fully and partially confined zones.
- Examination of fatigue and rutting failure criteria.

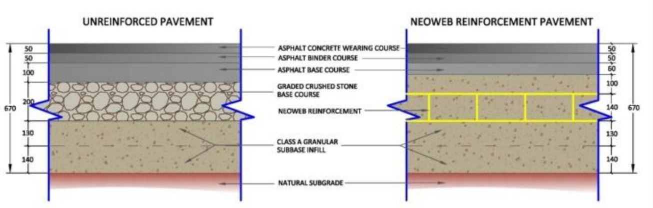

Figure 15. Conventional vs. Neoweb-reinforced pavement.

3.5.2 Results and Conclusions

The increased modulus of the Neoweb reinforced layer enables replacement of the base layer with less expensive subbase quality infill, as well as reduction in the asphalt base course. The following were achieved with Neoweb reinforcement:

- Asphalt concrete – reduced by 22.5% (45 mm) due to improved aggregate base modulus.
- Base layer – replaced base (crushed stone) with lower cost granular subbase infill (-38% /m^3).
- Subbase layer - reduced thickness by 7.4% (20mm).
- Improved modulus enables increased traffic (ESAL) loadings.
- Pavement maintenance – eliminate one complete deep scraping & overlaying of asphaltic layers over 20 year design life.

Figure 16. Installation of Neoweb in Cross Israel Highway 6

The economic benefits achieved by utilizing Neoweb include:

- Save \$3.29/m^2 or 5.8% of direct construction costs vs. the conventional design.
- Save \$15.58/m^2 (50%) of the conventional 20-year expected pavement maintenance costs.
- Total savings of 21.5% of the conventional life cycle cost anticipated.
- Additional in-direct savings due to lower equipment requirements – logistics, hauling, compaction, manpower and traffic restrictions.

3.6. Railroads Study – Railway Embankments Maintaining Ballast Geometry under Static and Dynamic Loads

Testing Organization/Authors: Dr. H.P. Ling, B. Leshchinsky, Geotechnical Engineering, Department of Civil Engineering, Columbia University, NY, USA.

3.6.1 Description

Embankments subjected to repeated loading are subject to progressive deformation and loss of strength over time. Railroad ballast embankments in particular are prone to a rapid loss of geometry under loading by heavy freight trains, requiring expensive maintenance and downtime.

Loading tests on unreinforced and Neoloy-based Neoweb reinforced representations of railroad ballast embankments were performed to study the impact of Neoweb on the strength and stability of confined ballast. Three test configurations (unreinforced, single-layer, double-layer) were used, each of which was loaded to failure under monotonic conditions, and separately loaded cyclically with stress amplitude of 140 kPa and 275 kPa for unreinforced and reinforced configurations, respectively.

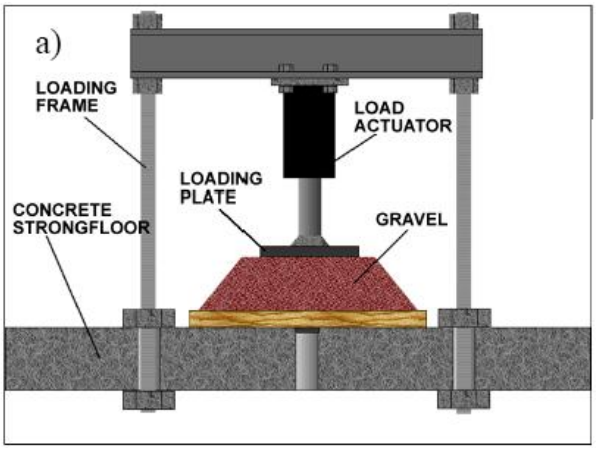

Figure 17. Schematic setup of loading frame

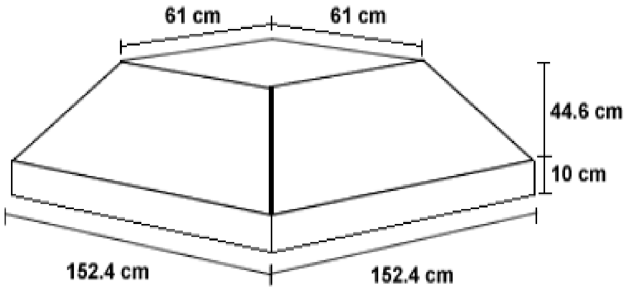

Figure 18. Schematic of ballast model with 45^0 slope

3.6.2 Results and Conclusion

The study showed that Neoweb significantly restricted vertical displacement (31-52%**)** and lateral displacement (24-31%) under static and cyclical loading. Test and device limits were reached during the testing of the Neoweb reinforced embankments for the loading frame capacity (~600 kPa) and for the number of loading cycles (50,000). Little displacement occurred in the last 45,000 cycles, indicating stiffening and stabilization of the railway ballast. On the other hand, maximum displacement (119 mm) of the device limits was reached in the unreinforced section during the initial few hundred cycles.

The researchers concluded that: "Neoweb was stable under controlled cyclic loading within the stress amplitude of many transportation applications (roadways, train, ballast, etc.); Measurements show that the presence of Neoweb allowed for a significant increase in stiffness and strength while reducing permanent deformation implying that an optimized use of reinforcement could lead to significant reduction in maintenance due to ballast degradation."

4. DESIGN METHODOLOGY

4.1. Neoweb-Reinforced Pavement Design According to Mechanistic-Empirical Method

Testing Organizations/Authors:
Dr. J. Han, Dr. S. Pokharel, Dr. X. Yang, Dr. J. Thakur, C. Manandhar, et al; University of Kansas, USA.

4.1.1 Introduction

The theoretical research into Neoloy-based Neoweb reinforcement mechanisms, influencing factors of loading in plate tests and accelerated wheel load tests at the University of Kansas, led to the development of a design method for Neoweb geocells. A simplified design method was developed for Neoweb-reinforced bases for unstable subgrades, utilizing bearing capacity, based on a modification of the Giroud and Han (2004) method for design with geosynthetics. The design method for incorporating Neoweb into roads with stable base and subgrade is based on the resilient behavior of pavement structures and follows the Mechanistic-Empirical design procedure.

4.1.3 Modulus Improvement Factor (MIF)

It was well accepted that confinement increases the resilient modulus values of granular materials used in pavement structures; and especially of inferior fill, such as fine granular soils and recycled materials. The increase in the modulus or stiffness of Neoweb reinforced base layers have been verified by modeling and numerical analysis by Han et al 2010, Yang, 2010, Pokharel 2010 and Meyer (2007). The increased modulus of the base course is defined as a Modulus Improvement Factor (MIF). The MIF of the base layer relates to the improvement of the modulus of the base by the Neoweb, as shown by the following formula:

$$MIF = \left(\frac{E_{bc\,(reinforced)}}{E_{bc\,(unreinforced)}} \right)$$

Generally, the MIF applied in Neoweb-based projects ranges between 1.5 to 5.0 dependent on material of infill, subgrade and relative location and depth of the reinforced layer.

4.1.2 Layered Elastic Model

The layered elastic model is one of the Mechanistic models that are used to mathematically model pavement physics. A layered elastic model can compute stresses, strains and deflections at any point in a pavement structure resulting from the application of a surface load.

A pavement design is evaluated by first modeling the multi-layered pavement configuration - each layer is defined by thickness, elastic modulus and Poisson's ratio. Then the typical load configuration is applied, using one of the commercially available layered-elastic analysis programs for pavements.

The design theory is based on replacing an unreinforced pavement design with one based on reinforcement. The Neoweb improved performance of the structure is expressed by improving the modulus of (usually) the base layer utilizing the MIF.

Implementation of the elastic response in transfer functions provides the ESAL's performance for reinforced pavement structure. This is then validated for the critical failure modes: fatigue – failure of the asphalt layer; and rutting – failure of subgrade bearing capacity. An iterative process is used to optimize the cost savings in terms of the layer thickness and infill type with an equal or greater performance compared to the unreinforced design.

4.2. Neoweb-Reinforced Pavement Design According to Vietnamese Specification No. 22 TCN 211-06

Testing Organizations/Authors:
Dr. D.T. Tan. Highway Department, Civil Engineering Faculty, Hanoi University of Transport & Communications, Vietnam; T.D. Toan, Engineering & Project Department, JIVC Joint Stock Company (PRS representative agency in Vietnam).

4.2.1 Vietnamese Design Methodology for Flexible Pavement Design No. 22 TCN 211-06

The Vietnamese standard defines a flexible pavement as a multi-layer structure consisting of surface course, base course and subbase course.

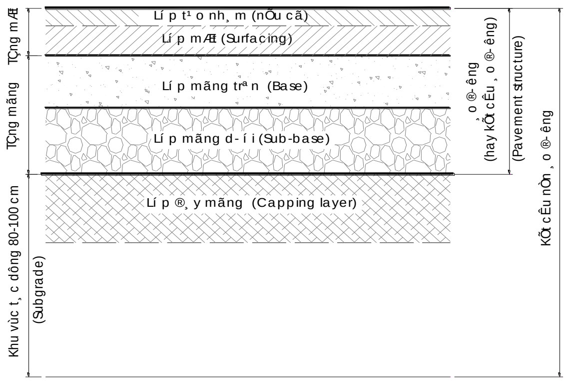

Figure 20. Vietnam standard section for flexible pavements

Flexible pavement structure design is based on factors such as: classification of the highway, design traffic volume for the future, design speed, geotechnical and hydrological conditions, and availability of local infill materials. In addition, planners must also consider constructional conditions, performance of pavements in the area, initial costs, and overall annual maintenance and service-life costs.

According to the current Vietnamese standard 22 TCN 211-06, the pavement is deemed to be sufficiently strong if the following three conditions are met:

- **The settlement of the pavement structure does not exceed the allowable value.** The design approach is based on controlling the elastic surface deformation of the structure under the design traffic volume. The design procedure specifies a required elastic modulus for the entire pavement structure. The pavement layer materials and thickness must be selected to provide an equivalent elastic modulus of the whole pavement structure equal to or higher than the required elastic modulus: ($E_{ch} \geq E_{yc}$)

- **No plastic deformation occurring in any of the pavement layers, including the embankment.** To guard against such failure, the shear stress in each layer is checked to ensure that the allowable limit is not exceeded. This check is carried out in by performing load bearing capacity and shear failure analysis of the pavement against the critical design wheel load, the standard calculation load: ($\tau < [\tau]$)
- **No damage to the continuity of pavement layers constructed of cemented or bound materials (termed as integrity layer)**. The continuity of each "integrity" layer is preserved if crack formation in the layer is prevented. In the pavement design, this is checked by ensuring that the flexural stress at the bottom of each "integrity" layer under the design load does not exceed the allowable tensile stress of the layer material: ($\sigma_u < R_u$)

4.2.2 Design Examples

The aim of this research was to develop a design methodology for incorporating the Neoweb-reinforced pavement structure into the current Vietnamese flexible pavement design procedure No. 22TCN211-06 utilizing the Modulus Improvement Factor (MIF) presented above. The methodology calibrated for Neoweb can be used to reduce the pavement thickness according to the design procedure No. 22 TCN 211-06, as in the following examples.

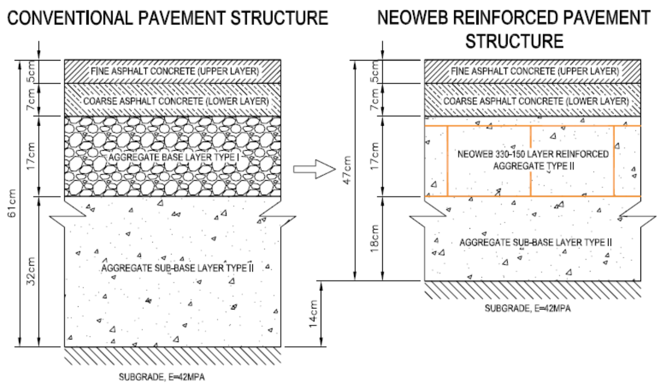

Figure 20. Reducing the pavement thickness using Neoweb

In heavy-duty pavement structures a Neoweb reinforced layer with local granular material can replace the cement stabilized base. The advantages of this solution are reduced construction time, better cracking resistance and reduction of the asphalt layer thickness.

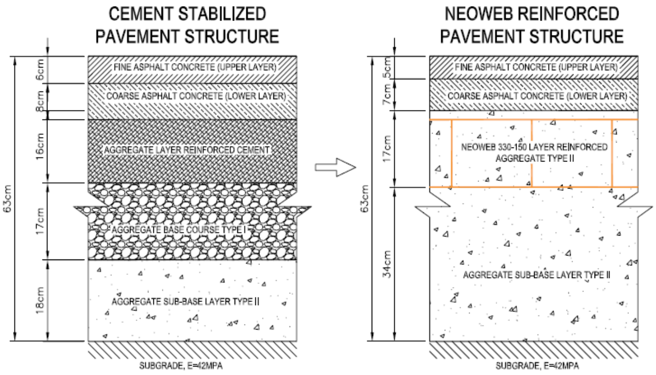

Figure 21. Neoweb solution replaces cement stabilized base

5. SUMMARY & CONCLUSION

Recent research has broadened our understanding of cellular confinement systems and proven the effectiveness of 3D reinforcement mechanisms. While the basic geometry and confinement principles of geocells are readily understood, only recently were the influencing factors of the reinforcement investigated, tested and qualified. The research demonstrates that not all geocells are equal. Geocells with a higher elastic modulus produced greater improvement in terms of stiffness, bearing capacity, stress distribution and reduced deformation.

The research and field demos clearly prove that novel polymeric alloy geocells, specifically Neoloy-based Neoweb, significantly improve the reinforcement efficacy of geocells better than HDPE based geocells. The research also helped fine-tune the development of the material properties of the Neoloy alloy – low coefficient of thermal expansion (CTE), long-term dimensional stability and resistance to creep and high temperatures – to improve their suitability for demanding applications requiring long-term performance, such as in roads and railways. In addition the research modeled and calibrated the mechanistic-empirical design methodology for load support applications based on the reinforcement factors specific to Neoloy-based Neoweb.

The ability to predict long term performance of Neoloy-based Neoweb aligns it with the typical lifespan of civil engineering projects. The high-strength of Neoweb validates the positioning of the geocells in the base layer of structural pavements, as opposed to conventional practice, which locates HDPE geocells on the subgrade level. This enables Neoweb reinforced bases to maximize the modulus improvement factor for the surface layer (asphalt or track).

In addition to a long lifespan, Neoloy-based Neoweb also improves the modulus of inferior quality infill material – locally available, low grade or recycled materials – for structural pavements with no degradation in performance. Not only is this an environmentally sustainable solution, which saves virgin aggregate, it is economically sustainable as well.

The location in and the replacement of the base layer with high-strength geocells and granular infill actually elevates Neoweb from a niche solution for problematic subgrades to a broad sustainable solution for the structural base of all roadway and railway applications.

Research into new and sustainable geosynthetics for construction is of crucial importance in rapidly developing countries such as Vietnam in particular and Asia in general, which face extensive needs with limited governmental budgets and diminishing aggregate reserves. This article exemplifies how collaborative research between academia and industry can effectively develop sustainable geosynthetic solutions for the 21st century.

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