Chapter 15
Case Studies on Geocell-Based Reinforced Roads, Railways and Ports

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Abstract Although geocells have been around for more than half a century, only recently were they adopted for heavy-duty infrastructure projects. This is due to a better understanding of geocell technology and to the creation of a novel polymeric alloy (Neoloy®) for geocells with high elastic modulus, low permanent deformation and high tensile strength. Case studies of Neoloy-based geocells used in airport, feeder road, railway and port projects demonstrate their suitability for long-term base reinforcement of heavy-duty pavements. These geocells show an improved engineering performance in terms of subgrade bearing capacity, layer stiffness and fatigue resistance beyond conventional geocells. The result is sustainable, stronger and stiffer pavements with an extended lifespan and lower maintenance.

Keywords Airport pavement · Rural road · Railway · Port platform · Heavy-duty pavements · Base reinforcement · Soil stabilization · Neoloy · Geocells

15.1 Introduction to Neoloy Geocells

Geocells are a proven soil stabilization and reinforcement solution used for over five decades for problematic soils, challenging environs and where aggregate is scarce. Yet their adoption by the civil engineering community was not widespread due to a lack of basic research, testing standards, design methodologies and R&D in advanced polymeric materials. This changed about 15 years ago with the introduction a novel polymeric alloy, Neoloy® that improved the key geocell performance factors, accompanied by a surge in experiential and field studies, published papers, the development of design methodologies, and more recently, international guidelines and testing standards. The Neoloy Geocell was developed specifically with performance properties to meet the demands of heavy-duty pavements: high elastic modulus, creep resistance and tensile strength. These provide the geocell with reliable dimensional stability,

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Table 15.1 Neoloy parameter properties evaluated by standard testing procedures (source PRS Geo-Technologies)

Performance parameter	Value	Description	Standard
Elastic stiffness (dynamic modulus)	>500 MPa @ 60 °C	DMA—dynamic mechanical analysis	ASTM E2254, ISO 6721-1 (DMA)
Permanent deformation (creep resistance)	<3% deformation at 75 years	SIM—stepped isothermal method	ASTM D-6992
Tensile strength	>19 kN/m	Wide-width method	ISO 10319:2015
Environmental durability	>1600 min	HPOIT—high pressure oxidative induction time	ASTM D5885 @ 150 °C

confinement and compaction for the entire lifespan of infrastructure projects (Table 15.1) (Kief et al. 2014).

Four case studies of Neoloy-based geocell reinforcement of heavy-duty, permanent pavements are provided in the following sections for airport, unpaved feeder road, railway and port platform projects.

15.2 Case Study A: Ground Reinforcement for New International Airport Roadways, Mexico

See Figs. 15.1, 15.2 and Table 15.2.

15.2.1 Introduction

Construction of the New International Airport Mexico City (NAICM) airport—one of the world's largest—on unstable, saturated and sinking clay mud of the ancient Lake Tenochtitlan lakebed is an enormously challenging geotechnical engineering project. Conventional soil stabilization and construction methods were insufficient, too costly or time consuming. After extensive trials, Neoloy Geocells were selected as the best qualified solution with the required performance that met the soil conditions.

15.2.2 Soil

The soil has high-water content with little capacity to support large loads. In addition, the area is seismic, and the effects of ground movement are magnified by the soil

Fig. 15.1 Soil stabilization of poor subgrade with Neoloy Geocells. *Photo credit* Innovater

Fig. 15.2 Neoloy Geocell stabilized asphalt pavement roadways. *Photo credit* Innovater

type in the area. Finally, the site is subject to substantial settlement over time, from groundwater extraction for the drinking water supply of the city.

The upper layer of this soft soil is a very thin layer (20–25 cm) of clay with a 1% CBR. Under this, is a 30–60-m deep layer of clay mud with a 0.6% CBR. This consolidated mud layer makes road building extremely difficult, the soil is extremely soft, saturated and highly plastic with wet-dry cycles that cause extensive potholes and cracking of the surface. A high groundwater level, coupled with high seasonal

Table 15.2 Case Study A: Project Snapshot

Description	Neoloy Geocell ground reinforcement and soil stabilization for heavily trafficked asphalt paved roads on very soft soil
Subgrade soil	20–25 cm clay with 1% CBR 30–60 m layer of clay mud with 0.6% CBR
Client	New International Airport, City of Mexico (NAICM) Authority
Project design	Innovater, Innovciones en Terracerias S.A. DE C.V., Mexico
Achievements	• Soil stabilization on extremely weak soil • Use of local volcanic rock for structural infill lowered weight of pavement by 60% • Reduced construction time by at least one year • Eliminated need for soil replacement • Lower construction costs
Date	Phase I and II—September 2015–June 2017
Keywords	Airport, clay mud, geocell, stabilization

Source PRS Geo-Technologies

rains, creates even more complicated ground conditions, limiting the mobility of construction trucks and equipment.

15.2.3 Conventional Solutions

Due to the extremely soft and deep clay soils, conventional road pavements were unfeasible—the weight of a pavement thick enough for the required traffic and loads on the compressible soil would actually cause it to sink, not to mention the costs.

Soil removal and replacement were also unfeasible as the 4.4-ha size of the site and the extreme 30–60 m depth of the problematic subgrade would have meant years of earthmoving, and unacceptable delays in the project timeline (Fig. 15.3).

Chemical soil stabilization was also ruled out due to problematic application—the application equipment breaks the upper crust and sinks in the soft mud—as well as concerns about curing time, durability, environmental impact and high costs.

Geosynthetic mechanical soil reinforcement appeared to be the only feasible choice. A geogrid-based solution comprised of a non-woven geotextile and two geogrid layers were tested in field trial sections. However, these also failed: the geogrids ruptured, the surface developed multiple potholes and loaded trucks sunk in the soil unable to traverse the road surface.

High-density polyethylene (HDPE) geocells were considered. The geocell confinement restricts lateral movement and deformation of the infill resulting in increased stiffness of the layer. However, questions arose about the suitability of HDPE-based geocells for this project as the design life was for a perpetual pavement– 50-year lifespan. HDPE geocells have low elastic stiffness (<600 MPa @ 45 °C), high creep and relatively low tensile strength (<11 kN/m).

Fig. 15.3 Loaded truck in section reinforced with geogrids (left) versus section reinforced with Neoloy Geocell (right). *Photo credit* Innovater

15.2.4 Neoloy Geocell Solution

A geocell based on Neoloy was proposed to the ground engineering experts of the NAICM airport authority by Innovater—Innovciones En Terracerias S.A. DE C.V, as the best available solution. Neoloy® is an advanced polymeric alloy developed by PRS, based on polyimide in a polyolefin matrix. The NAICM authorities examined the key properties for geocell reinforcement:

- Dynamic stiffness for cyclic loading at low-level elastic deformation
- Creep resistance for low-level accumulated plastic deformation less than 2%
- Radial tensile strength to withstand hoop stresses.

These properties are similar to those cited in a recently published guideline standard for geocells in road building, published by the SBRCUR/CROW road building and transportation research and standard institutes, Netherlands (Vega et al. 2018): “The most important material properties are the elastic stiffness and the resistance to permanent deformation (creep)…. Materials that exhibit a lot of creep will gradually lose their reinforcing capacity over time.”

The Neoloy Geocell properties enable an optimum performance of the airport pavement for the entire 50-year design life: For example, the improvement factor in geocell design is based on a maximum deformation of cell wall less than 2–3%. A volumetric increase of the cell beyond that may cause infill to settle, thereby invalidating the design.

Engineering proofs of testing were conclusive. Results of a comparative stepped isothermal method (SIM) accelerated-creep test (ASTM D6992 modified) under heavy loading (6.1 kN/m) show that permanent elastic deformation of a high-quality HDPE geocell was 22.5% after only 4.5 months, as compared to deformation of a Neoloy Geocell of 1.2% after 75 years (see Fig. 15.4).

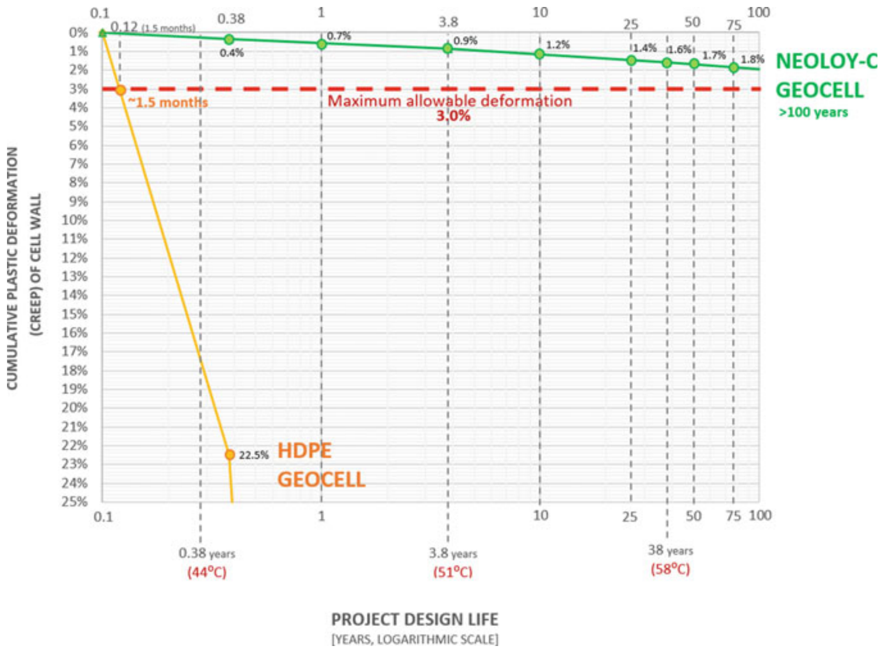


Fig. 15.4 SIM test results showing time (temperate) versus plastic deformation (max. allowable = 3%) under constant heavy-duty load (6.1 kN/m); test method ASTM D6992 (SIM). *Source* PRS Geo-Technologies

Of significance to the NACIM project is the locally available but low strength, ungraded, lightweight Tezontle volcanic rock. The Neoloy Geocell improves the modulus of Tezontle by a factor of 3.5 enabling its use as infill material. This very lightweight of the volcanic stone contributes to a significant reduction in the overall weight of the pavement and optimizes the entire design.

In addition, the Neoloy Geocell with Tezontle infill had previously demonstrated excellent results in apron and platform pavements in the current Mexico City Airport. Consolidated settlements were reduced from an annual average of 18 cm to zero settlement over a period of 4 years.

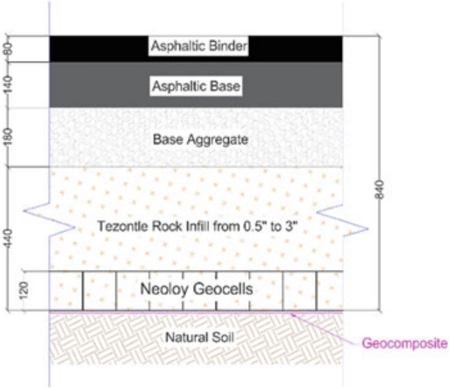
After a four-month field trial by NAICM involving 45-ton loaded trucks × 60 passes per day, the Neoloy Geocell-reinforced roads evidenced no surface deformation, potholes or settlement. Based on the trial and the factors described above, the NAICM authorities concluded that Neoloy Geocells were the best available solution for soil stabilization and ground improvement (Fig. 15.5).

Fig. 15.5 Compaction of volcanic rock infill, during installation of NPA Geocell in swampy soil. *Photo credit* Innovater

15.2.5 *Design and Construction*

The design of a typical pavement section is illustrated below (Fig. 15.6).

A "sacrificial" geogrid layer on the subgrade is a key component of the NAICM solution. The geogrid acts as a working platform, to improve the reinforcement factor



<u>Pavement Structure Design (typical)</u>

- 8 cm Asphalt Wearing Surface
- 14 cm Asphalt Base
- 18 cm Aggregate Base Layer
- 32 cm Tezontle rock infill
- 12 cm Neoloy-330-120-C
- Biaxial Geogrid
- Non-woven Geotextile

Fig. 15.6 Typical Neoloy Geocell-reinforced pavement section for NAICM. *Source* Innovater of the geocell installed above it. This hybrid geosynthetic combination exceeds the sum of its separate parts to maximize the reinforcement factor.

The first phase of 34 km of the airport road networks was built in 2016–2017. After clearing and grading, the geotextile and geogrid are installed over the subgrade layer. Next, the Neoloy Geocell sections were unfolded, fastened, expanded and staked on both sides of the roadway routes. The geocells were then infilled with 12 cm of Tezontle rock infill (0.5″ to 3″) with an additional 3 cm minimum overfill and compacted by standard procedures. The remaining subbase layer and base layer with high-quality aggregate were then constructed, with the asphalt concrete surface layer paved on top. Standard road construction quality control tests were used.

It is important to note that Neoloy Geocells were installed in all-weather conditions and continued throughout the 6-month rainy season—adding more economic value to the solution.

15.2.6 Results

The performance of the newly constructed asphalt roads exceeded the design requirements of the airport engineering—negligible settlements, with no evidence of rutting, hollows or bumps.

Quality control testing on the asphalt layer (surface deflection) verified that pavement structural layer stiffness and modulus increased by 3.5 times. This results in less deformation, thereby increasing the time between maintenance cycles by four times.

The use of local Tezontle rock as infill material increased the sustainability of the project immensely. It lowered the environmental impact of the construction—less quarrying, hauling, fuel pollution, carbon—aligning it with the NAICM goal to achieve the world's first sustainable airport.

The above case study demonstrated how innovative Neoloy Geocell technology and its contribution to building sustainable roads, highways and infrastructures.

15.3 Case Study B: Stabilization Feeder Roads, UN, South Sudan

See Figs. 15.7, 15.8 and Table 15.3.

Fig. 15.7 Installation of Neoloy Geocell on rural feeder road project, UN. *Photo Credit* UNOPS

Fig. 15.8 Neoloy Geocell-reinforced rural feeder road, UN. *Photo Credit* UNOPS

15.3.1 Introduction

One of the least developed countries in the world, the new country of South Sudan faces enormous challenges. Large parts of the country lack basic road infrastructure,

Table 15.3 Case Study B: Project Snapshot

Description	Creation of basic road infrastructure to provide security, aid and opportunity in remote regions of South Sudan characterized by poor site conditions, undeveloped markets, and political and food insecurity
Subgrade soil	Sand, loam and clay soils, 7% CBR, isolated marshland
Client	UNOPS—United Nations Office of Project Services, South Sudan
Project design	WSP|Parsons Brinckerhoff, South Africa
Results	• Helping people—sustainable access for food, aid, security and regional development • Permanent road achieved using local soil materials • 50% cost savings compared to conventional design • 35% reduction in installation time—all-weather construction (and all-weather use) • Sustainable objectives achieved—environmental and social
Date	December 2016 through February 2017
Keywords	Gravel road, road design, Sudan, UNOPS

Source PRS Geo-Technologies

which severely impacts all aspects of life: farming and economic opportunities are impeded, political-security situation becomes more perilous and displaced people and ensuing food crisis are more acute.

A vital strategy to address the chronic food insecurity, improve livelihoods and stimulate rural development is to improve the rural road infrastructure and provide sustainable access to markets. It is also critical for essential aid to get to those in need.

The United Nations Office of Project Services (UNOPS) together with the South Sudan government and the European Union (EU) established the 'Feeder Road Construction Project.' The goal is to increase small farmer's food production and sustainable livelihoods with access to market; an unforeseen but increasingly urgent goal is to enable safe, reliable access into these regions by international aid organizations for aid to displaced populations in distress.

The engineering firm of WSP|Parsons Brinckerhoff working as consultants for UNOPS arrived at an optimized pavement design for 225 km of roads that crossed four regions. Conditions included poor subgrade, high traffic loading and a lack of quality aggregate, all in a very remote and underdeveloped region, subject to tribal conflict and food insecurity.

After extensive investigations and road design analysis, WSP proposed soil stabilization with Neoloy Geocells. "*Considerable distances between the project road and approved gravel borrow areas also contributed to the selection of this solution.*" The subsequent UNOPS tender specifications for the type of geocells were based on the following design considerations (UNOPS 2016):

- Mechanistic design analysis
- Use of low-quality infill material

- Overall stiffness required for expected stresses and strains
- Limited allowable creep for pavement life cycle.

The UNOPS tender stated that "*the application of (Neoloy or approved equivalent) geocells on this project is for a* ***permanent*** *solution, rather than a* ***temporary*** *solution, as is often the case with haul roads or access roads. This project specifically requires a long-term stabilization of the layer to withstand high traffic loads, which correspond to the upper allowable envelope for gravel roads. This is the reason for the specification for long-term creep of the geocell material.*"

UNOPS awarded the tender for the supply and delivery of 1/2 million sqm of Neoloy Geocells, which met or exceeded the UNOPS tender minimum technical requirements for elastic stiffness, creep resistance and tensile strength.

15.3.2 Soil

The subgrade is generally characterized by sand, loam and clay with no rock outcrops. Black clayey loam and sedimentary material occupy the isolated marshlands. A significant part of the roads is in areas with poor subgrade material and/or poor drainage conditions, including marshlands. Average CBR of these soils is 7%. Seasonal rain causes flooding and makes large sections of road impassable due to poor design, construction and maintenance.

15.3.3 Conventional Solution

The road design includes a wearing course, a base (formation) layer and in situ material roadbed (subgrade layer). WSP considered several types of conventional solutions. A conventional pavement design according to the South African Pavement design manual comprised the following:

- 200 mm gravel wearing course
- No subbase
- Local fill material (CBR >7%).

However, the conventional pavement design was not feasible due to the considerable distance between the borrow area for the gravel wearing course borrow area and the project road. This distance, coupled with large haulage fees, made this design option unfeasible.

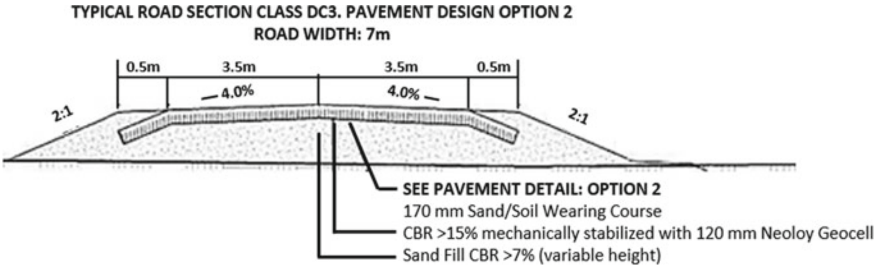


Fig. 15.9 Typical road section drawing with Neoloy Geocell base reinforcement. *Source* WSP

15.3.4 Neoloy Geocell Design

In order to reduce the amount of gravel required for the wearing course, only two geocell pavement design options were analyzed (see Fig. 15.9). The Neoloy Geocells confine the in situ material and improve compressive strength. The 330 mm small cell size and 120 mm height were chosen as the most effective configuration. The Neoloy Geocell design improved the subgrade elastic modulus between 1.5 and 5 times, while the subgrade elastic modulus was improved by a factor of at least two times.

The Average annual daily traffic (AADT) was less than 300; therefore, this road has been classified as a Low volume road (LVR) of design class DC4 with an intended level of service C. This road category provides for a DV4 design vehicle which is equivalent to a truck and semi-trailer. The design standards applied to this road are:

- Design speed: 50 km/h
- Road width: 7.0 m
- Minimum stopping site distance: 125 m
- Horizontal radius: 250 m
- Gradient: <2%
- Superelevation: 4%
- Camber: 4%.

The design and tender included a non-woven, needle-punched continuous-filament synthetic geotextile for separation, filtration, drainage and to reduce construction times over soft ground.

15.3.5 Installation

Over 1/2 million sqm of Neoloy Geocells were delivered in 16 weeks to Nairobi port, from which they were distributed overland to the UNOPS logistics centers and then to the local road sites. The project included knowledge management transfer, which included training local work crews in the use of Neoloy Geocells. The involvement of

Fig. 15.10 Installation and infill of Neoloy Geocell on rural feeder road project. *Photo Credit* UNOPS

the local population was a key aspect of the project, as stakeholders in the construction and maintenance.

The Neoloy Geocells were incorporated in the wearing course of the 7.0 m wide road with significant overfill. The road is basically constructed from sand, with the higher quality sandy-gravel infill limited to the wearing course. It should be noted that unforeseen delays were caused by the unstable security situation in the region (Figs. 15.10 and 15.11).

15.3.6 Results

The UNOPS, WPS, local government officials and the local contractors involved in the project expressed full satisfaction with the product, the installation and the stabilized road performance. The project was submitted by the UNOPS project management team to the annual UNOPS project of the year award. Additional tenders for geocell soil stabilization were issued, for example, in airfield pavement rehabilitation in South Sudan.

A key achievement of the project was a 50% cost savings compared to conventional design: due to the reduction in construction costs—reduced pavement thickness, less hauling (use of local sand, faster construction and reduced maintenance). This also helped achieve UNOPS sustainable objectives due to the road's durability, low environmental impact (using local materials) and employing the local populace in the road construction and maintenance. Installation time, costs and resources were

Fig. 15.11 Finished feeder road. *Photo Credit* UNOPS

also reduced by an estimated 35% due to reduced pavement thickness and in situ placement.

Finally, this project literally stabilizes an unstable world and helps people and improves their lives. The roads are literally a live-saving artery in the short term for the reliable delivery of food aid to get to those in need; and a key element enabling the development of a rural economy and opportunity for a better life in the long run.

15.4 Case Study C: Neoloy Geocell Soil Stabilization for High-Speed Passenger Rail Operations, Amtrak, USA

See Figs. 15.12, 15.13 and Table 15.4.

15.4.1 Introduction

Maintenance of track geometry is a key expenditure for railways, particularly, for high-speed passenger operations with strict geometry tolerances. Degradation of geometry requires frequent and expensive surfacing, tamping and downtime. A section in Maryland of Amtrak's high-volume Northeast corridor (NEC), which carries 2200 high-speed commuter and freight trains daily, suffered mud pumping and severe ballast fouling from problematic soils.

Fig. 15.12 Poor clay subgrade conditions on Track C (before rebuild). *Photo Credit* PRS Geo-Technologies

Fig. 15.13 Installation of Neoloy Geocell stabilized track (rebuild). *Photo Credit* PRS Geo-Technologies

Table 15.4 Case Study C: Project Snapshot

Description	Neoloy Geocells were used to stabilize subgrade on main line conditions of the Amtrak high-speed Northeast corridor, which suffered significant mud pumping and track geometry degradation from poor subgrade. Measurements demonstrated 50% less subgrade pressure and a reduction of the track geometry degradation/ extension of track surface maintenance by factor of 6.7
Subgrade soil	Highly plastic clay—1.2 MPa as per DCP Ballast strength was 30–40% (13.8 MPa) of normal resistance (34 to 41 MPa)
Client	Amtrak, National Railroad Passenger Corporation (USA) with research supported by US Federal Railway Administration (FRA), Department of Transportation (DOT)
Project design	Amtrak
Achievements	• Reduced track maintenance by factor of 6.7 • Reduced vertical pressure on substructure by 50% • Improved Track Quality Index by up to 10 times • Economically viable solution for high-speed rail systems
Date	September 2015
Keywords	Railroad track, track geometry, subgrade stabilization, geocells, track maintenance

Source PRS Geo-Technologies

Amtrak undertook a subgrade renewal project utilizing Neoloy® Geocells. The aim of the total track rebuild was to rectify the frequent geometry track degradation, insufficient substructure and weak subgrade. The project was part of a US Federal Railway Administration (FHA) program to promote innovative railway technologies for high-speed passenger operations.

A comprehensive full-scale in-track field and performance evaluation were conducted on this section of high-speed rail track, including long-term monitoring by the Harsco Rail Consulting Group and researchers from the Universities of Delaware and Colombia, in addition to the FHA and Amtrak.

The goal was to assess the impact of Novel polymeric alloy (NPA) Neoloy Geocells on the track geometry performance as a potential solution for other locations with subgrade problems and high track geometry degradation. Comprehensive analysis of the data qualified the efficacy of Neoloy Geocells in reducing the rate of degradation, which translates into reduced surfacing cycles and maintenance compared to a conventional structure (Palese et al. 2017; Zarembski et al. 2017) (Fig. 15.14).

15.4.2 Soil

The cause of ballast fouling the high-speed rail section in Maryland stemmed from undercutting operations in the 1990s on the middle of three tracks. This disturbed the underlying highly plastic clay layer causing migration in saturated conditions into

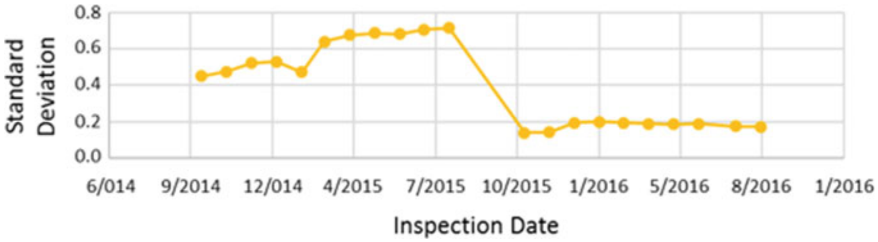


Fig. 15.14 Track geometry degradation rate before and after geocell installation (10/2015) measured in TQI—track quality index. *Source* Amtrak

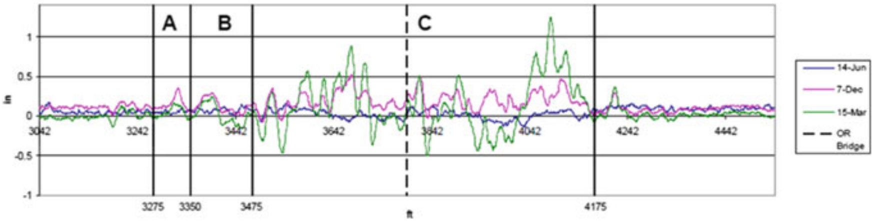


Fig. 15.15 Cross-level measurements before rebuild. *Source* Amtrak

the track's ballast layer. Soil investigation verified that the overall track substructure in general and the subgrade clay were very weak. Tip resistance measurements showed that the top 1.5 m of the ballast were at a maximum 13.8 MPa instead of the expected tip resistance of 34–41 MPa. Track geometry measurements over an 8-month period prior to the rebuild showed significant degradation of cross-level and surface geometry (see Fig. 15.15). Frequent surfacing was required to maintain track geometry.

15.4.3 Design with Neoloy Geocell

The test site is an FRA Class 7 high-speed 200 kph (125 mph) passenger track with 20–25 Million gross tons of traffic (MGT), but which often deteriorates to a Class 6 (176 kph) or even Class 5 (144 kph).

The goal of the rebuild was to stabilize the weak subgrade and eliminate the factors fouling the ballast. The rebuild for all three tracks in the section included removing track and substructure. The subballast was recompacted, and additional drainage and clean ballast were installed. Neoloy Geocells were installed on the middle track only to compare the performance of the reinforced (geocell) vs. control (unreinforced) zones of track.

After a comparative analysis, Amtrak chose the Neoloy (Novel polymeric alloy—NPA) Geocell category type, small cell (330 mm), 150 mm height, heavy-duty category D, due to the following long-term performance properties:

- High elastic stiffness (>600 MPa @ 60 °C)
- High resistance to permanent (plastic) deformation (<3%)
- High tensile strength (>26 kN/m).

A "hybrid" solution was used, which include a Tensar BX Type 2-450 geogrid installed on the subgrade. The geogrid acts as a stable working platform, which enables the stiff NPA geocell layer embedded in the ballast layer to achieve a higher Modulus improvement factor (MIF). The stiff geocell in the subballast layer acts like an "I" shape steel girder. Its high resistance to swelling renders it unaffected by moisture variations in the clay subgrade. This hybrid solution has been proven effective in preventing heaving from expansive clay soils in railway applications (Kief 2016).

Pressure load cells (force transducers) (20 cm diameter) with a capacity of 500 kPa were installed at the top of the subbase layer to measure vertical loading resistance over time in both the reinforced and unreinforced sections (see Fig. 15.16).

The Neoloy Geocells were filled in with subballast 2A 2-in. max. size stone with many fines for good compaction and drainability. Standard Amtrak quality 3-in. max. size AASHTO #57 open graded, clean stone was used for the ballast layer. The immediate impact of the Neoloy was visually noticeable by those present on-site. For example, haul trucks loaded with ballast infill caused severe rutting to the wet mud subgrade as they approached the site, but easily traversed the areas in which geocell was already installed with no noticeable rutting whatsoever.

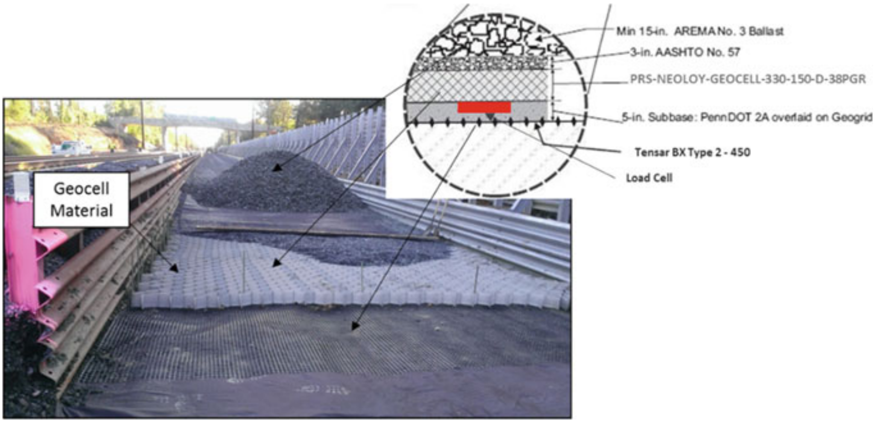


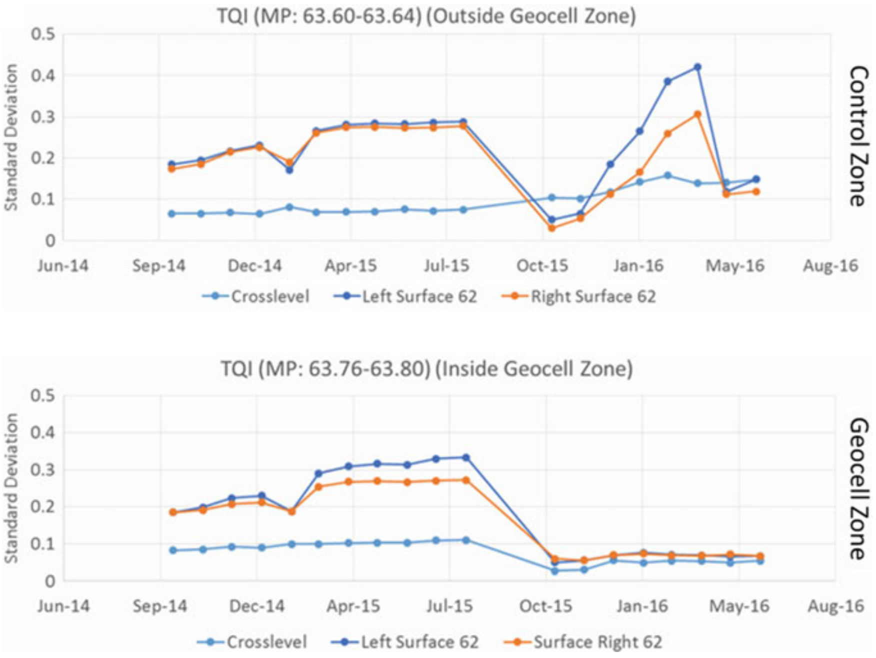
Fig. 15.16 Cross-section of the geocell-reinforced substructure. *Source* Amtrak

15.4.4 Results

Track geometry data was collected by Amtrak track geometry vehicles, from pre-build and post-build measurements including data from the pressure load cells installed in the track subgrade. Data include surface (vertical), cross-level (elevation of two tracks), gauge and twist (change in cross-level). Measurements from the control section (rebuild without geocell reinforcement) showed significant degradation in the track geometry within 6-7 months after the rebuild.

Data from the Neoloy stabilized section showed that the subgrade pressure was consistently 50% of that in the control zone (no geocell). Track geometry variations in the NPA geocell zone were significantly smaller—for left and right track, cross-level data and the TQI standard deviation (shown in Fig. 15.17).

The data results show that the NPA geocell improved track support, reduced bearing pressures on the subgrade and provided improved track geometry performance over time. The rate of track geometry degradation was reduced, thereby extending the time between surfacing maintenance cycles by a factor of 6.7. This results in marked maintenance savings to Amtrak and an exceptional ROI on the project.


TQI (MP: 63.60-63.64) (Outside Geocell Zone)

TQI (MP: 63.76-63.80) (Inside Geocell Zone)

Fig. 15.17 TQI standard deviation variation before and after track rebuild (Oct 15) in unreinforced control zone (top) and geocell zone (bottom). *Source* Amtrak

15.5 Case Study D: Load Transfer Platforms for Vertical Columns, Manzanillo Port, Mexico

See Fig. 15.18 and Table 15.5.

15.5.1 Introduction

A new 50,000 m^2 multiple use terminal (MUT) was planned for Manzanillo port to handle 2.5 million tons of general purpose cargo and bulk minerals per year. The objective was to build five 10,000 m^2 platforms within a year. Design was to be according to the highest international standards with a goal to exceed the planned handling capacity. A stated objective was to utilize the best available environmental-friendly and sustainable infrastructure.

Marine port terminals are often constructed as Load transfer platforms (LTP) to resolve the typically challenging site and subgrade conditions on one hand with the heavy-duty loading requirements from port operations on the other. LTPs mobilize soil arching to transfer the applied loads onto vertical pile columns. If the layer thickness is decreased, the arching effect decreases as well. Therefore, geogrids, concrete base plates or hydraulic-bonded layers are needed to increase the soil stiffness to mobilize the load transfer from the soil to the vertical elements.

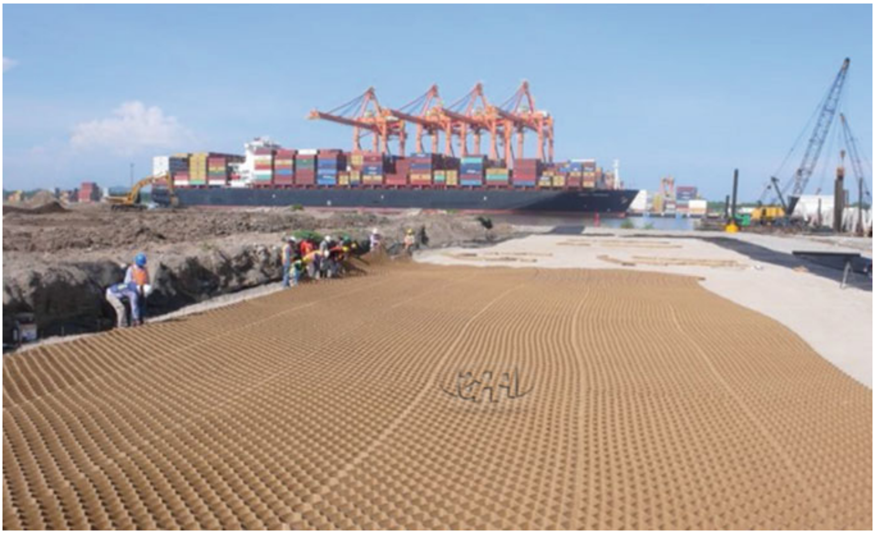


Fig. 15.18 Installation of Neoloy Geocell layer in load transfer platform, Manzanillo Port, Mexico. *Photo credit* Innovator

Table 15.5 Case Study D: Project Snapshot

Description	Neoloy Geocells provided stabilization for Load transfer platform (LTP) on saturated silty sand, for heavy port platform, in Manzillo Port, enabling a reduction pavement thickness and significant cost savings
Subgrade soil	Saturated silty sand with CBR <2%
Client	Group Hazesa—contractor with experience in multiple use terminal (MUT) construction
Project design	Ancora Ingenieria—structural pavement designers, Mexico, Innovater, Innovciones en Terracerias S.A. DE C.V., Mexico
Achievements	• Optimized pavement—modulus improved by 2–3 times, total pavement thickness reduced by 37%, including 17% reduction in concrete surface layer • Eliminated need and time for soil consolidation • Locally available used for structural infill • Fast, simple and all-weather installation • Significant cost savings
Date	Q4 2014—Q2 2015
Keywords	Load transfer platforms, port, platform, geocell reinforcement

Source PRS Geo-Technologies

Neoloy Geocells were chosen to reinforce the earth LTP for their excellent load distribution mechanism, due to their very stiff, strong and low creep properties. The Neoloy Geocells act as a flexible beam (or slab), distributing vertical loads widely. This effectively transfers applied loads directly to the vertical columns via soil arching instead of the soft soils.

15.5.2 Soil

Extreme site conditions for the terminal platform included soft marine foundation soils of saturated silty sand with a CBR of <2%. Bulk handling of lead and zinc minerals on the dock could reach loads of 35 ton/m^2. The foundation for the terminal was constructed on vertical columns; therefore, the reinforcement solution had to function as a load transfer platform as well.

Load transfer platforms of concrete, hydraulic-bonded or composite geosynthetic (geogrid) layers are too expensive or insufficient, while unreinforced solutions are too heavy and costly. The thickness of a conventional unreinforced platform would have been thick and costly in terms of the concrete surface layer and the high-quality aggregate required for the base and subbase layers.

15.5.3 Neoloy Geocell Design

The project design included a 5 × 5 m grid of vertical columns (piles), each approximately 10 m high and 1 m diameter for each platform. Research demonstrated that geocells can be directly placed above vertical columns; the load transfer mechanism significantly stiffens the geocell stabilized soil and applied loads are transferred from the soft soil directly into the columns (Emersleben and Meyer 2012; Collin et al. 2018).

To meet the challenging site conditions and project requirements, Innovator, Ancora Engineering and PRS Engineering developed a design for a geocell-reinforced load transfer platform (LTP). MePADS pavement design software was used to compare the vertical static stresses on the subgrade surface from the applied load (35 tons/m^2) in the conventional design vs. the Neoloy Geocell-reinforced design to determine the modulus improvement factor, based on an equivalent performance. The maximal vertical stress (σ_{zz}) at the subgrade surface was 315.7 kPa for the unreinforced pavement vs. 266.5 kPa for the Neoloy Geocell-reinforced pavement with a pavement thickness 37% less.

Neoloy Geocells were selected as they were the only geocell offering high elastic stiffness (>500 MPa @ 63 °C), low permanent degradation (<1.5% at 50 years) and high tensile strength (>19 kN/m). These properties are crucial for heavy-duty loading over the 30-year pavement design life. The Neoloy-based Geocell gave the design engineers the confidence to meet the following three key project challenges:

- Geotechnical—the 3D mechanical stabilization technology acts as a flexible mattress with a wide load distribution angle (~35°) for maximum load distribution in each layer.
- Engineering—optimized load transfer by improving the modulus by 2.3 times; enabling 60% reduction in subgrade layer thickness, 30% in base layer and 17% of concrete thickness.
- Economics—cost-effective, sustainable solution, eliminating the need for consolidation and expediating construction.

15.5.4 Installation

The first step involved creating a 5 cm working platform of poured lightweight concrete to create a stable working foundation, after natural subgrade excavation and capping. Two layers of Neoloy Geocell 330–120 (330 mm cell size, 120 mm height) with 12 cm of 1″ gravel fill were installed directly over the working platform and compacted to 3 cm overfill. A layer of 115 cm controlled subgrade undercut was placed with quality-controlled compaction every 15 cm. The Neoloy Geocell reinforcement enabled a reduction in the subgrade thickness by approximately 50%, while increasing the elastic modulus of the subgrade layer by 1.4 times. It also caused a “jump” in the modulus of the granular base layer above it by more than three times.

Fig. 15.19 Installation of Neoloy Geocells on subgrade of LTP. *Photo credit* Innovator

The additional layer of Neoloy Geocells was installed in the base layer filled with base quality granular aggregate (+3 cm overfill), with a calculated Neoloy Geocell Modulus improvement factor (MIF) of 3.1. This increased the base layer modulus by a factor of 2.3 while enabling a 17% reduction in the Portland concrete cement slab from 30 to 25 cm with no reduction in performance (Fig. 15.19).

15.5.5 Results

This reinforced load transfer platform structure was very cost-effective. It resolved problems with settlement and consolidation, enabled a thickness reduction in the platform structural layers, and used locally available dredged sand for structural infill. The Neoloy Geocell reinforcement also increases the efficiency of LTP design so that the number of piles can be decreased.

The geocell cellular confinement system works as load distribution system and is therefore well suited to a load transfer platform above vertical columns (piles). Neoloy Geocells were selected for this heavy-duty pavement due to their high modulus and low creep characteristics. Dual layers of Neoloy Geocells above the piles work as a composite that distributes the pressure bulbs generated by the piles into a larger area to successfully resist penetration. Deformations between the center grid of the piles is not significant. The top Neoloy Geocell layer distributes the pressure bulbs generated by the loading of the mineral ore (35 ton/m_2) into a larger area as well. Vertical stresses on the subgrade are reduced as is settlement between the load distribution platform and the subgrade material. The increased bearing capacity of Neoloy Geocell reinforcement of the subgrade had additional benefits for the project: significant decrease in the overall pavement thickness, the ability to use local materials and a demonstrated decrease in the construction time.

15.6 Conclusions

The use of geocells to reinforce heavy-duty pavements was demonstrated in four case studies involving demanding project requirements and challenging soil and site conditions: (a) stabilize asphalt pavements in a Mexican airport built on extremely soft soil; (b) use low-quality infill to build a permanent pavement in a very remote region of Africa; (c) reduce maintenance of high-speed track by 82% over problematic soils; (d) stabilization of marine port load transfer platforms in Mexico while reducing pavement thickness by 50%.

The use of Neoloy-based geocells led to significant engineering improvements in each project: higher modulus, increased soil bearing capacity and reduced deformation more than any other geocell or geosynthetic reinforcement; and enabled optimization of the pavements in terms of layer thickness, infill materials and lifespan.

The extended lifespan and reduced maintenance were critical factors in each of these projects. Therefore, it was essential that the elastic modulus and resistance to permanent deformation of the geocell would maintain dimensional confinement, compaction and reinforcement for the entire design life of the project—up to 50 years.

In addition to the extensive engineering proofs provided by Neoloy-based geocells test methods, methodologies, research and field trials, the use of these geocells had significant economic benefits. This included road construction using locally available but marginal quality soils for structural infill, and extended service life with less maintenance. These same economic benefits are aligned with the sustainability goals for each of the projects in terms of environmental footprint and durable construction.

These case studies validated the important contributions advanced geocells made to large-scale, heavy-duty transportation and infrastructure projects.

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