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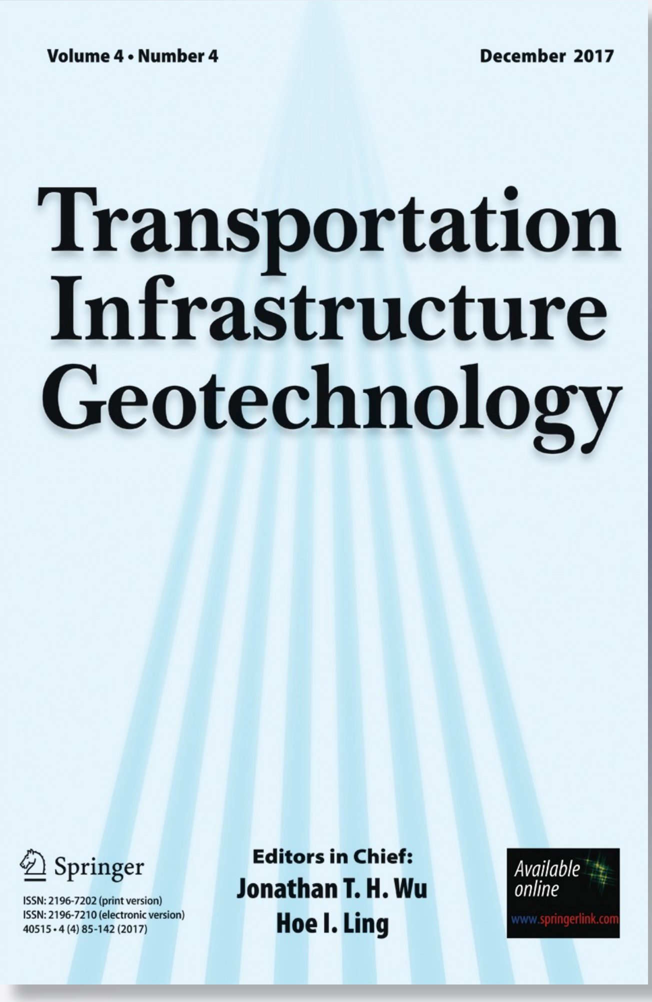

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Hoe I. Ling

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TECHNICAL PAPER

Application of Geocell Track Substructure Support System to Correct Surface Degradation Problems Under High-Speed Passenger Railroad Operations

Allan M. Zarembski[1] · **Joseph Palese**[2] ·
Christopher M. Hartsough[2] · **Hoe I. Ling**[3] ·
Hugh Thompson[4]

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Abstract Ballast fouling and associated degradation of track geometry is a serious problem for railway systems in general and high-speed passenger rail systems in particular. This paper presents the results of a field test on Amtrak's Northeast Corridor where a long-term problem area existed near Oakington Road, Havre de Grace, Maryland, near MP 63.7 between Philadelphia and Washington DC. This test looked at the application of a new generation of three-dimensional cellular confinement systems (geocells) in reducing the rate of track geometry degradation, particularly in poor subgrade and ballast locations which require frequent, expensive, track surface maintenance. The field test compared two distinct sets of rebuilt track conditions, to include zones with and without a layer of geocell material. Both zones were rebuilt with

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✉ Allan M. Zarembski
dramz@udel.edu

Joseph Palese
jpalese@harsco.com

Christopher M. Hartsough
chartsough@harsco.com

Hoe I. Ling
Hil9@columbia.edu

Hugh Thompson
Hugh.thompson@dot.gov

[1] University of Delaware, Newark, DE, USA

[2] Harsco Rail, Cherry Hill, NJ, USA

[3] Columbia University, New York, NY, USA

[4] Federal Railroad Administration, Washington, DC, USA

improved drainage and a good, well-defined track structure and substructure (to include a well-defined depth of clean ballast). The test measurements included pre-maintenance and post-maintenance track geometry measurements together with comparative subgrade pressure measurements inside and outside the geocell cell zones. The pressure cell measurements, which looked at subgrade pressure under left and right rails in both the geocell zone and the control (non-geocell) zones, included measurements under both Acela high-speed trains and lower speed regional trains. In all cases, the subgrade pressures in the geocell zone were approximately half of those for the cells in the control zone (no geocell). Track geometry measurements were made using Amtrak's track geometry vehicle which measures key track geometry parameters at 1-ft intervals along the track. There were several well-defined locations in the overall test zone that experienced significant track geometry degradation; these were all corrected during reconstruction. In the zones with no geocell material, these geometry variations reappeared within 6 to 7 months with the same if not greater amplitudes. By contract, in the geocell zone, the "after" geometry variations were significantly smaller than the pre-reconstruction geometry variations. Furthermore, the rate of geometry degradation was signficantly less for the geocell zones compared to the pre-geocell time periods for the exact same track. This indicated the effectiveness of the geocell material in reducing the rate of track geometry degradation and extending the surfacing maintenance cycles. Analysis of the rate of degradation showed that the effect of installing the geocell material was to significantly reduce the rate of degradation (and thus increase the surfacing cycle) by a factor of 6.7 times the pre-geocell installation surfacing cycle.

Keywords Railroad track · Ballast · Track geometry degradation · Geocells · Track substructure

Introduction

Ballast fouling and associated degradation of track geometry is a serious problem for railway systems in general and high-speed passenger rail systems in particular. This is the case for Amtrak's Northeast Corridor (NEC) where a long-term problem area existed near Oakington Road, Havre de Grace, Maryland, near MP 63.7 between Philadelphia and Washington DC. The original problem seems to have developed after undercutting of the middle track, track 3, was performed in the 1990s as part of a double stack clearance project. Over time, the ballast became fouled with clay, and after rain, the ballast would become muddy, as illustrated in Fig. 1.

In addition, the clay had been migrating to the adjacent high-speed tracks which then required frequent surfacing.

This paper presents the results of a research study[1] looking at the application of a new generation of three-dimensional cellular confinement systems (geocells) in reducing the rate of track geometry degradation, particularly in poor subgrade and ballast locations which require frequent and expensive track surface maintenance.

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[1] This research was funded by the US Department of Transportation, Federal Railroad Administration under contract DTFR5315C00019, "Field Demonstration of a Geocell Track Substructure Support System Under High Speed Passenger Rail Operations"

Fig. 1 Fouling and mud spots at Oakington Road, 2010

Background

Maintenance of track geometry is a key element in the maintenance of the railroad track structure, particularly for high-speed passenger operations. In locations with poor subgrade (parent soil) and/or ballast conditions, track geometry degrades rapidly resulting in the need for frequent and expensive maintenance such as surfacing and other ballast maintenance activities. Track geometry maintenance, to include surfacing, ballast cleaning, and related maintenance activities, represents one of the major maintenance cost areas for the track structure. In the case of high-speed rail, it is often the largest single maintenance cost area, since the geometry requirements for high-speed rail are extremely tight, with little tolerance for degradation. This in turn, results in the need for frequent surfacing to maintain these tight geometry standards. In locations of poor track substructure, due to either weak or water susceptible soils or fouled ballast, the rate of surface degradation is increased, with the need for very frequent surface maintenance resulting in very high costs and loss of track time for train operations. The new generation of geotechnical materials based on three-dimensional cellular confinement system technology (geocells) provides reinforcement to the substructure and serves as a structural support element at the ballast/subgrade interface in railroad track. The use of these geocell materials, placed under the ballast layer, usually at the ballast/subgrade interface area, has been shown to decrease the rate of track surface geometry degradation (both surface and cross-level) under a range of traffic loadings [1–3].

Application of geocells in railway track, particularly in the ballast/subgrade layer, is relatively recent and has been limited to date. Early testing at Transportation Test Center, Inc. (TTCI) in Pueblo Colorado showed good promise in soft subgrade conditions [1, 2] together with limited testing and applications [3–8]. To investigate the effectiveness of new generation geocells in reinforcing the ballast, a series of monotonic and cyclic loading tests were conducted on a sandstone ballast embankment at Columbia University in the period 2009–2012 [4–7]. Significant improvement in performance compared to unreinforced embankments, such as reduction in vertical settlement and lateral spreading, was confirmed. Application of the geocells in the ballast/subgrade interface results in the geocells generating a basic confinement of the subgrade material, which testing shows will result in an improvement in the mechanical behavior of any soil composition.

In the Columbia testing of a geocell layer in the ballast, the geocells confine the ballast particles. When subjected to repeated vertical stress due to train loading, this confinement constrains movement of the individual ballast particles thus exhibiting stiffer reaction (i.e., less elastic settlement under given load) and less abrasive plastic deformation of the ballast. Confinement also increases the apparent strength of the composite ballast geocells. All of these factors appear to reduce the rate of ballast degradation as well as track geometry loss.

The latest generation of geotechnical materials based on three-dimensional cellular confinement system technology (geocells) shows significant promise in being able to provide reinforcement to the substructure and serve as a structural support element at the ballast/subgrade interface in railroad track. Laboratory testing such as the recent test program at Columbia University [4–7] and preliminary field testing such as at TTCI in Pueblo Colorado [1, 2] and in some overseas test locations (e.g., South Africa [8]) have shown reductions in rate of degradation (corresponding to extension in surfacing intervention cycles) ranging from factors of 1.7 to 10 under very well-controlled conditions.

Oakington Road Site

The test site for this activity was on Amtrak's NEC Main Line-Mid-Atlantic Division, NEC AP-Line MP63.7, at Oakington Road, Havre de Grace, Maryland. As shown previously in Fig. 1, this site exhibits ballast fouling and develops significant mud spotting, particularly after rain. The original problem seems to have developed after undercutting of the middle track, track 3, was performed in the 1990s as part of a double stack clearance project. This undercutting appeared to have impinged upon an underlying clay layer beneath the track with the result that fouling and drainage problems developed in the area of Oakington Road MP 63.7.

Traffic on this route includes high-speed Acela service, conventional and regional rail service, and occasional freight traffic. Because the traffic includes high-speed passenger operations, the track is Federal Railway Administration (FRA) Class 7 with a maximum authorized speed of 125 mph (200 kph). Class 7 track requires frequent track maintenance because of the very tight track geometry limits imposed. The presence of the clay in the ballast and the development of mud spots result in more rapid degradation of the track geometry and the need for more frequent surfacing (an expensive activity).

Testing at this site has shown that this is a location with known soil problems including highly plastic clay, which has been showed to be a particularly weak subgrade. Information was available about this site's soil condition (cone penetrometer and ground-penetrating radar information) and its history of track geometry degradation to include extensive track geometry history data.

Cone penetrometer testing was used to measure soil strength in this area in the mid-1990s. The resistance of the ballast, and in particular the top 2 ft of the ballast, had lower than expected resistance, with a maximum of ~2000 psi (13.8 MPa) as opposed to the expected resistance of between 5000 and 6000 psi (34 to 41 MPa) which is typical for good clean ballast. The next 10 ft (300 cm) of clay had very low resistance, with a very low measured tip resistance of ~175 psi (1200 kPa). This poor subgrade condition was subsequently confirmed by subsequent ground penetrating radar (GPR) measurements of the site.

Likewise, track geometry measurements show that this zone near Oakington Road has a rapid rate of track geometry degradation. This is clearly illustrated in the overlay of three different geometry runs in Fig. 2a–c for right profile, left profile, and cross-level measurement, respectively. As can be seen, the center zone near Oakington Road experiences very rapid geometry degradation over a period of 8 months.

Based on the analysis of these geometry degradation zones, a decision was made to install geocell material in section C only, as this was determined to be the most cost-effective and time-efficient option, requiring a minimum track outage to disrupt traffic on the NEC. It also allowed for a portion of the track that experiences significant geometry degradation to be left as a “control” zone (zone A) for comparative analysis.

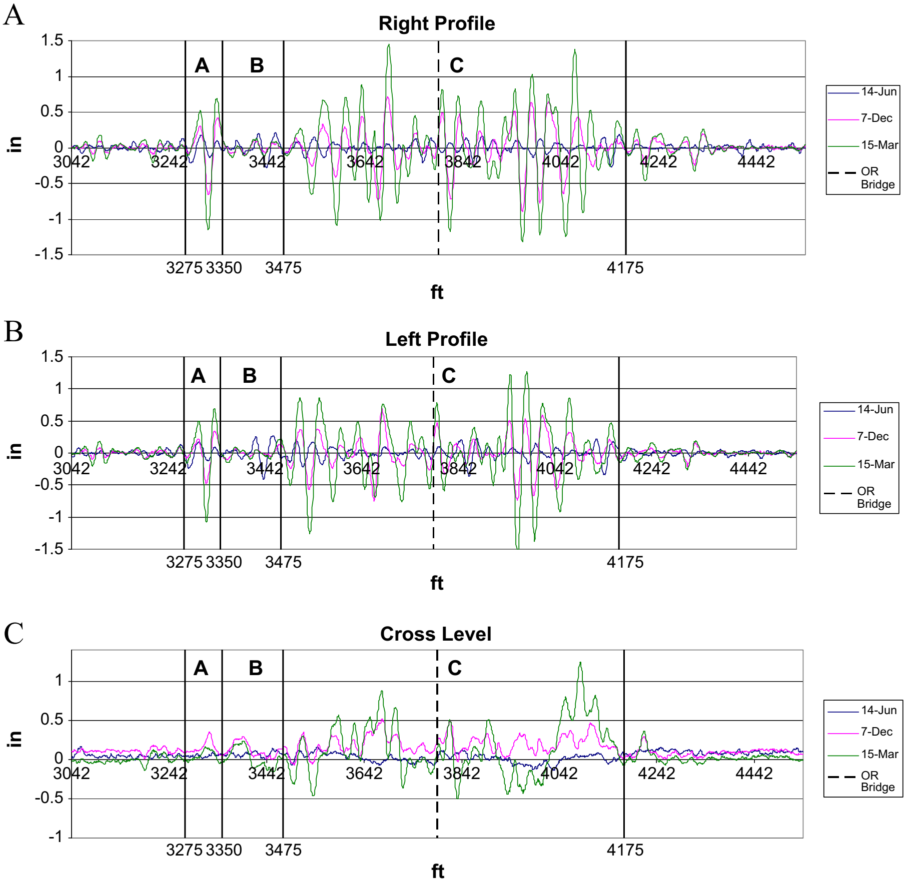

Fig. 2 **a** Right profile measurements (three runs overlaid). **b** Left profile measurements (three runs overlaid). **c** Cross-level measurements (three runs overlaid)

Test Overview

As noted previously, the purpose of this test was to perform a full scale in-track field evaluation of geocell materials under actual main line track conditions on Amtrak track on the Northeast Corridor. Specifically, track with a high rate of track geometry degradation and corresponding high level of track geometry maintenance was selected by Amtrak, the owner of the track, for testing. The selected location, MP 63.7 near Havre de Grace, Maryland, is an existing three track location with significant mud pumping and track geometry degradation, particularly in the center track. A geocell material[2] was installed in the ballast/subgrade interface area to improve the strength of the poor performing soil. The installation of the geocell material was expected to reduce the rate of ballast degradation as well as track geometry loss.

The purpose of this test was to examine and demonstrate the effectiveness of the geocell technology in reducing the rate of track geometry degradation, with the expectation that there will be an increase in surfacing cycle (reduction in rate of geometry degradation to failure) of the order of a factor of two or even more.

The original test plan was to install the geocell material on the center track, track 3. However, Amtrak was most concerned about the two high-speed tracks, tracks 2 and 4, and subsequently shifted the focus of the test to track 2 because of concern that the same type of ballast fouling/subgrade failure problems which occurred on the center track will occur on track 2.

In addition to the installation of the geocell material in the test zone, undercutting of track 2 occurred in spring 2015, with the goal of increasing clearances, since track 2 has the highest elevation of all three tracks (see Figs. 4 and 9). In addition, drainage was improved in the test zone and in the adjacent tracks that were part of the upgrade and rehabilitation activity.

As a result, rehabilitation of approximately 2400 ft (720 m) of track 2 was performed in September 2015. Approximately 800 ft (240 m) of geocell material was installed in the center of the zone, around Oakington Road. In addition, track 2 was shifted down approximately 18″ (45 cm) by undercutting and was shifted away from track 3 approximately 18″ (45 cm). Also, as noted previously, additional drainage in the entire test zone was installed, to include the geocell and non-geocell portions of the rehabilated site.

Design of Test Site with Geocell Material

The Oakington Road test site, MP 63.7 track 2, is shown in Fig. 3 below. Track 2 is a high-speed 125 mph (200 kph) passenger track with 20 to 25 millions of gross tons of traffic (MGT) of traffic annually that experiences track geometry degradation.

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[2] The specific geocell used was a nano-polymeric alloy (NPA), based on nano-fibers in a polyolefin matrix. It is manufactured in a multi-layer process to maximize strength, flexibility, and chemical stability. Properties include tensile strength at yield of perforated strip >19 kN/m, according to ISO 10319. Creep resistance/cumulated plastic (permanent) deformation <3% at three isothermal steps: 44, 51, and 58 °C, according to SIM Test ASTM D6992, testing of a wide-width perforated strip subject to a constant load of 6.1 kN/m.

Net elastic stiffness: at 45 °C >675 MPa, at 60 °C >525 MPa, according to Dynamic Mechanical Analysis (DMA), ISO 6721-1/ASTM E2254

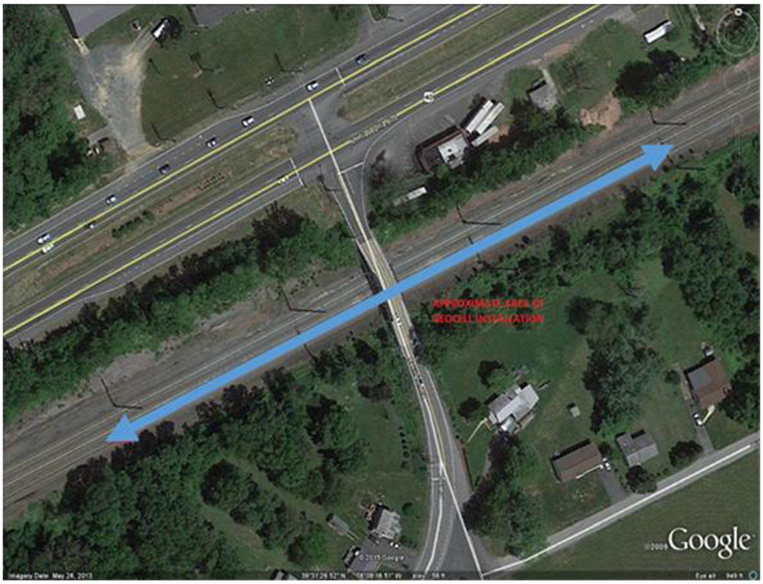

Fig. 3 Geocell installation area

The geocell test zone is approximately 800 ft (240 m) of track centered under the Oakington Road overpass, as shown in Fig. 3. An additional 800+ (240+ m) ft of track was rebuilt on each end of the geocell test zone, with improved drainage but without the use of the geocell. Figure 4 presents the final design of the geocell test zone under track 2.

As can be seen in Fig. 4, there is a minimum 15 in (450 cm) of AREMA No. 3 ballast under the concrete ties, above the Neoweb geocell material. Underneath this ballast layer and directly above the Neoweb geocell material is a 3-in (75 mm) layer of

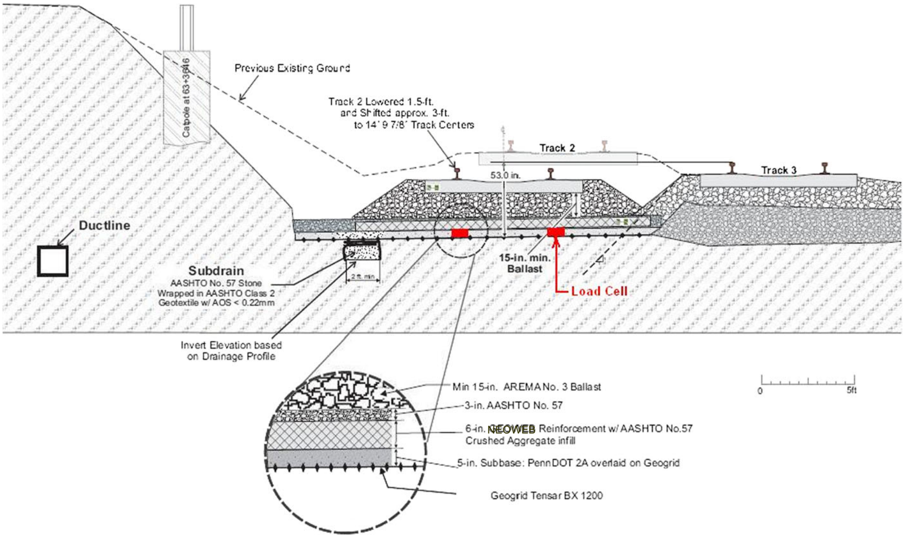

Fig. 4 Final design for geocell installation (1 in = 2.54 cm)

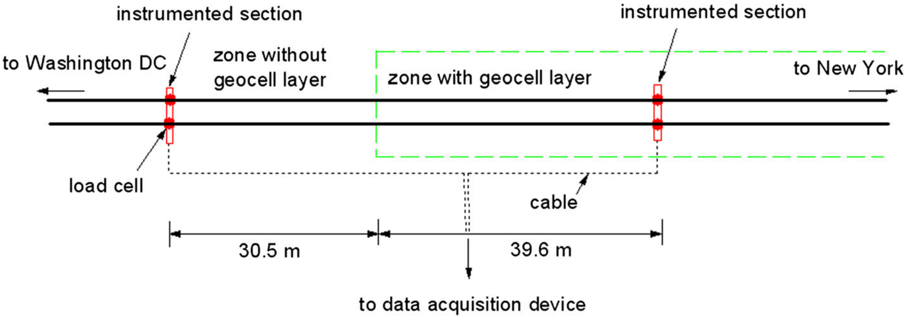

Fig. 5 Plan of instrumented site

AASHTO No. 57 subballast followed by a 6-in (150 mm) thick layer of the Neoweb geocell material filled with the same AASHTO No. 57 crushed aggregate subballast.[3] Note the geocell layer is full track width, approximately 12 ft (3.6 m) in width. Directly under the Neoweb geocell layer is an additional 5 in (125 mm) of subballast (Penn DOT 2A) overlaid on a layer of biaxial geogrid material. The purpose of the geogrid layer was to provide a footing for the maintenance work and to support the work equipment.[4] Instrumented pressure cells were inserted below the geocell layer, see discussion below.

Instrumentation

Primary instrumentation of the test zones consisted of four load cells (pressure transducers) positioned as shown in Fig. 5. These load cells (pressure transducers) are located along the interface with the subgrade (Fig. 6). The objective was to measure how much stress reduction was achieved due to load redistribution resulting from the geocell layer acting as a flexible plate. The pressure transducers were installed concurrent with the installation of the geocell material: two transducers in the unmodified sections of track (without geocell material) south of the southern end of the geocell material and two in the modified sections (with geocell material) approximately 100 ft (30 m) north of the southern end of the geocell material. The four transducers were split between the two rails and placed directly under the rail.

The two sections were approximately 200 ft (70 m) apart, and more than 100 ft (30 m) from the boundary of reinforced and unreinforced zones. In the reinforced section, the load cells were installed under the geocell layer, at the same depth as in the case of unreinforced section, thus allowing for a direct comparison of measured results.

The force transducers (pressure cells) were 8 in (20 cm) in diameter and 6.6 in (2.6 cm) thick and were manufactured by Tokyo Sokki Kenkyujo, Ltd. They had a capacity of 72 psi (500 kPa). During the installation, a biaxial geogrid was laid with sand above it, followed by the load cell. Then, sand bag was put over the surface of the

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[3] Stone size of between 3/16″ and 1″ (5 and 25 mm)

[4] Note that the cross section of the unreinforced zone was the same as for the reinforced section (without the geocell) and contained the geogrid for approximately 15′ (5 m) adjacent to the reinforced zone. This was the only length of the test site where there was geogrid and no geocell (see Fig. 7).

Fig. 6 Pressure cell installation in no geocell zone

load cells, such that the ballasts maintained uniform contact with the surface of load cell (see Fig. 6). Data acquisition was conducted using a portable high-speed dynamic strain recorder with a sampling rate of 5000 Hz (or interval of 200 μs). Data logging was controlled through a portable computer.

Installation

Installation of geocell materials and load cells was conducted on September 28–30, 2015. Installation was performed by Amtrak forces supported by PRS Mediterranean Ltd. and the Harsco Rail/Columbia team. Amtrak personnel performed the actual section rehabilitation which included geocell installation. The process required taking the track out of service, removing the track superstructure, and then the actual ballast/subgrade rehabilitation and upgrade (with geocell material). PRS Mediterranean Ltd., the manufacturer of the Neoweb geocell material, contributed the material and on-site advice to Amtrak both in the design of the installation and in the actual installation procedure. Figure 7 illustrates the installation of the geocell material.

Monitoring and Data Recording

Amtrak, as part of its ongoing maintenance activity (and in accordance with FRA track safety standards for high-speed track), operates a high-speed track geometry car on the Northeast Corridor, recording key track geometry data monthly. As part of this monthly inspection, the geometry car measures key track geometry parameters to include surface[5] (vertical), cross-level,[6] gauge, and twist (change in cross-level). These parameters are used to define the geometric condition of the track and to determine when the track requires maintenance. This is illustrated in the proposed test site, where track

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[5] Surface is the vertical alignment or profile of the track as measured using a 31 or 62-ft chord.

[6] Crosslevel (or "cross-level") is the measurement of the difference in elevation (height) between the top surface of the two rails at any point of railroad track.

Fig. 7 Installation of the geocell material to build geocell reinforced track

number 2 is a 125 mph (200 kph) track (FRA Class 7) but which deteriorates to Class 6 (110 mph [176 kph]) or even Class 5 (90 mph [144 kph]) [9]. This requires slow ordering the track, i.e., imposing speed restrictions on the operating trains, until the track is surfaced and the geometry is restored.

The key track geometry parameters which are addressed by the use of the geocell technology are the vertical surface, cross-level, and twist. These were recorded by the Amtrak track geometry car during each of the regular (monthly) inspections and the data used for analysis.

Upon commencement of rail service on track 2, measurement data, to include pressure cell data (related to the four load cells) as well as track geometry data, were measured and analyzed. Train service was resumed on October 31, 2015, and the test site was monitored for approximately 10 months afterwards.

The pressure cell monitoring plan was accomplished in several phases. In the first phase, daily measurements were taken for a week, followed by the second phase where weekly (10 days) measurements were taken for a month. In the third phase, measurements were taken monthly for a period of 6 months. The main purpose was to observe possible changes in pressure readings after the accumulation of tonnage caused from the flow of regular traffic.

Track geometry measurements occurred as part of Amtrak's normal inspection scheduled and were made routinely once a month. Track geometry data was supplied for both pre-and post-geocell installation from June 2013 to September 2016.

Measurement Results and Analysis

After installation of the geocell materials and instrumentation, the performance of the test and control sites was monitored to include the key parameter of subgrade pressure and vertical track geometry. The test was monitored over a 10-month time period.

Subgrade Pressure Data

Subgrade pressure was monitored using four pressure cells (load cells), two each under each rail of the geocell and control sections, respectively. Figure 8 shows the load cell numeral designations. Load cells 2 and 4 are in the geocell zone, and cells 1 and 3 are in

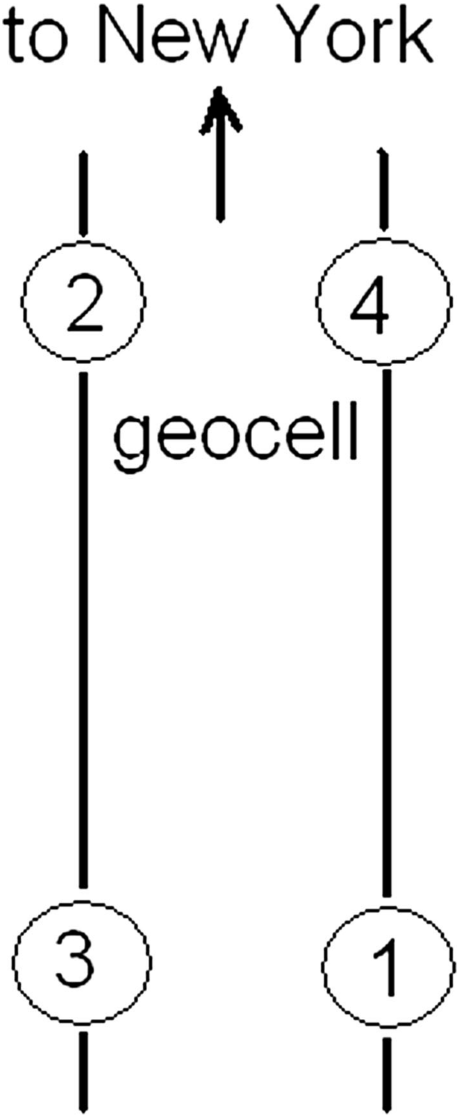


Fig. 8 Load cell numbers and locations

the outside control zone. The results for the passage of one train as recorded by the load cells are shown in Fig. 9. As can be seen from the figure, the locomotives (front and rear) generate higher loads than the passenger cars. The figure shows clearly that the pressure increments measured in the geocell-reinforced zone (cells 2 and 4) were less than those of the unreinforced zone (cells 1 and 4). The average values acting in the reinforced and unreinforced zones were 9.6 psi (66.5 kPa) and 4.6 psi (31.6 kPa), respectively. Thus, the geocell layer resulted in a redistribution and reduction of vertical pressure by nearly half.

Figure 10 shows the results of daily, weekly, and monthly measurements for Acela and Regional trains for a period of approximately 7 months after installation and

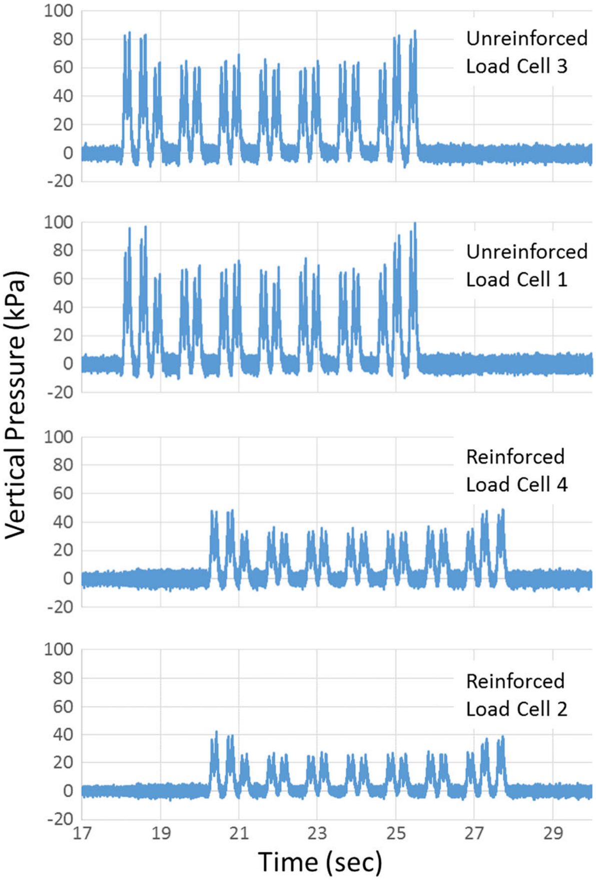


Fig. 9 Load cells and measurements during train passage

resumption of service. Note that separate measurements are presented for the Acela and Regional trains because of differences in car weight and speed. Some of result variations were related to maintenance work. It can be clearly seen that the values along the left and right rails were quite consistent with the pressure measurements in the geocell zone, approximately half of those for the cells in the control zone (no geocell).

Track Geometry Measurement Data

Track geometry measurement were made using Amtrak's track geometry vehicle which measures left and right rail surface (profile), cross-level, and twist at 1-ft intervals along the track. It also records all exceptions to both Amtrak and FRA track standards.

Measurements are made monthly, and data was collected as far back as 2013. Figure 11a, b presents track geometry data for surface (left and right) immediately before and immediately after the track reconstruction and geocell installation. The geocell zone is noted, and the non-geocell zone appears on both sides fo the geocell zone. Four geometry runs are presented in these figures: August 2015 (the month

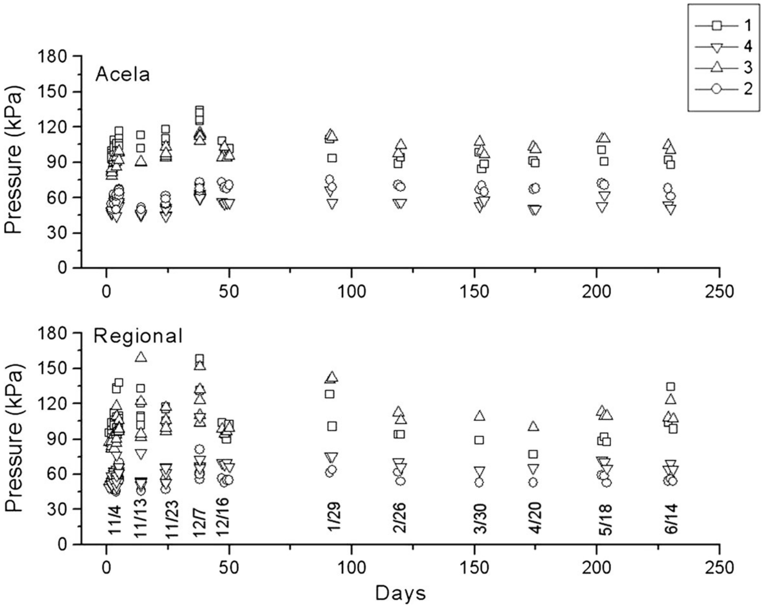


Fig. 10 Pressure cell results over 7 months of measurements

before the reconstruction) and January, April, and June 2016, all after the reconstruction. Note, the June 2016 data is approximately 7 months after traffic resumed on the reconstructed track.

As can be clearly seen in the control zone north of (and outside) the geocell zone (vicinity of MP 63.62), there were significant geometry variations immediately before reconstruction. These were corrected during reconstruction, but by June 2016, these geometry variations reappeared at the same, if not greater, amplitudes. By contrast, in the geocell zone, such as in the vicinity of 63.78, the "after" geometry variations are significantly smaller than the pre-reconstruction geometry variations (less than half the magnitude in several locations). This behavior was also observed in the cross-level data.

Thus, the geocell test zone(s) clearly have a lower rate of track degradation and a correspondingly longer surfacing cycle.

The mechanical roles of the geocell layer are confirmed through this full-scale case study. The geocell layer kept the ballasts in place by restraining their lateral spreading when subjected to vertical cyclic loading. By doing so, the vertical deformation is also minimized. In addition, the geocell layer helps to distribute the vertical loads exerted by the rail ties over a wider area; thus, a smaller vertical stress was measured below the geocell layer compared to the case of unreinforced ballasts.

The track geometry data was also converted to an equivalent track quality index (TQI) for each test zone which was calculated for each measurement cycle (monthly based on current Amtrak testing frequency) and then plotted against traffic (defined in terms of MGT). TQI is a "figure of merit" that objectively quantifies the condition of a homogeneous section of track. The TQI allows for analysis of the section of track, to include the determination of the rate of degradation of each of the test zones and serves

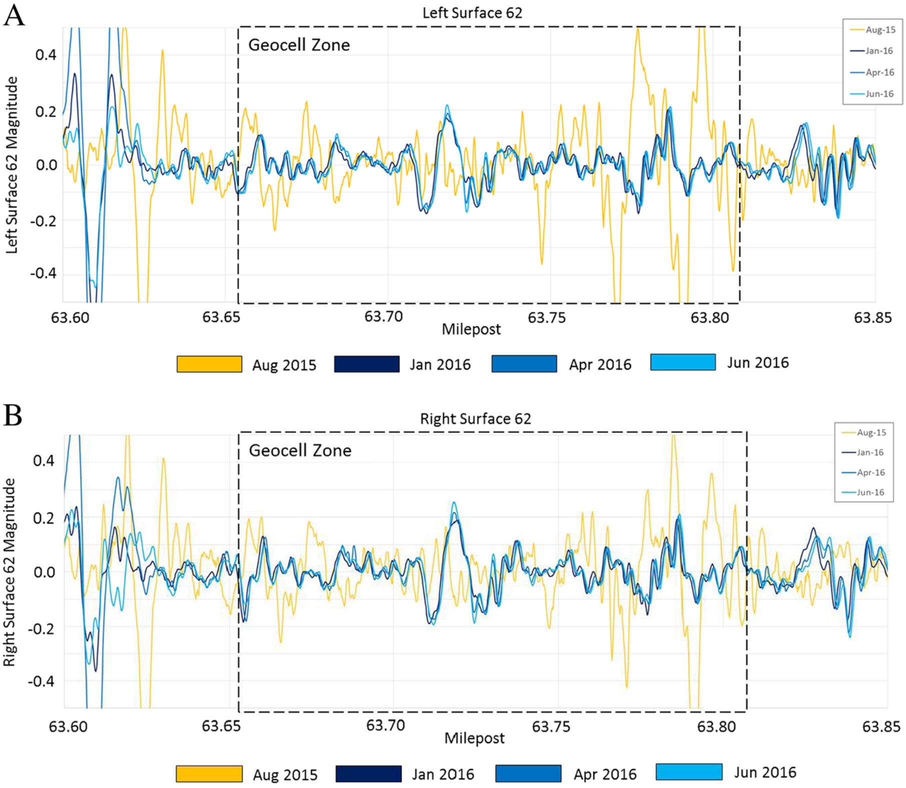


Fig. 11 **a** Pre-installation and post-installation track geometry data—left surface (62′ chord). **b** Pre-installation and post-installation track geometry data—right surface (62′ chord)

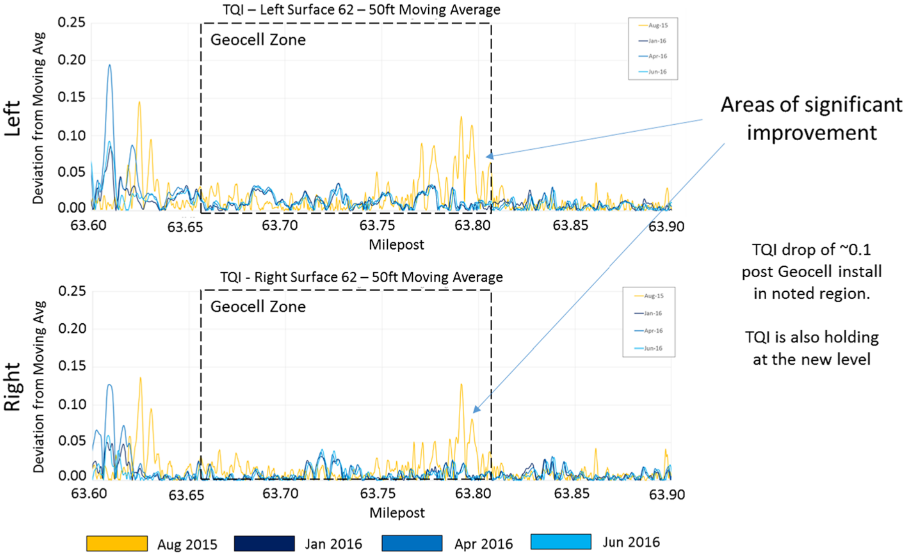
as the basis of performance comparison. The TQI window (length of track section) was varied, to allow for optimization of the degradation analysis.

TQI was defined as the standard deviation of a particular channel, e.g., left surface 62′.

Total TQI was defined as the sum of the TQI of left surface 62, right surface 62, and cross-level. The TQI was calculated both continuously, using a 50-ft moving average window, and with various segmented window sizes: 50, 200, and 800 ft.

Figure 12 presents a 50-ft moving window calculation for combined left and right surface TQI for the same four time periods as shown previously in Fig. 11. Here too, the results match those presented in Fig. 11, with the non-geocell control zone north of the geocell zone showing high pre-reconstruction TQI values, corrected during reconstruction, and then reappearing and growing even larger by 7 months after reconstruction. By contrast, the geocell zone had large pre-reconstruction TQI values which were corrected during reconstruction and has a significantly reduced rate of regrowth, such that 7 months after reconstruction, the TQI values were about one third the pre-reconstruction values (as opposed to the northern control zone where they exceeded the August 2015 pre-reconstruction maximum values).

Figure 13a, b presents TQI data for all three measurements as a function of time, starting from September 2014 and going through June 2016 (reconstruction was September 2016). The results are quite significant.



Areas of significant improvement

TQI drop of ~0.1 post Geocell install in noted region.

TQI is also holding at the new level

Fig. 12 TQI calculated with moving 50-ft window, left and right surface

In the northern reconstructed control zone (Fig. 13a, MP 63.6 to 63.64), there was significant levels of TQI pre-construction, dropping to good quality track after construction and then reappearing and growing to levels greater than the pre-contruction levels within 6 months. The data indicates that a follow-up surfacing cycle was required and performed at that time in this zone.

By contrast, the geocell zone showed extremely good post-construction performance. This was most clearly illustrated in the geocell zone between MP 63.76 and 63.8 (Fig. 13b) where the high pre-reconstruction TQI values never reappeared after reconstruction and installation of the geocell material but instead remained at a very low level even 7 months after reconstruction. The rate of track degradation, in this zone, appears to be reduced by more than a factor of 3, suggesting a corresponding increase in surfacing cycles by the same factor of more than 3.

It should be noted that the south control zone (MP 63.81 through 63.85) did not show this level of improvement because the corresponding rate of geometry degradation for this zone was low, suggesting better subgrade support conditions here than north of the geocell zone.

Figure 14 presents a “cross-mapping” of the TQI and pressure cell data for the Acela and Regional traffic, respectively. This cross-mapping is a correlation analysis between the two different sets of data. The results are quite interesting. For the geocell zone, under both the left and right rails, there is a well-defined relationship between lower pressure and lower TQI, corresponding to better track quality. This appears in the lower left quadrant of the graph in Fig. 14. For the non-geocell zone, under both the left and right rails, there is likewise a well-defined relationship between higher pressure and higher TQI, corresponding to poorer track quality. This appears in the upper right quadrant of the graph in Fig. 14. In each of the four cases, corresponding to each one of the pressure cells, there is a linear relationship between the actual pressure and TQI values. Furthermore, this relationship appears to exist for both the Acela and the

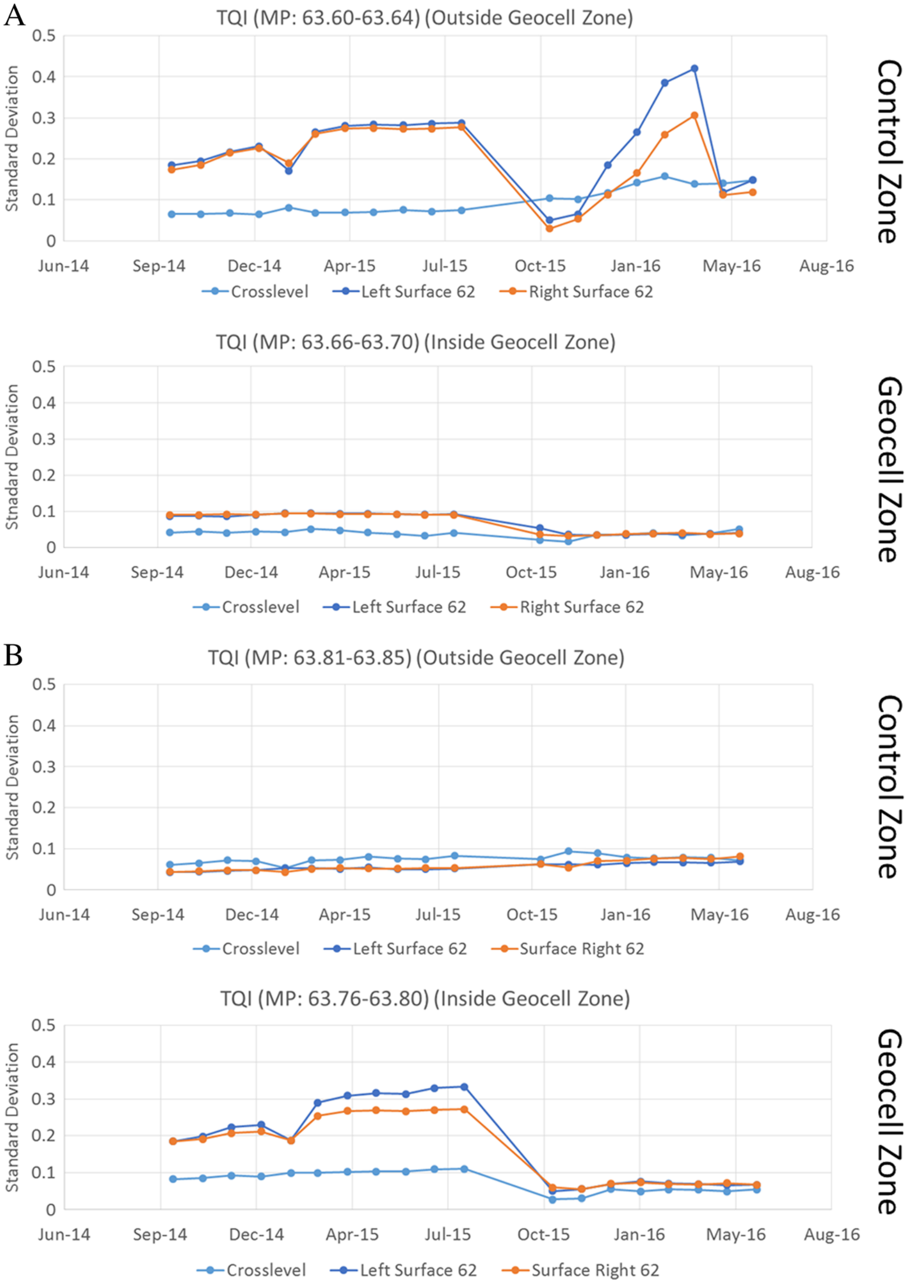


Fig. 13 **a** Two hundred-feet window TQI: north control and northernmost geocell zones. **b** Two hundred-feet window TQI: south control and southernmost geocell zone

Regional traffic, though the actual loads, speeds, and pressure values are different. This data supports the previously shown results that the introduction of the geocell material improved track support, reduced bearing pressures on the subgrade, and provided improved track geometry performance over time.

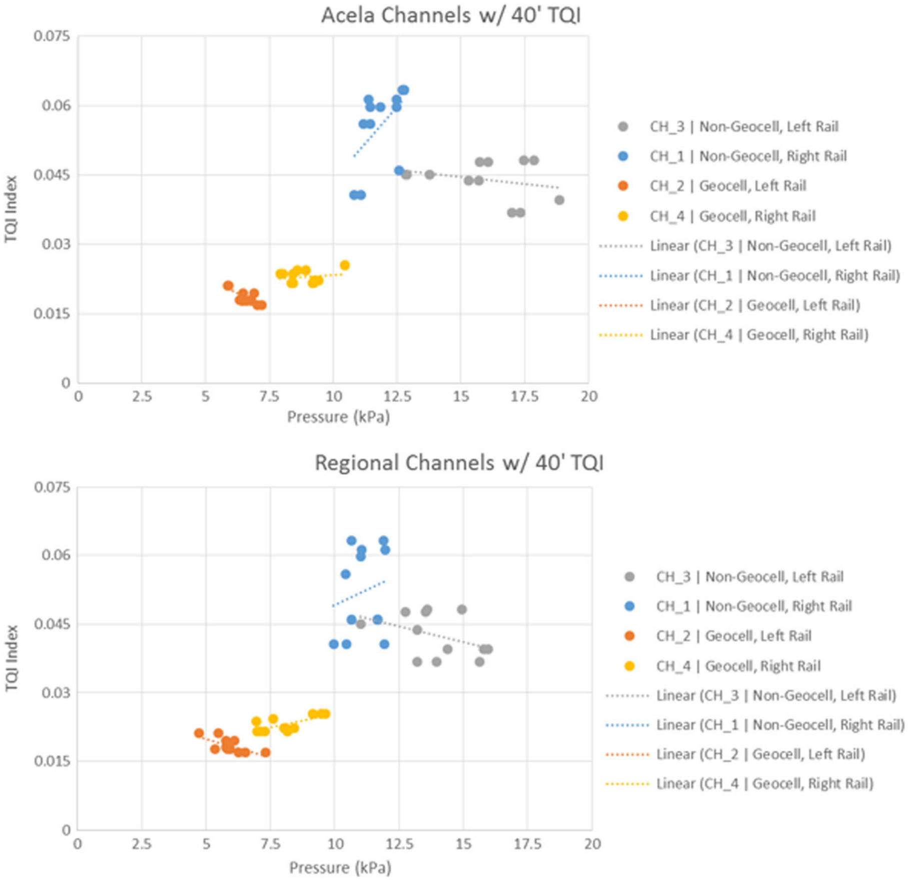


Fig. 14 Cross-mapping of pressure and TQI data

Increase in Surfacing Cycle

One of the key determinants of the effectiveness of the geocell reinforcement technology is its ability to reduce the rate of degradation of the track geometry. This was accomplished by analyzing the track geometry data measured by the Amtrak track geometry car and calculating a TQI for each defined segment, as shown in the previous Fig. 13. The track quality indices used in this analysis include the standard deviation (SD) of the left and right profiles (surfaces) and the SD of the cross-level. The track degradation rate is defined by the slope of the TQI vs. time graph as shown in Fig. 15 which shows the change in TQI over time. Figure 15 represents a track segment of 200 ft, over a period of just under 2 years, with the installation of the geocell material occurring in September 2015, corresponding to the large improvement (reduction) in TQI shown at that time. In addition, there was what appears to be a spot tamping (maintenance) cycle in January 2015.

Looking at the left and right surface TQIs, the pre-geocell installation behavior can be seen in the period from January 2015 through August 2015 where there was a change in total TQI value of approximately 0.15 over a period of 7 months for a slope

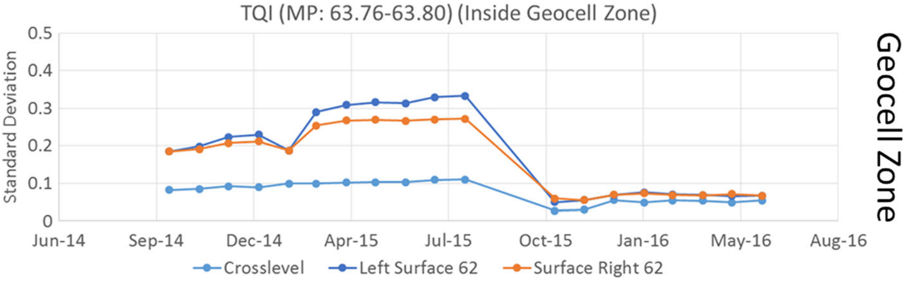


Fig. 15 Track geometry degradation rate before and after geocell installation

of 0.021. The post-geocell installation behavior can be seen in the period October 2015 through June 2016, where there was a change in TQI value of approximately 0.25 over a period of 8 months for a slope of 0.03. The result of the geocell installation appears to be a reduction in the rate of change of track geometry degradation (slope of the curve in Fig. 15) of a factor of 7.

Figure 16 presents the results of the combined track quality Indices which consist of the SD of the left and right profiles (surfaces) and the SD of the cross-level, combined linearly using the following equation:

$$\mathrm{SD}_{combined} = a \times \mathrm{SD}_{left\ profile} + b \times \mathrm{SD}_{right\ profile} + c \times \mathrm{SD}_{cross-level}$$

where $a = b = c = 1$

For the combined TQI, the pre-geocell installation behavior can be seen in the period from January 2015 through August 2015 where there was a change in total TQI value of approximately 0.185 over a period of 7 months for a slope of 0.0265. The post-geocell installation behavior can be seen in the period November 2015 through August 2016, where there was a change in TQI value of approximately 0.036 over a period of 9 months for a slope of 0.004. The result of the geocell installation appears to be a reduction in rate of change of track geometry degradation (slope of curve in Fig. 16) of a factor of 6.7.

Other parts of the geocell zone experienced smaller levels of improvement. However, it should be noted that surfacing cycle is determined by the “worst” segment in a zone, so that the surfacing of the entire geocell zone (and most probably the entire test zone) would be set by the “worst case” 200-ft segment shown in Fig. 13.

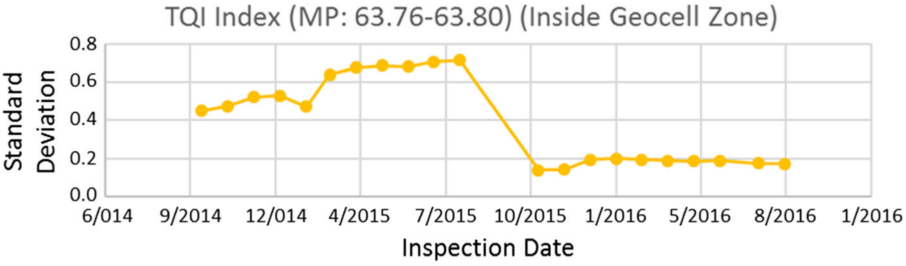


Fig. 16 Combined TQI degradation behavior

Overall, the effect of installing the geocell material was to significantly increase the surfacing cycle by a factor of 6.7 times the pre-geocell installation surfacing cycle.

Summary and Conclusions

This paper presents the results of a field test which compared two distinct sets of rebuilt track conditions, to include zones with and without a layer of geocell material.[7] It should be noted that all measurement zones were rebuilt with improved drainage and a good, well-defined, track structure and substructure (to include a well-defined depth of clean ballast). The test measurements included pre-reconstruction and post-reconstruction track geometry measurements together with comparative subgrade pressure measurements inside and outside the geocell installation zones. Pre-installation/rebuild geometry data was available dating back to 2013, while post-rebuild data encompassed a period of approximately 10 months. The geocell layer plays a role of restraining the lateral deformation of ballasts as well as redistributing the vertical stress below which when subjected to cyclic loading.

The pressure cell measurements, which looked at subgrade pressure under left and right rails in both the geocell zone and the control (non-geocell) zones, included measurements under both Acela high-speed trains and lower speed regional trains. In all cases, the subgrade pressures in the geocell zone were approximately half of those for the cells in the control zone (no geocell).

Track geometry measurement were made by Amtrak's track geometry vehicle which measures left and right rail surface (profile), cross-level, and twist at 1-ft intervals along the track. Measurements are made monthly. Examination of the pre-rebuild data shows that there were several well-defined locations in the overall test zone that experienced signficant track geometry degradation with signficant geometry variations. These were all corrected during reconstruction.

In the zones with no geocell material, these geometry variations reappeared within 6 to 7 months with the same, if not greater, amplitudes. By contract, in the geocell zone, such as in the vicinity of MP 63.78, the after geometry variations were significantly smaller than the pre-reconstruction geometry variations (less than half the magnitude in several locations). This behavior was seen in the left and right surface plots as well as in the cross-level data. Furthermore, the rate of geometry degradation was signficantly less for the geocell zones when compared to pre-reconstruction degradation rates, indicating the effectiveness of the geocell material in reducing the rate of track geometry degradation and extending the surfacing maintenance cycles. Analysis of the rate of degradation showed that the effect of installing the geocell material was to significantly reduce the rate of degradation (and thus increase the surfacing cycle) by a factor of 6.7 times the pre-geocell installation surfacing cycle.

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[7] The geocell layer also has a geogrid layer beneath it (see Fig. 4), that was part of the cross-sectional design used here.

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