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In-Track Railway Track Tie/Ballast Interfacial Pressure Measurements Using Granular Material Pressure Cells

By

Jerry G. Rose, Ph.D., P.E.
Professor
Department of Civil Engineering
University of Kentucky
Email: jerry.rose@uky.edu

David B. Clarke, Ph.D., P.E.
Director
Center for Transportation Research
University of Tennessee
Email: dclarke@utk.edu

and

Qunglie Liu, Ph.D.
Assistant Professor
School of Civil Engineering
East China Jiaotong University
Email: liuqingjie06@163.com

Travis J. Watts, EIT
Graduate Research Assistant
Department of Civil Engineering
University of Kentucky
Email: travis.watts@uky.edu

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DISCLAIMER

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TECHNICAL SUMMARY

Title

In-Track Railway Track Tie/Ballast Interfacial Pressure Measurements Using Granular Material Pressure Cells

Introduction

This report describes a research study to measure railroad track tie/ballast interfacial pressure using pressure cells specially designed for granular materials. Measurements were taken during a several month period at a test site located at Mascot, TN on a Norfolk Southern (NS) Railway mainline. The track has a 45 mph (72 km/h) speed limit and carries 37 million gross tons (33.6 million gross tonnes) annually. It is constructed with timber crossties and 136 RE continuous welded rail.

A group of six timber ties containing granular material pressure cells imbedded within recesses in the undersurface of the ties were successfully installed on an NS mainline track at Mascot, TN. A series of nine trackbed tie/ballast interfacial pressure measurements were taken of typical revenue trains over a seven-month period.

Approach and Methodology

The experiment employed new timber crossties routed to recess the pressure cell within the tie. Thus, the active surface of the pressure cell was flush with the tie bottom. Cabling was run through a recess to the tie end. This greatly reduced the likelihood of damage to the instrumentation during track surfacing and lining activity. The ties were installed such that multiple cells were directly under consecutive rail seats of one rail. Several ties also had cells either at the center or the rail seat of the opposite rail.

The report presents ballast pressure magnitudes and distributions and discusses results, including the effects of variable ballast support, wheel loadings, and flat wheels. Typical maximum vertical ballast pressure measurements directly under the rail seat, with ballast fully compacted, averages 20 psi (140 kPa) under the heaviest common revenue wheel loadings.

Findings

The consistency of recorded ballast pressures depended on the stability and tightness of the ballast support. The researchers expended considerable effort to provide consistent ballast conditions for the instrumented ties and adjacent, undisturbed (transition) ties. NS crews surface and tamped through and on either side of the test section. This, plus consolidation through normal accruing train traffic, resulted in consistent measurements through the section.

Ballast in the vicinity of the inserted instrumented recessed ties was disturbed (loosened) much less during the installation of the ties than previous attempts to excavate under existing solid ties to provide space for the cells positioned under the ties.

Imbedding the active area of the cells, transducer housing, and instrument cable within the recesses in the underside of the routed ties leaves the crib areas between the ties void of the cell instrumentation so that the instrumented ties can be adequately tamped to consolidate/compact the partially disturbed ballast.

Within cell pressure variations, for repeated train passages, are less variable than between cell variations for the same trains.

The average tie/ballast interfacial pressure under the rail seat for six-axle locomotives is 20 psi (140 kPa). The data is very consistent, with the maximum to minimum range by date averaging 18 to 22 psi (125 to 150 kPa) during the measurements for over twenty trains during the six-month period.

Conclusions

Initial testing revealed that the properties of the track and pressure distribution within the support are highly dependent on the relative consolidation/denseness of the ballast. Initial pressure measurements were considered marginally representative of typical pressure distributions for a well-consolidated, ballast supported trackbed.

The measured pressures are considerably lower than typically assumed for a high-tonnage ballasted timber tie track.

Pressures at the tie/ballast interface in the center of the track are initially very low. This is due to the center of the track not being routinely tamped during the installation of ties and surfacing track. However, with the passage of trains the track settles and the ballast in the center of the track readily contacts the ties providing the media for pressure transferal from the tie to the ballast.

Recommendations

Imbedding the cells within the ties and securing the cells to the ties negates the cells from settling in the ballast over time to develop gaps and “bridging”, however the ballast must be adequately and uniformly tamped to realize this advantage.

The ballast in the vicinity of the instrumented and approach ties should be uniformly consolidated/tamped to achieve equal vertical support for the ties assuring an equalized track modulus throughout the test area.

It is desirable for the test area to accumulate several months of normal train traffic and tonnage to further homogenize the trackbed support prior to drawing specific conclusions relative to the results of a testing program.

Publications

Rose, J.G. Clarke, D.B. Liu, L. and T.J. Watts. "Application of Granular Material Pressure Cells to Measure Railroad Track Tie/Ballast Interfacial Pressures". Transportation Research Record: Journal of the Transportation Research Board, 2018. 2671: In Press.

Primary Contact

Principal Investigator
Jerry G. Rose, Ph.D., P.E.
Professor
Department of Civil Engineering
University of Kentucky
161 Raymond Building, Lexington, KY 40506
Email: jerry.rose@uky.edu

Other Faculty and Students Involved

David B. Clarke, Ph.D., P.E.
Director
Center for Transportation Research
University of Tennessee
309 Conference Center Building
Knoxville, TN 37996
Email: dclarke@utk.edu

Qunglie Liu, Ph.D.
Assistant Professor
School of Civil Engineering
East China Jiaotong University
808 Shuanggang East Road
Nanchang, China 330013
Email: liuqingjie06@163.com

Travis J. Watts, EIT
Graduate Research Assistant
Department of Civil Engineering
University of Kentucky
216 Raymond Building
Lexington, KY 40506
Email: travis.watts@uky.edu

NURail Center
217 244-2999
nurail@illinois.edu
http://www.nurailcenter.org/

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SECTION 1 INTRODUCTION

This report describes a research study to measure railroad track tie/ballast interfacial pressure using pressure cells specially designed for granular materials. Measurements were taken during a several month period at a test site located at Mascot, TN on a Norfolk Southern (NS) Railway mainline. The track has a 45 mph (72 km/h) speed limit and carries 37 million gross tons (33.6 million gross tonnes) annually. It is constructed with timber crossties and 136 RE continuous welded rail.

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SECTION 2 BACKGROUND

The magnitudes and relative distributions of typical pressures induced by heavily-loaded revenue freight cars and locomotives at the tie-ballast interface have been difficult to quantify and assess. The American Railway Engineering and Maintenance-of-Way Association (AREMA) design methodology assumes that only the outer thirds of the timber tie conveys rail loads to the ballast. The center third of the tie is typically not tamped during tie installation and subsequent track surfacing. Thus, the ballast is not tightly consolidated in this area. As the tie is loaded through the rails, the center third of the tie is not initially in contact with the ballast, therefore no pressure distribution occurs.

Figure 2.1 contains the calculations for timber tie/ballast pressure determination as contained in the AREMA Manual for Railway Engineering (1). This procedure is largely based on the original Talbot design practice. The calculations are for a typical 100 ton (91 tonne) capacity car

assuming 40 percent of the axle load is carried by the tie directly under the axle and further assuming an impact factor of 50 percent for a 50 mph (80 km/h) velocity.

The calculations indicate an average tie/ballast dynamic interfacial pressure of 65 psi (450 kPa) under the outer two-thirds of the tie. The analysis makes no allowance for variations in the transmitted pressure within the effective tie length. Were the center third of the tie to be in equal bearing, the average tie-ballast interface pressure decreases to 43 psi (300 kPa). However, this scenario has not been measured or confirmed from direct in-track tie-ballast interfacial pressure measurements.

$$\mathbf{P_{Dyn} = P_S + \theta P_S}$$

P_{Dyn} = Dynamic Wheel Load, lbf

P_S = Static Wheel Load, lbf

θ = Impact Factor

$$\mathbf{\theta = \frac{33 \times V}{D_w \times 100}}$$

V = Velocity, mph

$\mathbf{D_w}$ = Wheel Diameter, in.

$$\mathbf{P_a = \frac{2P_{Dyn}}{\left(\frac{2}{3}\right) bL} \times \%}$$

$\mathbf{P_a}$ = Tie/Ballast Pressure, psi

b = Width of Tie, in.

L = Length of Tie, in.

% = Percent of Wheel Load carried by Tie directly under the load, typically 40%

For a static 33,000 lbf wheel load, 33-in diameter wheel, 50 mph velocity, 9 in. wide and 8 1/2 ft long wood tie, the calculated tie/ballast interfacial pressure is 65 psi (450 kPa).

Figure 2.1. Typical calculations for tie/ballast contact pressures as contained in the AREMA Book of Recommended Practices (1).

SECTION 3 PREVIOUS TIE/BALLAST PRESSURE TESTING

Considerable effort has been expended at developing a consistent, reliable, and accurate procedure to measure pressures at the tie/ballast interface directly below the rail seat. This is the location considered to have the highest pressure. Following sections describe several initial tests, with the bulk of the paper addressing the most recent series of in-track tests at Mascot, TN.

3.1 Instrumentation

All tests employed Geokon Model 3515 granular materials pressure cells. These are designed to measure dynamic pressure changes in aggregate of similar size and grading to railroad ballast. A cell consists of two circular 8 in. (200 mm) diameter stainless steel plates welded together around the periphery, separated by a small gap (void) filled with hydraulic fluid. The pressure cells have

an active area of 50.3 in^2 (324 cm^2). Applied pressure squeezes the two plates together, creating fluid pressure in the cell. The two plates are sufficiently thick so they do not deflect locally under the point loads from surrounding large aggregate particles.

A pressure transducer installed in the steel cell housing transforms the fluid pressure to a current signal. The measured pressure is the average pressure on the active area. The pressure range of the pressure transducer is 0 to 360 psi (0 to 2.5 MPa).

A National Instruments Model NI 9203 C Series Current Input Module was used for data acquisition. The 12Vdc module has eight analog -20 mA to 20 mA current input channels with a maximum 200 kHz sample rate. Figure 3.1.1 shows a pressure cell and the data logger module.

Figure 3.1.1. Pressure cell (left) and data logger module (right).

A user-friendly program for data collection was developed using LabVIEW. Figure 3.1.2 shows the main interface. The program can change units from mA to MPa and psi synchronously and show the pressure magnitude trace in real time during a test. It also induces an automatic zero setting. The experiment sampling rate was 2000 samples/s.

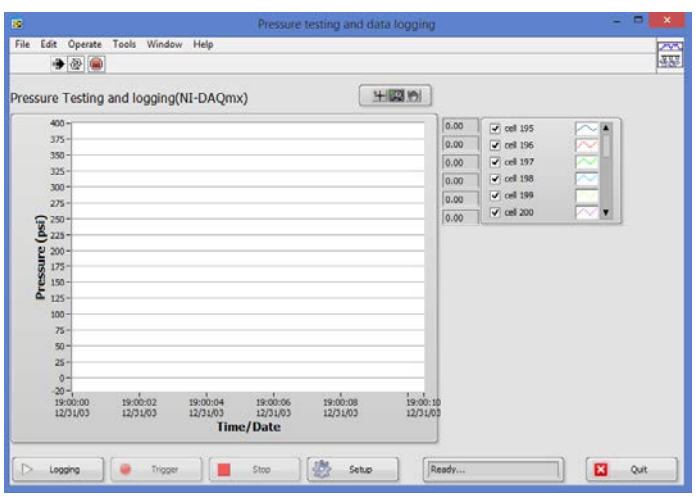


Figure 3.1.2. Interface for LabVIEW program.

3.2 Laboratory Prototype Tests

To develop and validate in-service test procedures, the researchers initially conducted laboratory tests of pressure cells installed in a prototype trackbed section consisting a rail, timber tie, ballast, and subballast. This simulated a typical trackbed.

A Model 3515 granular material pressure cell was installed in the tie section directly below the rail seat. Using a testing machine, the team applied controlled and known loadings to the rail/tie section. The cell measured the pressure at the tie-ballast interface.

The research determined that the cell measurements were accurate and consistent. Cell measurements correlated perfectly with calculated tie/ballast interface pressures based on applied loads (2,3). Measurement repeatability within and between individual cells was excellent for loadings encompassing typical maximum tie/ballast pressure magnitudes. The test data indicates that the cells accurately reflect pressure under laboratory conditions where the applied load can be measured and controlled.

3.3 Transition to in-track installations

The next step was to transition to in-track testing. In-service track differs from the laboratory tests in that a tie carries only a portion of the imposed wheel load. The continuous rail distributes the wheel load to several consecutive ties.

For in-track tests, the team placed pressure cells at the ballast interface below the rail seat for six consecutive ties. The experiment protocol was to maintain ballast in an undisturbed, compact condition when the cells were installed. However, this proved to be difficult in practice and ballast was disturbed.

Initial tests were conducted at two separate sites. A summary of these tests follows.

3.3.1 TTI Railroad at Paris, KY

The first site was on a TTI Railroad track connecting CSX Transportation's nearby mainline with the TTI Paris, KY yard. Maximum operating speed over the track was 10 mph (15 km/h). The lead track has 132 lb. jointed rail affixed with cut spikes to timber crossties. The trackbed was a tightly compacted, highly fouled mixture of ballast, degraded ballast, coal dust, and soil. The pressure cells were positioned at the ballast interface below the rail seat of in-situ ties, with the transducer housing and electrical cable in the crib area. Figure 3.3.1a shows the TTI track site.

Test results varied as a function of how tightly the particular cell was in contact with the bottom of the tie. Cells in direct contact with a tie recorded reasonably to extremely high pressure levels. However, cells that were positioned lower, thereby providing a "gap" or void between the tie and the cell, recorded pressures much lower, since the tie "bridged over" the cell.

Figure 3.3.1a. TTI Railroad test site (left) and Flatrock test site (right).

Some cells measured contact pressures in the 60 to 80 psi (415-550 kPa) range, considered typical for 4-axle weight locomotives. Other cells measured significantly lower pressures. The team shimmed adjacent cells measuring lower pressures with thin metal plates to fill the voids and provide uniform bearing.

Ultimately, longitudinal pressures for a typical 2-axle truck locomotive were distributed over 13 ties, with 38 percent of the axle load being carried by the tie directly under that particular axle. Figure 3.3.1b shows the load distribution pattern derived from the test data.

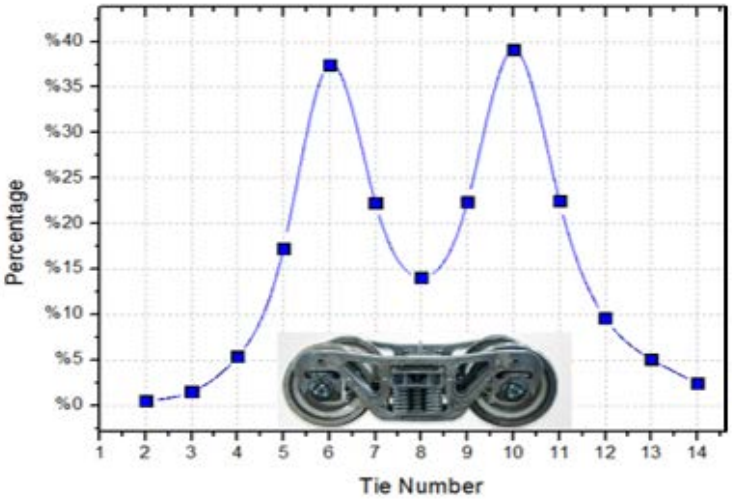


Figure 3.3.1b. Longitudinal distribution of the tie-ballast pressure for a 2-axle locomotive truck, axle spacing = 82 in. (2080 mm), wheel load = 32,000 lbf (142 kN).

Due to the extremely low tonnage and speeds and the fouled ballast, the cells were basically fixed in position so it was difficult to determine if the measured pressures were typical of those developed in an un-disturbed track. However, the relative longitudinal distribution of the pressures was evident from the pressures vs. time traces. Specific findings from the TTI tests follow:

- Pressure cells are applicable for measuring the interfacial pressures at the tie/ballast interface.
- The data acquisition system is adequate to develop realistic pressure vs. time traces.
- It is difficult to position the cells within fouled ballast to maintain constant contact with the underside of the ties. The cells are "peaked" or "bridged across" resulting in highly variable test data.
- Adequate consolidation/tamping of ballast under the instrumented ties and within the crib areas is essential to obtain accurate test results. However, this is impractical with the transducer housing and instrument cable within the crib area and the cell exposed under the tie,
- Cells must be positioned properly so that the applied pressures reflect undisturbed track.
- The tests produced results that can be used only for relative comparisons; absolute values are highly variable and not realistic for this test arrangement.

3.3.2 Norfolk Southern at Flatrock, KY

The second site was at Flatrock, KY on a very heavy tonnage Norfolk Southern (NS) Corporation mainline freight track. This was a concrete tie track positioned on clean thick ballast with asphalt underlayment support adjacent to a wheel impact load detector (WILD) installation. The maximum train speed was 45 mph (72 km/h). Figure 3.3.1a shows the Flatrock test site.

As with the Paris test, the cells were inserted at the tie/ballast interface under six consecutive ties of one rail. However, the disturbed ballast was reasonably loose in the vicinity of the cells, due to the effects of inserting the cells, so the ties initially "bridged across" the cells. Little to no force (pressure) from the axles passed through the cells. The team installed thin metal shims between the ties and cells so the ties would be in direct contact with the compacted ballast.

After multiple phases of shimming, each following two-weeks of train traffic, higher pressure magnitudes were initially obtained. The typical tie/ballast pressures obtained under locomotives or loaded freight cars varied significantly between cells. Excellent resolution of the pressure vs. time relationship traces were obtained showing the relative pressure as a function of axle loads (4).

Figure 3.3.2 contains the averages and ranges of pressure measurements at Flatrock over a period of time for the six cells. The magnitude of the pressure measurements was highly dependent on the position of the cells within the ballast. Ideally, the cells were in direct contact with the bottom of the ties and level with the adjoining ballast section. Furthermore, the cells should be fixed in the locations so as to maintain their positions along a level plane. Ultimate, the cells gradually settled in the ballast under continued train traffic and the "bridging" phenomenon reduced pressure readings.

Specific findings from the Flatrock tests follow:

- Ballast was disturbed (loosened) during the installation of the cells.
- There is no feasible method to adequately consolidate/compact the disturbed ballast without destroying the exposed instrumentation.
- Metal shims can be used to temporarily fill gaps between the underside of the ties and the surface of the cells, but do not provide long-term uniform support.
- It is impossible to position the cells on a uniform horizontal plane corresponding with the level of the undersides of the ties.
- Cells continue to settle in the ballast under train traffic with gaps developing between the underside of the ties and cells.
- Measured pressures vary significantly depending on the relative vertical position of the cells within the trackbed – can be "on a peak" thus higher pressures or "bridged over" thus lower pressures.
- The cells do accurately measure the pressures applied from the loadings at a given time based on contact conditions.

Clearly, the cell, transducer housing, and instrument cable need to be affixed within the tie bottom so that the tie can be tamped to uniformly consolidate the ballast without damaging the instrumentation.

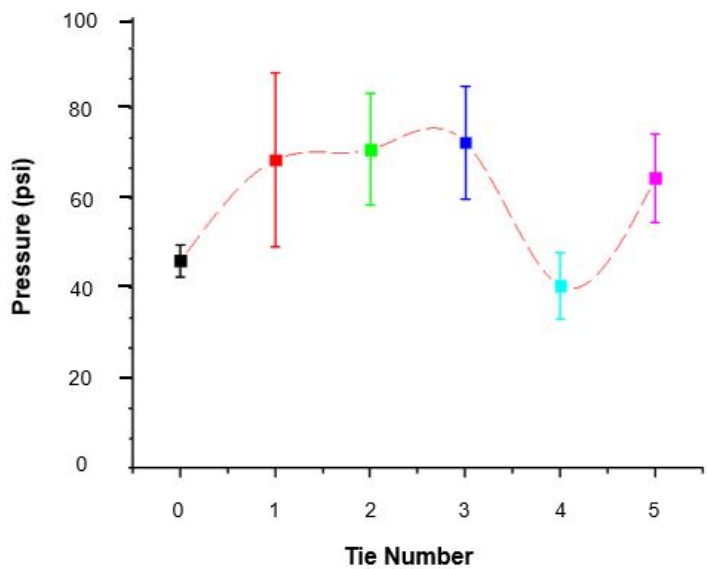


Figure 3.3.2. Longitudinal distribution pressures under consecutive ties, containing averages and ranges of data.

3.4 Lessons Learned for In-Track Installations

Based on the experiences at the Paris and Flatrock installations, future in-track test installations would have the pressure cells inserted in a routed (recessed) area in the tie with the cell's active surface flush with the tie bottom. This leaves the crib areas between the ties and ballast under the ties void of instrumentation so that the track can be surfaced and consolidated by tamping to

obtain uniform ballast compaction. Attaching the cell to the tie negates the issue of a gap or void lowering applied pressures. The ability to tamp and consolidate the ballast uniformly should provide more consistent pressure distributions from tie-to-tie and from date-to-date.

SECTION 4 IN-TRACK TEST EQUIPMENT AND DATA ACQUISITION PRACTICES AT MASCOT SITE

The site subsequently selected to evaluate the applicability of encasing the cells in the underside of timber ties to accurately and consistently measure the pressures at the tie/ballast interface was on an NS mainline at Mascot, TN. The following sections describe recent activities associated with this test site and provide the major aspects of this paper.

The Mascot test site is located on a mainline track with 136 RE continuous welded rail secured with cut spike fasteners to timber ties. Ties are positioned on 20 in. (500 mm) centers and each tie is box anchored. The track support consists of standard NS mainline granite ballast on a well-seasoned roadbed. There are no indications of mud or fouling. NS personnel report that the area has a long record of stable roadbed/trackbed requiring minimal track maintenance. The test area was timbered and surfaced in November 2015.

The site is on a horizontal tangent with a 0.25 percent vertical grade eastbound ascending. The track annually carries 37 million gross tons (33.6 million gross tonnes) of traffic, with a maximum train speed of 45 mph (72 km/h).

All east-west bound trains passing through Knoxville traverse the test section. A wayside automatic equipment identification (ADI) reader adjacent to the test site documents passing train consists. In addition, through trains pass over WILD sites west of Knoxville at either Ebenezer, TN or Flatrock, KY. Data from these installations permits subsequent comparisons of the tie/ballast pressures versus axle load.

Figure 4 contains a view of the test site, a schematic of the through NS mainlines in the Knoxville area, and a detailed schematic of the test site showing the locations of the instrumented ties.

4.1 Instrumented Tie Installation Procedures

To help obtain representative and consistent pressure data (4, 5), the tie bottoms were recessed to precisely conform to the shape of the cells. The recesses provided space for the active circular area of the pressure cell, the transducer housing, and the instrument cable. This operation was performed in a machine shop using a computer controlled router. Compliance with shop environmental requirements required copper naphthenate treated ties.

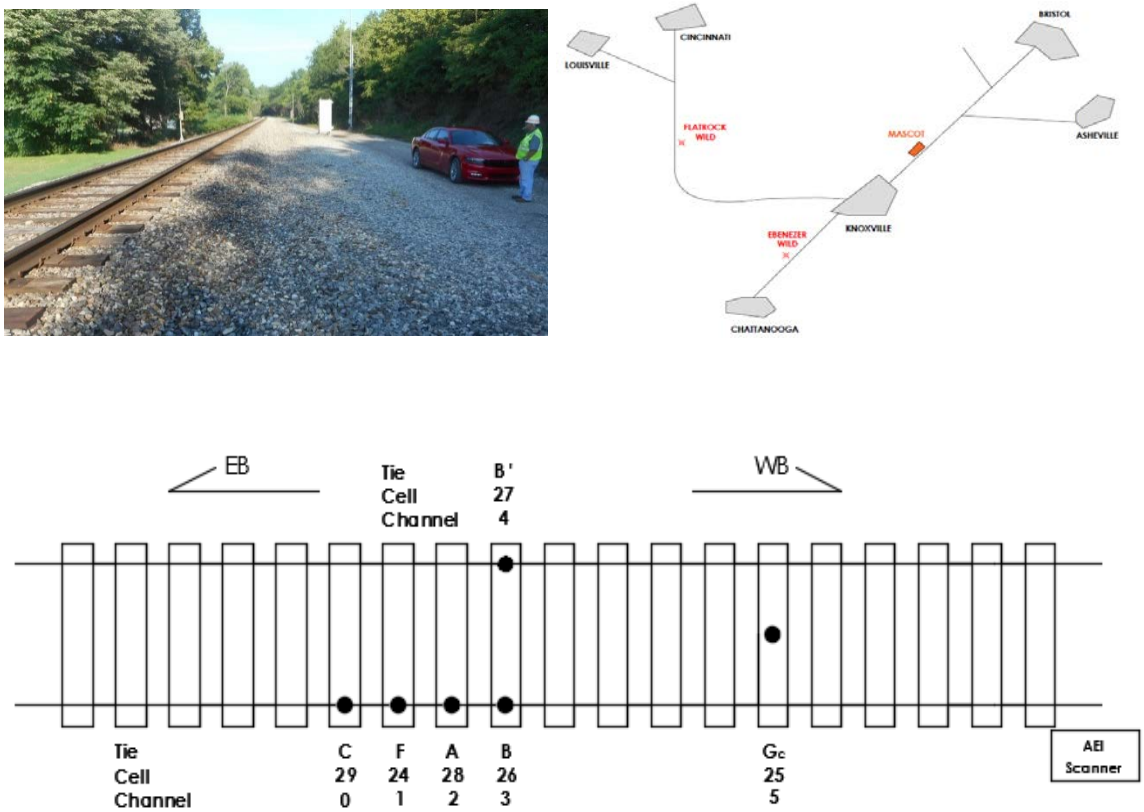


Figure 4. View of the test site, schematic of the NS through mainlines in the area, and detailed schematic for the test site.

The routing was precisely 1 in. (25 mm) deep. The active cell area was flush with the tie bottom to ensure representative ballast contact. The cell was attached to the tie using either screws or corner braces. Thin metal plates protected the transducer housing and instrument cable. A waterproof plastic box beyond the end of the tie contained the coiled cable length when not in use. With all of the instrumentation setup protected, railroad personnel could raise/surface the track using normal procedures.

Cells could be placed directly under one or both rails or the center of the tie. Figure 4.1.1 shows the three routing patterns, the routing process, and a cell partially installed within a tie prior to inserting the tie in the track.

NS provided the equipment and personnel to install the five instrumented ties. The crew took extreme care to avoid damage to the instrumented ties during the installation process. Figure 4.1.2 illustrates the handling and placement of the instrumented ties.

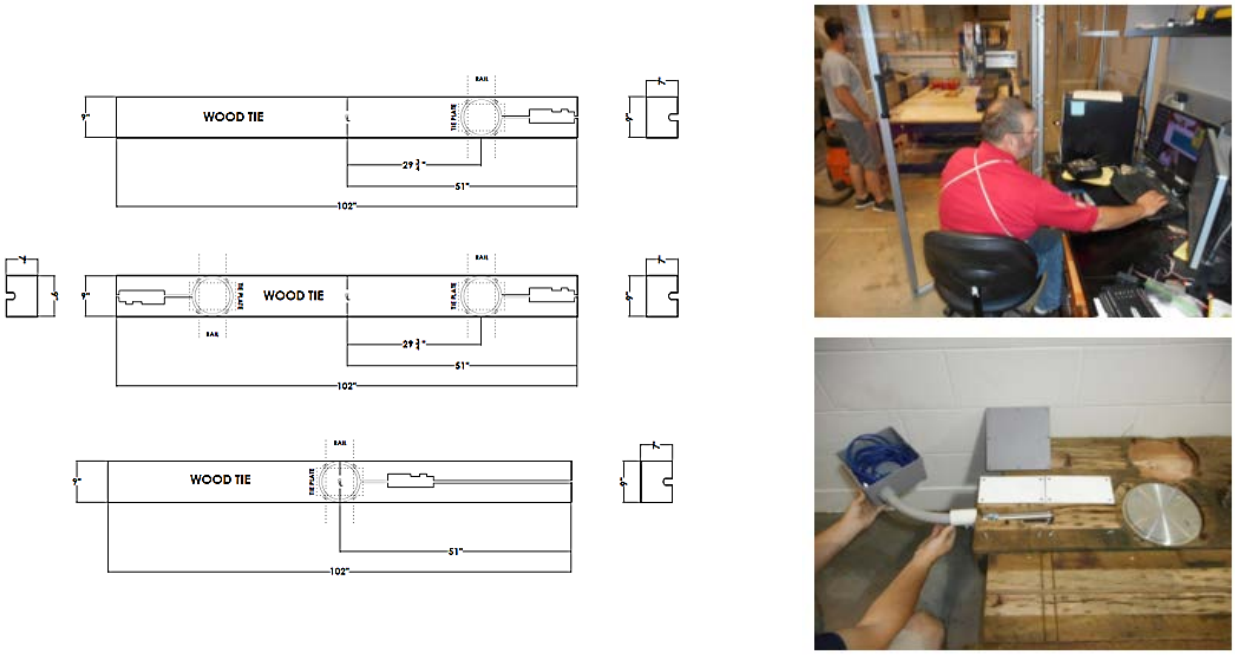


Figure 4.1.1. The three routing patterns for under the rails and in the center of the track, the routing process and a partially inserted cell and housing.

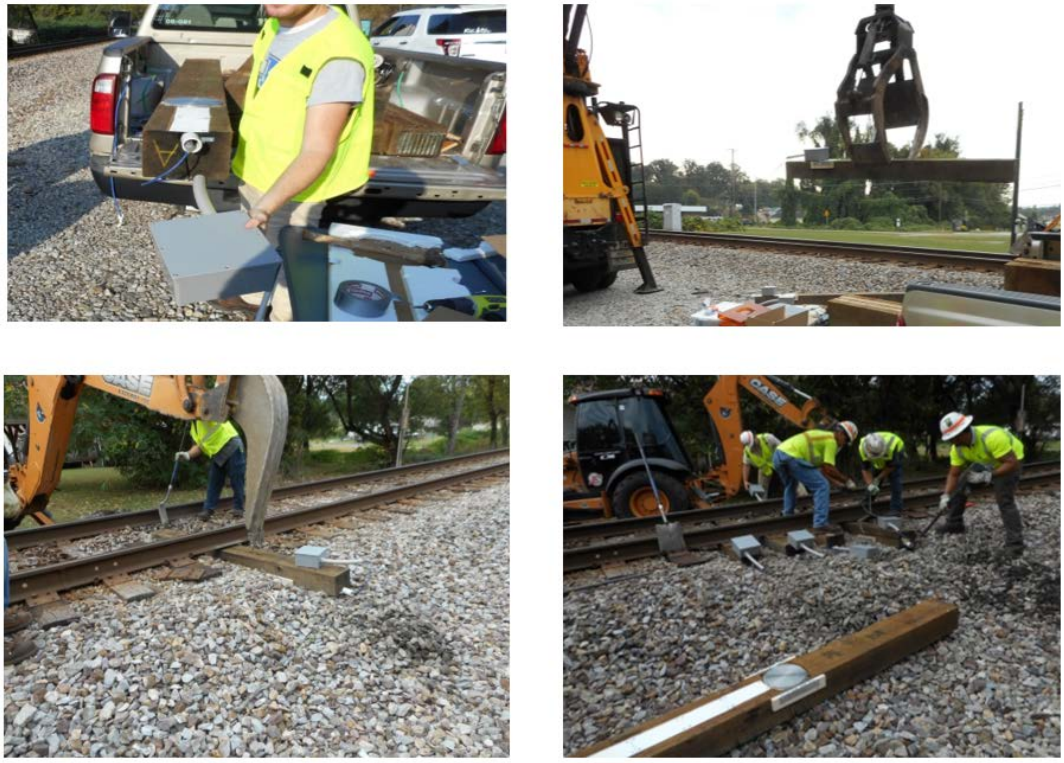


Figure 4.1.2. Inserting instrumented ties in the track.

The instrumented ties were immediately tamped and the initial testing procedure followed. Figure 4.1.3 shows the tamping process and the instrumented ties that were tamped. Initially only the instrumented ties were tamped, as shown in the upper sketch; subsequently after the initial test series the approach ties were also tamped, as shown in the lower sketch.

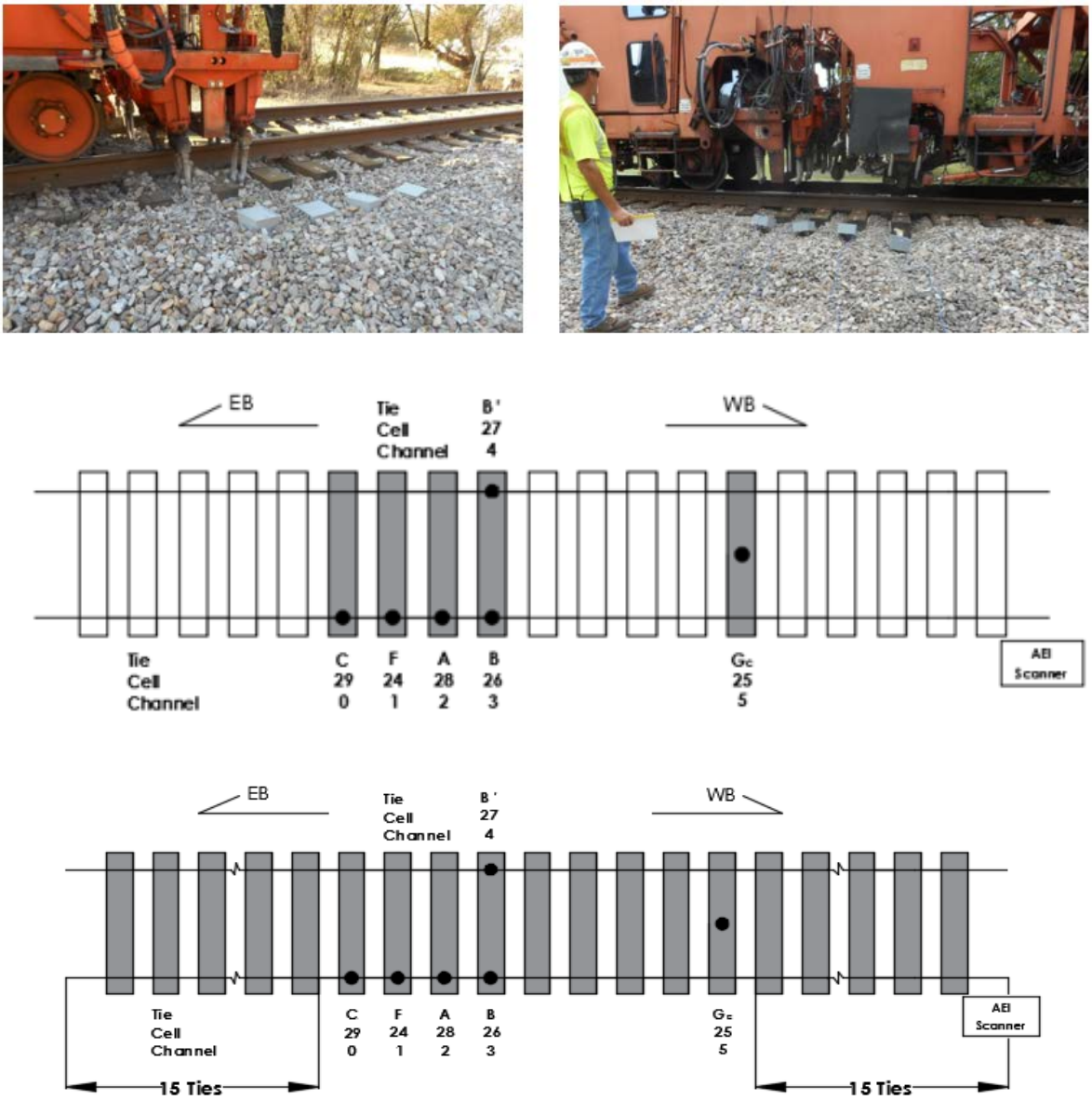


Figure 4.1.3. Track tamping process and the tamped instrumented ties shown in shaded gray. The upper sketch shows the instrumented ties (shaded) that were tamped for the initial two test series. After the initial two test series the 15 ties on each approach plus the ties in the instrumented area were tamped as shown in the lower sketch.

4.2 Test Procedure

Figure 4.2 contains a schematic of the data acquisition equipment and the wayside test equipment. The pressures exciting the six individual cells were simultaneously recorded in real time sequences (sampling rate of 2000 samples/s). The following information was obtained for each test train:

Train Number	Lead Locomotive Number
Time	Type of Train
Number/Axles of Locomotives	Direction of Travel
Speed of Train	Length of Train
Tonnage of Train	Number of Cars

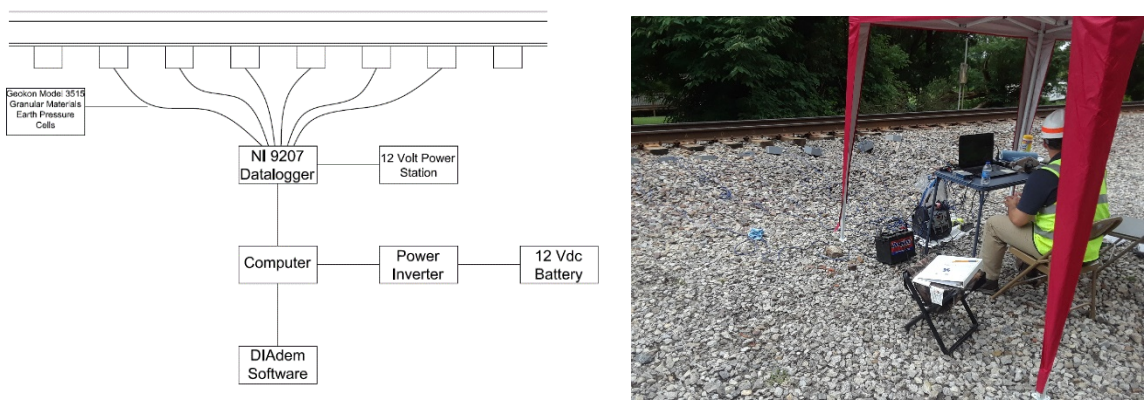


Figure 4.2. Schematic of data acquisition equipment and wayside measuring equipment.

Table 4.2 provides the chronologies for the tamping and testing sequences. For the initial two series of tests only the five instrumented ties were tamped per the layout in Figure 10. Additional tamping included nine ties in the instrumented area and fifteen ties on each approach. Later in the testing sequence, a more thorough double tamping procedure was performed to insure that the instrumented and approach ties were uniformly tamped so that the contact pressures would be equivalent for all ties. Since that time four more series of tests have been conducted, extending the test program to seven months.

4.3 Mascot Data Presentation

Nine series of pressure measurements have been conducted. Figure 4.3.1 contains typical pressure traces for a mixed freight train after all tamping was complete. The bottom trace is for

Table 4.2. Chronology for tamping and testing the instrumented ties.

Mascot, TN Site	
Date	
2016	
September 26	*Installed 6 Sensors (5 Ties)* *Single Tamped 5 Ties with Sensors* *Test – (variable & low)*
October 12	*Test – (variable & low)* *Single Tamped 39 Ties (15 + 9 + 15)*
October 26	*Test – (more consistent)*
November 7	*Test – (more consistent)*
November 15 & 16	*Double Tamped 39 Ties with Double Insertion*
November 28	*Test – (more consistent)*
December 15	*Test – (more consistent)*
2017	
April 13	*Test – (little change, except centerline of tie)*
April 27 & 28	*Test – (little change, except centerline of tie)*

the cell installed in the center of the track. All other cells were located under the rail seat per Figure 4.1.3. The train's consist was six 6-axle locomotives, shown by the 12 uniform peaks at the left of the traces, and twenty trailing freight cars (six loads and fourteen empties). Subsequent peaks of similar magnitude reflect axles of loaded cars.

Figure 4.3.2 shows the locomotives axles using an expanded time scale. Each individual peak is a wheel load, with six loads for each locomotive. Individual wheel loads for the locomotives are approximately 33,000 lbf (148 kN).

Table 4.3.1 provides average cell pressure readings for the nine test series. For simplicity of data presentation, only the locomotive pressure data is shown. The typical wheel loading from the 6-axle locomotives is approximately 33, 000 lbf (148 kN) so direct comparisons can be made from cell-to-cell and date-to-date. The pressure readings for the five cells directly under the rail are shown.

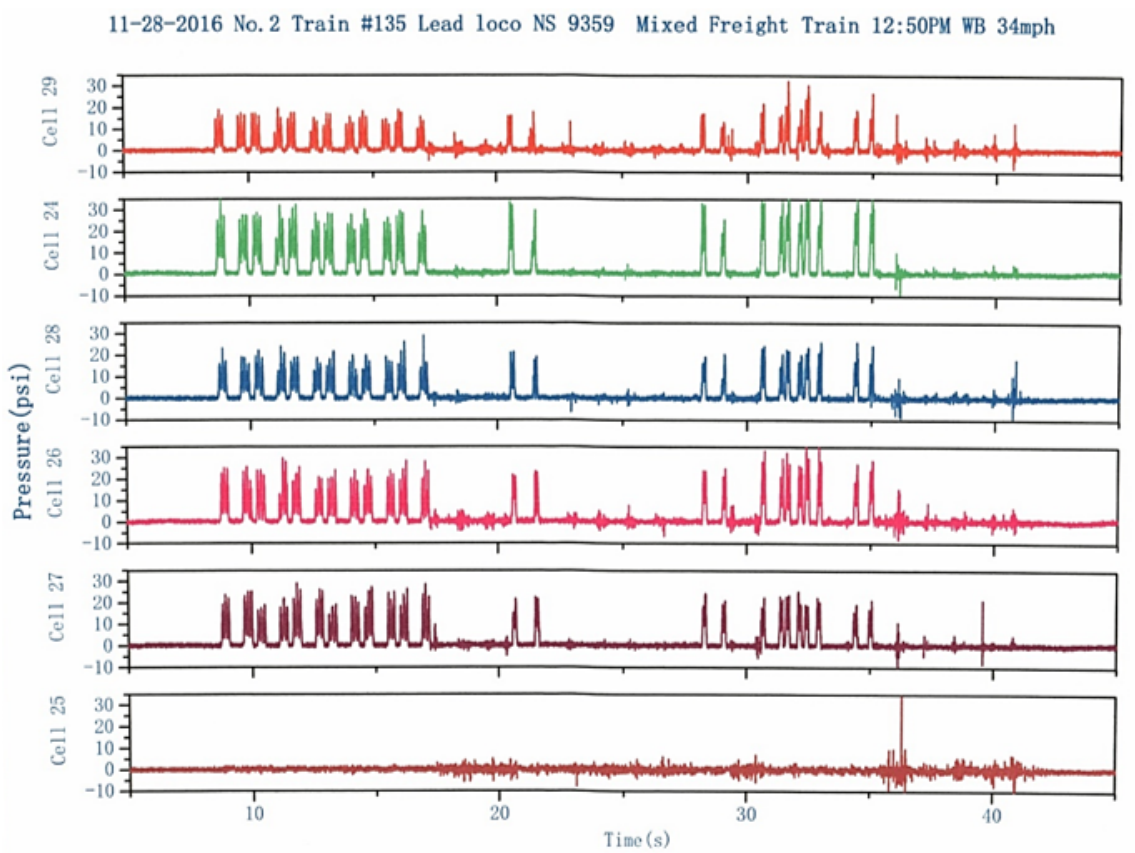


Figure 4.3.1. Pressure traces for a typical mixed freight train. The 12 peaks on the left represent the tie/ballast pressures recorded during the passage of the six locomotives, the remaining peaks represent six loaded freight cars. The upper five traces are for cells located under the rail, the bottom one is for a cell located in the center of the track.

The pressures were lower for the first two series of tests due to the ballast compaction being disturbed during insertion of the five instrumented ties. The instrumented ties "bridged over" the inadequately consolidated ballast. The pressures averaged just 20 psi (140 kPa), excluding the September 26 and October 12 series of tests.

Figure 4.3.3 graphically presents the average pressure data in Table 2, along with the range of pressure measurements, excluding data for the center-of-tie pressure cell.

Figure 4.3.4 summarizes the average pressure readings over time for the cell installed in the tie center. The pressures remained very low for the initial two months of traffic. As the tonnage accumulated during the seven-month period, pressures at the tie center increased to values near those recorded under the rail seat. The initial low pressures appear related to the lack of initial compaction/tamping of ballast under the tie middle third. Ballast is not in firm contact with the tie bottom. However, as the ballast compacts with accumulating tonnage, the tie settles and more load is transferred in the center third. Thus, the tie center cell records higher pressure reading.

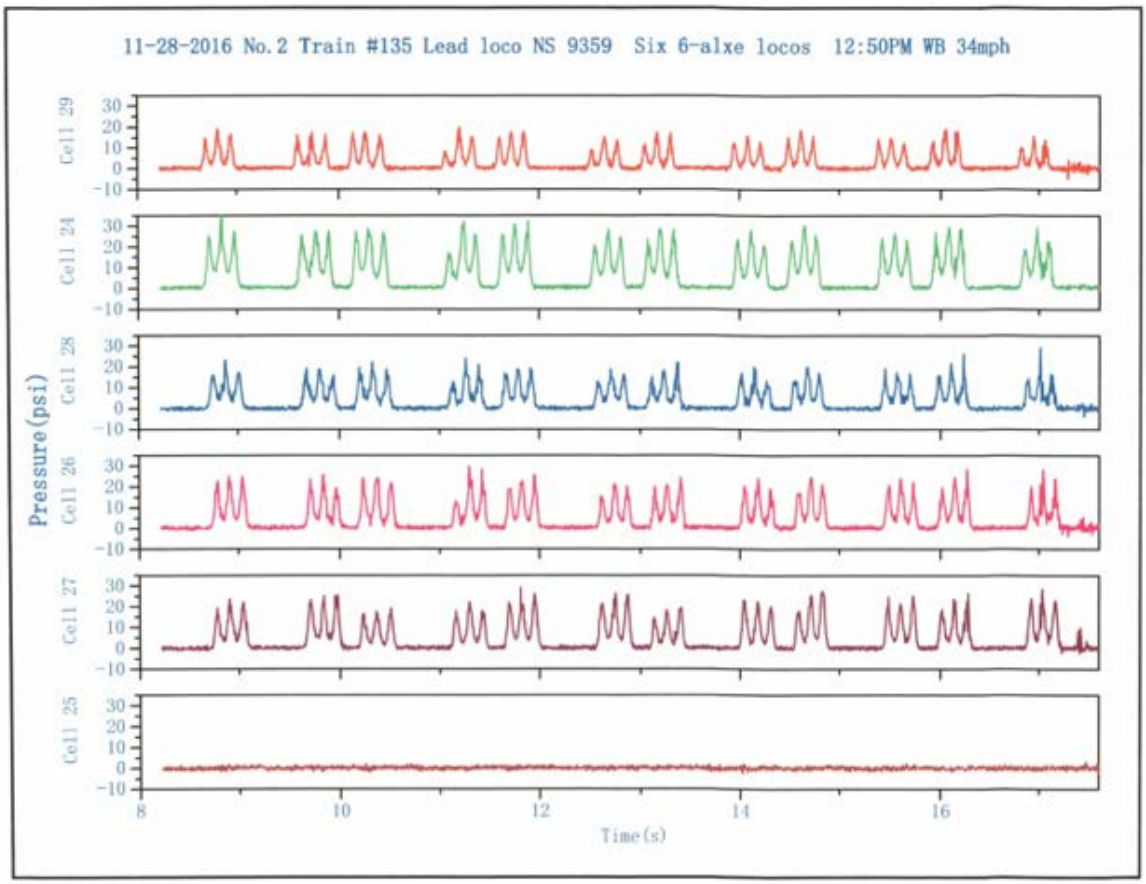


Figure 4.3.2. Expanded time scale for the six locomotives shown in Figure 4.3.1.

SECTION 5 CONCLUDING REMARKS

A group of six timber ties containing granular material pressure cells imbedded within recesses in the undersurface of the ties were successfully installed on an NS mainline track at Mascot, TN. A series of nine trackbed tie/ballast interfacial pressure measurements were taken of typical revenue trains over a seven-month period.

Ballast in the vicinity of the inserted instrumented recessed ties was disturbed (loosened) much less during the installation of the ties than previous attempts to excavate under existing solid ties to provide space for the cells positioned under the ties.

Imbedding the active area of the cells, transducer housing, and instrument cable within the recesses in the underside of the routed ties leaves the crib areas between the ties void of the cell instrumentation so that the instrumented ties can be adequately tamped to consolidate/compact the partially disturbed ballast.

Table 4.3.1. Average rail seat cell pressure, locomotives, by cell and test date.

Cell/Date	*29*	*24*	*28*	*26*	*27*	**Average**
9/26 [1]	**21.14**	**23.20**	**9.21**	**22.72**	**12.30**	17.71
10/12 [2]	**6.62**	**19.32**	**6.23**	**12.81**	**5.97**	10.19
10/26	**12.39**	**26.07**	**13.39**	**28.45**	**19.93**	20.05
11/7 [2]	**15.08**	**29.25**	**15.59**	**25.30**	**17.40**	20.52
11/28	**15.54**	**27.53**	**20.31**	**24.63**	**22.89**	22.18
12/15 [3]	**9.26**	**26.94**	**14.33**	**21.10**	**18.05**	17.94
4/13	**15.10**	**23.20**	**15.40**	**23.20**	**24.70**	20.32
4/27	**19.30**	**29.70**	**15.70**	**21.30**	**22.00**	21.60
4/28	**15.30**	**24.00**	**12.30**	**19.00**	**19.00**	17.92
Average	**14.41**	**25.47**	**13.61**	**22.06**	**18.03**	**18.71** [4]

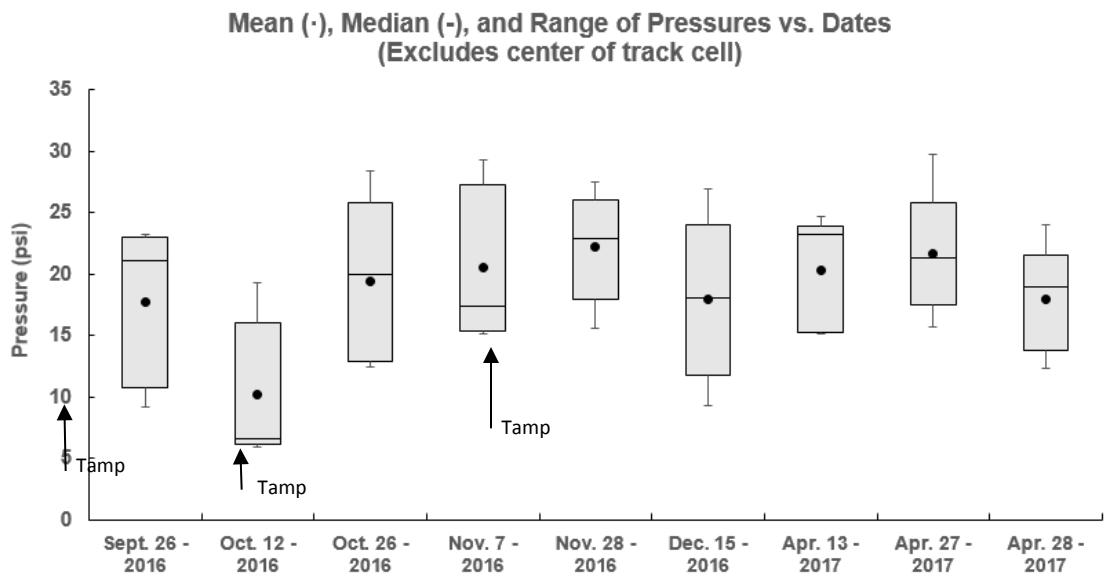
[1] Single tamping performed on instrumented ties
[2] Double tamping performed on instrumented and approach ties
[3] 12/15 data – Very cold temperatures
[4] Average is 20.08 psi excluding the 9/26 and 10/12 test series

Initial testing revealed that the properties of the track and pressure distribution within the support are highly dependent on the relative consolidation/denseness of the ballast. Initial pressure measurements were considered marginally representative of typical pressure distributions for a well-consolidated, ballast supported trackbed.

It is highly desirable to thoroughly tamp approach (undisturbed) existing ties in addition to instrumented ties to homogenize the compaction of the ballast in the vicinity of the ties.

Within cell pressure variations, for repeated train passages, are less variable than between cell variations for the same trains.

Imbedding the cells within the ties and securing the cells to the ties negates the cells from settling in the ballast over time to develop gaps and “bridging”, however the ballast must be adequately and uniformly tamped to realize this advantage.



Note: Initial tamping performed on 9/26. Follow-up tamping, including approaches performed on 10/12 & 11/28.

Figure 4.3.3. Graphical representation of the average pressures from Table 2 and the range in values.

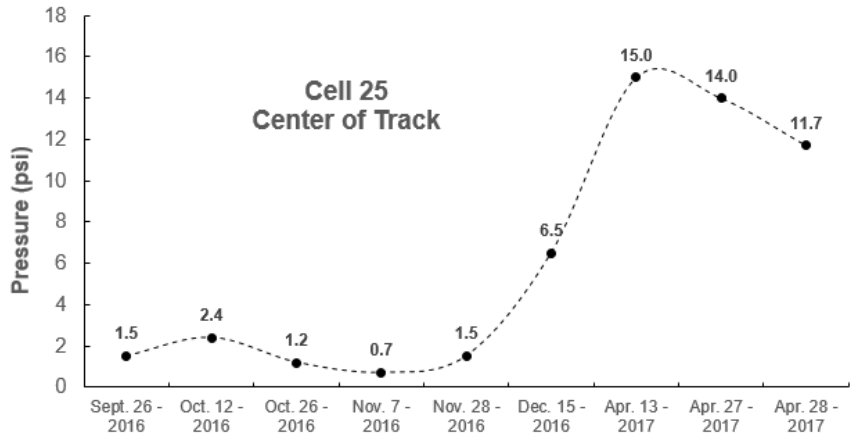


Figure 4.3.4. Average pressure readings for the cell installed in the center of the track for the nine test dates.

Disregarding the initial two series of measurements, during which the ballast appeared not to be adequately and uniformly compacted, the average tie/ballast interfacial pressure under the rail seat for six-axle locomotives is 20 psi (140 kPa). The data is very consistent, with the maximum to minimum range by date averaging 18 to 22 psi (125 to 150 kPa) during the measurements for over twenty trains during the six-month period.

The measured pressures are considerably lower than typically assumed for a high-tonnage ballasted timber tie track.

Pressures at the tie/ballast interface in the center of the track are initially very low. This is due to the center of the track not being routinely tamped during the installation of ties and surfacing track. However, with the passage of trains the track settles and the ballast in the center of the track readily contacts the ties providing the media for pressure transferal from the tie to the ballast.

The ballast in the vicinity of the instrumented and approach ties should be uniformly consolidated/tamped to achieve equal vertical support for the ties assuring an equalized track modulus throughout the test area.

It is desirable for the test area to accumulate several months of normal train traffic and tonnage to further homogenize the trackbed support prior to drawing specific conclusions relative to the results of a testing program.

SECTION 6 ACKNOWLEDGMENTS

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