INVESTIGATION OF THE INFLUENCE OF TRACK MAINTENANCE ON THE LATERAL RESISTANCE OF CONCRETE TIE TRACK

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ABSTRACT

Adequate lateral resistance is required to provide the stable track structure necessary for safe rail operations on passenger and freight railroad track. Insufficient lateral resistance coupled with a large thermal compression force in the rail from high rail temperature could buckle the track structure. Railroads typically employ mechanical stabilization, slow orders, or both following maintenance operations that disturb the ballast section such as surfacing and alignment of track. The objective of the test reported in this paper was to improve the understanding of lateral resistance variations on concrete tie track due to surfacing and subsequent stabilization/compaction. The paper begins with a summary of the factors influencing track stability, briefly describes the maintenance procedures, describes the testing conducted using the single tie push test, and presents the results. The test was conducted to evaluate the changes in lateral resistance from the trafficked, well-consolidated track structure prior to surfacing and alignment through the laterally weak track structure after surfacing and then to evaluate the influence of stabilization on the lateral resistance of the track structure. The results of the test indicate that surfacing significantly reduces the lateral stability of the track to a potentially critical level. Mechanical stabilization following surfacing provided a significant increase in lateral stability in all sections tested.

INTRODUCTION

Track buckling became a critical track safety concern with the installation of continuous welded rail on many miles of mainline track in high speed and heavy tonnage corridors since the 1960's. Because of this concern, an investigation was conducted to improve the understanding of the influence of maintenance practices on track buckling potential and to ensure maintenance practices provide an adequate margin of safety against track buckling.

Railroad maintenance practices that help mitigate the development of buckling prone conditions include rail laying, welding, and repair practices that help to maintain a high rail neutral temperature (the temperature at which the net longitudinal force in the rail is zero). Track stabilization following ballast disturbance such as surfacing or ballast renewal helps to ensure track stability against buckling. Railroads typically employ various means of track stabilization to compact and stiffen the ballast bed to ensure that the track is stable.

Lateral resistance is defined as the resistance to lateral movement offered to the rail/tie structure by the ballast. Investigations of lateral resistance were previously conducted on concrete tie track to assess the influence of current maintenance practices. The first of these investigations was conducted near Foxboro, Massachusetts in 1998 to evaluate the influence of curve realignment (including tamping, destressing, and dynamic stabilization) on the lateral track stability [1]. With this test in mind, the objective of the present investigation was to improve the understanding of lateral resistance variations on concrete tie track due to surfacing and subsequent stabilization/compaction. To accomplish this objective, lateral resistance and rail strain (to evaluate changes in rail neutral temperature) were measured during each stage of a track surfacing operation (both before and after tamping), followed by measurements either after stabilization or after operation of a train (electric locomotive and 3 passenger cars) 12 times over the maintained zone, creating approximately 3360 gross tons of traffic operating between 5 and 20 mph over the site. The lateral track resistance was measured using the Single Tie Push Test (STPT) technique, which records the load as the tie moves laterally. This paper presents some basic concepts of track buckling and describes the results of the testing conducted to evaluate lateral resistance variations due to maintenance.

FUNDAMENTALS OF TRACK BUCKLING

Railway track is subject to vertical, lateral, and longitudinal forces from the environment, traffic, and maintenance, which the track structure must safely resist. When the longitudinal rail force is not adequately constrained by the lateral resistance of the track, a track buckle can occur. The main factors influencing track buckling are:

- the rail longitudinal force (neutral temperature),
- track lateral resistance,
- the magnitude of dynamic uplift occurring between the trucks of a rail vehicle, and
- the magnitude of track geometry lateral alignment deviations.

Longitudinal rail force is the driving factor for track buckling. When ambient temperature is high, rail temperature rises, sometimes 17°C (about 30°F) more than ambient temperature, and the thermal expansion of the rail is constrained, causing a large compressive force in the rail. The large compressive force can cause the track to buckle in the lateral plane in various mode shapes and amplitudes. Curves, especially in the presence of initial lateral alignment defects, tend to be more vulnerable than tangent track [2].

The lateral resistance can be divided into three components: tie bottom friction, tie side friction, and tie end or shoulder restraint. All three vary with tie material, ballast type, ballast gradation, and strength, which is partly a function of ballast compaction. The bottom friction component is most influenced by tie type, weight, and vertical load, which affects the friction developed at the tie bottom-ballast interface. Side friction is most influenced by crib content due to interlocking of the ballast and friction of the ballast against the side of the tie. End restraint is mostly dependent upon the shoulder geometry since the shoulder ballast resists tie movement mainly through ballast shearing resistance (i.e., an increase in shoulder width generally results in an increase in shoulder restraint). Track maintenance such as ballast cleaning, tamping for surface/alignment, and subsequent compaction of the ballast layer under traffic or using mechanical stabilization influences the bottom and side restraint by changing the ballast characteristics [3].

Dynamic rail uplift, the uplift between two trucks of a car also influences track buckling behavior. In the uplift zone, in extreme cases, the tie bottom can lose contact with the ballast, reducing or eliminating that component of lateral resistance to buckling. The applied vehicle loading, vehicle dimensions, track weight, and track vertical modulus (stiffness of track support) define the magnitude and extent of dynamic uplift.

Another factor contributing to buckling is track alignment. Track alignment deviations are a concern for track buckling since any deviation from straight reduces the load needed to induce buckling. In addition, alignment deviations have been shown to grow under thermal load and vehicle passage (i.e. the lateral load from the vehicle traversing the misalignment can increase its size under multiple passes), which can cause the track to suddenly snap into a buckled configuration when the misalignment amplitudes and thermal loads are high.

MAINTENANCE PROCEDURES

During this test, lateral resistance was measured before and after track surfacing maintenance conducted on the Northeast Corridor (NEC). During track surfacing, the track (rails and ties) was lifted approximately 0.4 in. (10 mm) to the desired profile and alignment with ballast added as needed to fill the cribs. A tamper similar to the one used during the test is shown in Figure 1.

Tamping is a necessary maintenance procedure used to restore track surface and alignment. One undesired side effect of the tamping process is the ballast being disturbed and loosened, resulting in reduced lateral stability. The vibration of the tamper tines combined with the squeezing action to compress the ballast under the tie [4] results in completely disturbed ballast (and ballast breakdown) in the tamped zone, which is directly below the rail and under the tie. The disturbed ballast can lead to track vertical settlement and lateral alignment defects. To recompact the ballast after tamping, mechanical stabilization is often used. A track stabilizer, shown in Figure 2, provides a downward load combined with horizontal vibration that results in ballast compaction (mainly through particle rearrangement), increasing lateral resistance.

TESTING

The test was conducted using the Single Tie Push Test (STPT) to measure the variation in lateral resistance during a common track maintenance surfacing operation. Lateral resistance was measured prior to surfacing, after surfacing/before stabilization, and after stabilization. Prior to each STPT, the track and tie condition (particularly track shoulder and crib ballast condition and concrete tie condition or breakage) were noted and the test setup was double checked to help ensure good results. Immediately following each STPT, the peak lateral resistance was estimated and tabulated. Typically after a series of 10 tests, the mean, range, and standard deviation were calculated to evaluate whether additional tests were required or not. The goal of this analysis was to ensure that the standard deviation did not exceed one-half the range of the values.

Track and Tie Conditions

The test was conducted in New Carrollton, MD on approximately 610 m (2000 ft) of the Northeast Corridor (NEC), starting at Milepost 128. The test site consisted of a relatively uniform, tangent track section. The test site was divided into four test zones of 150 ties (610 mm (24 in.) tie spacing) with a 50 tie buffer zone between each test zone, as shown in Figure 3A. Each of the 150 tie test zones was divided into six 25 tie sections.

The three track right-of-way is tangent track with a slight grade change/vertical curve through the site. All tracks have Rocla concrete ties spaced 610 mm (24 in.) center to center and track 1, the location of the test, has 140 RE rail fastened with the Pandrol Fastclip system. Track 1 carries approximately 13 MGT of freight traffic and tracks 2 and 3 carry approximately 35 MGT of mixed high-speed passenger and freight traffic. Track 1 is maintained to FRA track class 4 standards and Tracks 2 and 3 are maintained to FRA track class 8 standards. All three tracks are typical of the track structure and conditions along the Northeast Corridor (NEC).

The track shoulder along the site varies between 0.6 and 1.5 m (2 and 5 ft) wide with a gradual variation from one end of the site to the other. The shape of the shoulder is not typical in that the ballast extends level with ties for approximately 0.3 to 0.5 m (12 to 18 in.) and then slopes down slightly to another point where the ballast drops off sharply. These two distinct break points in the track shoulder were measured during the test, as depicted in Figure 4.

Test Setup and Equipment

The lateral resistance was measured using the STPT. The test involves pushing an unfastened tie laterally in the ballast bed and measuring the load as a function of deflection. The resulting peak values on the load-deflection curves are used to define the peak lateral resistance of the track. Lateral resistance can typically range from 13 kN to 22 kN (3000 to 5000 lb) for well-compacted concrete tie track, and 6.2 to 10.7 kN (1400 to 2400 lb) for track after surfacing when the ballast is loose.

The STPT device consists of a hydraulic control unit with a pump to develop the hydraulic pressure required to move the tie in a load-controlled test. A hydraulic cylinder attachment frame is connected to the rail at the location of the test tie. Two reaction blocks are attached to the adjacent ties. A hydraulic cylinder is attached to the frame at the test tie and the cylinder reacts against the fastener base on the concrete test tie. The load is measured using a calibrated pressure transducer in the hydraulic pump. A string potentiometer is attached to the opposite rail to monitor the tie displacement. Figure 5 depicts the test setup showing the load frame and hydraulic cylinder attached to the test tie and the string potentiometer attached to the opposite rail. The signals from the string potentiometer and the load cell were connected to an analog plotter, which plotted load as a function of displacement for each test. A 6 KW generator was used to power the hydraulic pump and the data acquisition system.

Test Procedures

Test equipment installation starts with removal of rail fasteners from both rails for 11 ties, the center of which becomes the test tie, and jacking up both rails so that the test tie can move freely. As a safeguard to prevent lateral movement of the field rail, since that rail is used as a reaction against the applied load, two reaction blocks are installed on each tie adjacent to the test tie. The cylinder attachment frame and the hydraulic cylinder are installed between the reaction frame and the field rail fastener base at the test tie. The string potentiometer is then installed on the opposite rail and the base is placed on the test tie. The plotter is then attached to the string potentiometer and pressure transducer and the plotter calibration is checked.

The test starts with measurement of the shoulder width; in this case two break points in the shoulder shape are measured. The hydraulic pump is then started and pressurized hydraulic fluid is built up in the accumulator. With the pump running, the pressure from the accumulator is applied to the cylinder on the test tie with a switch on the hydraulic control unit. The tie is then pushed laterally until a clear peak was measured, generally less than 25 mm (1 in.) displacement. The adjacent ties with reaction blocks are observed during testing to note any displacement. Following the test, the test tie is pushed back in place by reversing the STPT device.

The load-deflection behavior of the tie was recorded on the analog plotter, which facilitated observation of the peak load and the associated deflection. The peak loads were then tabulated. All references to lateral resistance values throughout the paper indicate the peak lateral resistance of a single tie.

Test Operations

The STPT testing was conducted in four stages on four sites: (a) pre-surfacing on all 4 sites, (b) post surfacing/pre-stabilization on all 4 sites, (c) post-stabilization conducted at three sites, and (d) post-traffic at 1 site. The STPTs conducted during the pre-surfacing stage captured the lateral resistance of the track in its pre-test consolidated state. The STPTs conducted after surfacing measured the lateral resistance of the track after the track was tamped and the ballast was loosened, reducing the lateral resistance. The STPTs conducted during the post-stabilization stage captured the lateral resistance of the track following one pass of the dynamic track stabilizer (DTS). On one test segment, STPTs were conducted to measure the lateral resistance after 12 train passes over the surfaced track (no dynamic track stabilization) to evaluate the train induced consolidation influence.

The STPTs were conducted in four test sites so that variations in the maintenance procedures could be evaluated. The difference in the maintenance of the four sites was that in site 1 the dynamic track stabilizer was operated at 1 km/hr (0.7 mph), in site 2 the stabilizer was operated at 2 km/hr (1.5 mph), in site 3 the stabilizer was operated at 3 km/hr (2.0 mph), and in site 4, twelve train passes provided the stabilization of the track. The trainset consisted of an AEM-7 locomotive, two bi-level passenger cars, and a single level passenger car. The 12 passes of this trainset provided a traffic volume of approximately 3360 gross tons operating between 5 and 20 mph.

Each test site was divided into six sections of 25 ties (15 m), each with five test ties. Three of the sections (the second, fourth, and sixth), were used to measure the lateral resistance of the track before and after surfacing (pre-surfacing and pre-stabilization). The other three sections (the first, third, and fifth) were used to measure the lateral resistance of the track following stabilization using either the dynamic track stabilizer or traffic. Following this layout, there were a maximum of 15 pre-surfacing, 15 post-surfacing, and 15 post-stabilization measurements in each test site.

Rail Neutral Temperature Variation

Strain gages were installed on each rail in between each test site to monitor the changes in rail strain due to maintenance. The strain measurements were used to estimate the changes in the rail neutral temperature. Research has shown that rail movement (longitudinal creep and curve breathing) is a large contributor to neutral temperature change [5]. The intent of this measurement was to determine any rail neutral temperature change due to the track surfacing (lifting/lining) operation or stabilization, whether from the stabilizer or passing traffic. The strain gages were installed between the test sites (buffer zones) to limit the effect of the STPTs on the results. The buffer zones between test sites were subject to the same maintenance as the test sites, but no STPTs were conducted.

RESULTS

STPT Results

The STPT results will be discussed based on the test stage: pre-surfacing, post-surfacing/pre-stabilization, post-stabilization, and post-traffic.

Pre-Surfacing

The pre-surfacing STPT measurements were made to characterize the condition of the track in operational condition. Common characteristics of the pre-surfacing tests are a steep initial slope, distinct peak, and a post-peak decrease to a stable lateral resistance value approximately constant for large deflections, shown in an example load-deflection plot in Figure 6A, where the peak values are typically used to define track resistance. The results from Table 1 indicate that the overall average lateral resistance was 15.1 kN (3393 lbs) for 37 tests over the four test zones with a standard deviation of approximately 9.7% of the average.

Post Surfacing/Pre-Stabilization

The STPTs conducted during the pre-stabilization stage of the test characterize the stability of the track immediately after tamping, while the ballast is loose and the track has the least lateral resistance. Common characteristics of the pre-stabilization STPTs, depicted in Figure 6B, are a gradual increase to a maximum constant value. The results indicate that the overall average lateral resistance was 8.6 kN (1926 lbs) for 42 tests with a standard deviation of approximately 7.1% of the average. This represents a decrease in lateral resistance of approximately 43% from the pre-surfacing condition. The data is more uniform than the pre-surfacing stage as indicated by the reduced standard deviation.

Post-Stabilization

The STPTs conducted in the post-stabilization stage of the test characterized the stability of the track after surfacing maintenance followed by the dynamic track stabilizer, just before the track would typically be subject to revenue traffic. Common characteristics of the post-stabilization STPTs are a steeper initial increase than the pre-stabilization stage to a peak value as shown in Figure 6C. Stabilization produced an initial peak value similar to the trend of the data from the pre-surfacing stage, but the peak value was significantly lower and less well defined than the pre-surfacing stage peak. The increase in the initial slope (although less discernable) of the load-deflection curve and the observance of the peak is consistent with behavior associated with the more dense, stronger and stiffer ballast. The results indicate that the overall average lateral resistance was 11.2 kN (2520 lbs) for 35 tests with a standard deviation of 9.5% of the average. This represents an average increase in lateral resistance of approximately 31% over the post-surfacing condition.

Post-Traffic

The STPTs conducted in the post-traffic stage of the test characterized the stability of the track after surfacing maintenance followed by 12 train passes to stabilize the track. Twelve train passes or 12 passes with a work train is an Amtrak requirement in lieu of dynamic track stabilization. An observed characteristic of the post-traffic STPTs is the steeper initial increase than the pre-stabilization stage to an approximately constant lateral resistance to the full deflection tested, shown in Figure 6D. The results indicate that the overall average peak lateral resistance was 9.6 kN (2150 lbs) for 10 tests with a standard deviation of 7.6% of the average. This represents an increase in lateral resistance of approximately 13% over the post-surfacing condition.

Rail Strain Results

The rail strain was measured at six (3 per rail) locations as shown in Figure 7 using standard four-arm strain gauge circuits. The strain measurements were used to determine the rail neutral temperature variation during the test in accordance with the strain gage/rail force measurement equations detailed in [6].

The rail neutral temperature variations observed during the maintenance performed at the site are indicated on Figure 7. The change in neutral temperature varied from –2.8°C to 1.7°F (–5°F to +3°F), indicating a relatively small effect of surfacing and dynamic stabilization induced rail kinematics on the neutral temperature condition. It should be noted that larger changes may be possible for lifts greater than the 10 mm lift performed for this surfacing operation. Since rail neutral temperature variations contribute to track buckling instability, the rail neutral temperature change associated with various maintenance operations and lift magnitudes should be investigated further.

Summary of Results

Table 2 presents a summary of the average peak lateral resistance variations observed during the test. The highest average peak lateral resistance values were measured during the pre-surfacing test stage. The lowest average peak lateral resistance values were measured after surfacing, as expected, when the ballast was loosened, resulting in an average reduction of between 37% and 48% of the pre-surfacing resistance.

The average post-stabilization lateral resistance values increased over the pre-stabilization condition by between 24% and 37%, with no significant trend with the operating speed variations of 1, 2, and 3 km/hr (0.7, 1.5, and 2.0 mph). The slowest observed operating speed, 1 km/hr, provided the highest average peak lateral resistance value of 11.6 kN (2611 lb), but the highest speed, 3 km/hr, provided the largest lateral resistance increase of 3.1 kN (690 lbs or 37%). Thus, the effect of speed on lateral resistance was not evident in the data and was likely masked by track condition variations such as the shoulder width variation depicted in Figure 4B.

The average post-traffic lateral resistance was 9.6 kN (2150 lbs), or a slight increase over the pre-stabilization average lateral stability. The small increase in lateral resistance was most likely due to the light train used to stabilize the track during this test stage. The lateral resistance could possibly be increased by using additional accumulated traffic tonnage by implementing either a heavier train or more train passes.

SUMMARY AND CONCLUSIONS

Tests were conducted to evaluate the variation of concrete tie track lateral resistance and rail neutral temperature change during routine track surfacing maintenance on the Northeast Corridor. The testing indicated that the lateral track resistance was reduced by up to 48% of the pre-surfacing condition following surfacing and that a 21% to 37% increase in lateral resistance was achieved by mechanized stabilization equipment.

The average pre-surfacing lateral resistance ranged from 13.5 to 16.1 kN (3030 to 3610 lbs). The variation in the data is indicative of the variability of the pre-surfacing peak lateral resistance values that had a standard deviation of 1.5 kN (330 lbs). The average post surfacing (pre-stabilization) lateral resistance ranged from 8.4 to 8.9 kN (1885 to 2000 lbs), a decrease of between 37 and 48% of the pre-surfacing values. The relatively small range in the data is an indicator of the uniformity of the pre-stabilization peak lateral resistance data that had a standard deviation of approximately 0.6 kN (136 lbs). Results from the previous lateral strength tests on an approximately 2° curve in Foxboro [1] showed almost identical average lateral resistance values for the pre-surfacing and the post-surfacing conditions, but with fewer tests conducted. The post-stabilization lateral resistance data are most appropriately characterized by the average lateral resistance, which ranged from 10.5 to 11.6 kN (2355 to 2611 lbs).

The stabilization was performed using a track stabilizer operating at speeds of 1, 2, and 3 km/hr (0.7, 1.5, and 2.0 mph), which may account for some of the variability of the data although no clear trend was identified. The highest average lateral resistance measured during the post-stabilization stage was found where the stabilizer operated at the slowest speed, but the maximum net increase was obtained in fastest stabilization speed zone. Hence within the stabilizer working speeds observed, the influence of the operating speeds on lateral resistance was not evident and was possibly masked by track condition variations along the site. The average post-traffic (12 passes with locomotive and 3 passenger cars creating approximately 3360 gross tons of traffic operating between 5 and 20 mph) peak lateral resistance recovery was 9.6 kN (2150 lbs), which does not appear to improve track resistance appreciably.

The rail neutral temperature change during maintenance and stabilization operations was determined from measurements of rail strain between test sites where maintenance was performed but no STPTs were conducted, so that measured rail strains were not influenced by the testing. The maximum variation in rail neutral temperature ranged from approximately –3° C to +2° C (–5° F to +3° F) during the entire test, a relatively small change. However, it should be noted that larger changes might be possible for track surfacing lifts greater than 10mm.

The results obtained in these tests were used to conduct a buckling safety assessment study for typical track conditions and parameters. This study identified temperature regimes under which the loss of stability could lead to buckling prone conditions [7].

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List of Tables

TABLE 1 Peak Lateral Resistance Test Results and Statistics

Test Stage	**Average**		**Standard Deviation (%)**	**Number of Tests**
	kN	**lbs**		
Pre-surfacing	15.1	3393	9.7	37
Post-surfacing	8.6	1926	7.1	42
Post-stabilization	11.2	2520	9.5	35
Post-traffic	9.6	2150	7.6	10

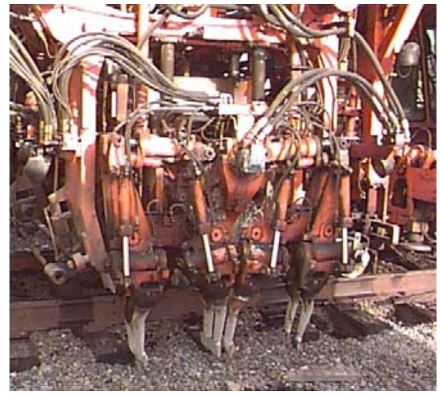
TABLE 2 Track Lateral Resistance Variation with Maintenance

Test Site	Stabilization Mechanism / Speed (km/hr)	Average peak lateral resistance							
		Pre-surfacing		Post-surfacing			Post-stabilization		
		kN	lbs	kN	lbs	kN reduction	kN	lbs	kN increase / % increase
1	DTS / 0.7	15.5	3483	8.9	2000	6.6	11.6	2611	2.7 / 31
2	DTS / 1.5	13.5	3030	8.5	1900	5.0	10.5	2355	2.0 / 24
3	DTS / 2	16.1	3610	8.4	1885	7.7	11.5	2575	3.1 / 37
4	Traffic / NA	15.4	3470	8.5	1905	7.0	9.6	2150	1.1 / 13

Note: DTS refers to the Dynamic Track Stabilizer.

List of Figures

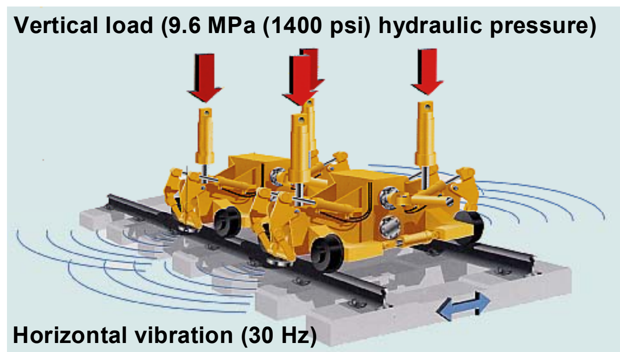
A) Track Tamper



B) Tamper Tines

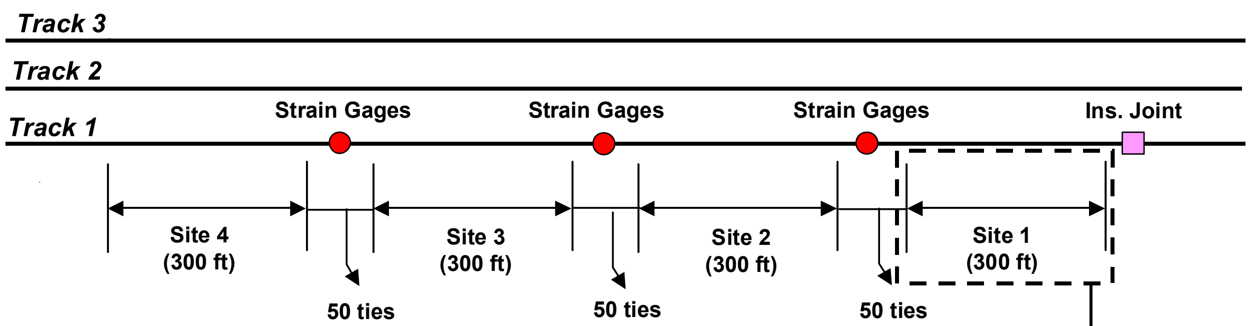
FIGURE 1 Two Tie Tamper

A) Track Stabilizer

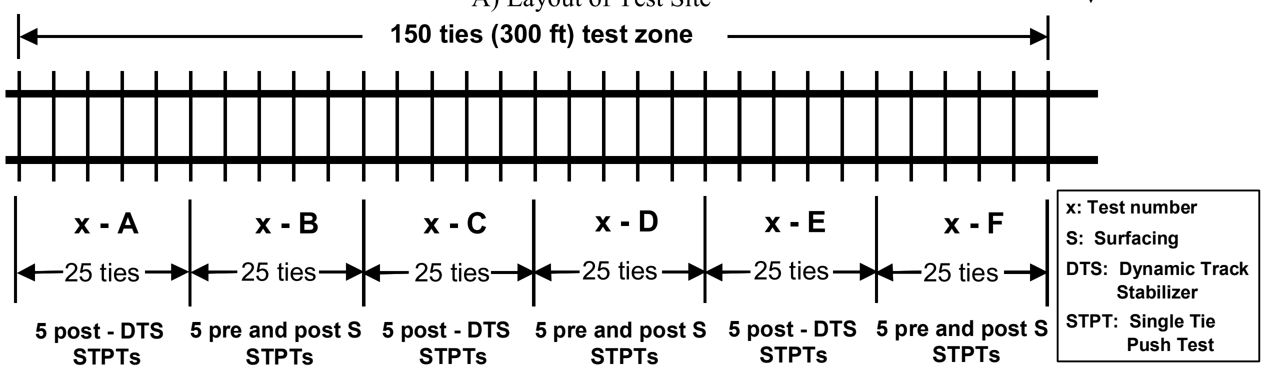


B) Stabilizer Apparatus

FIGURE 2 Dynamic Track Stabilization Equipment

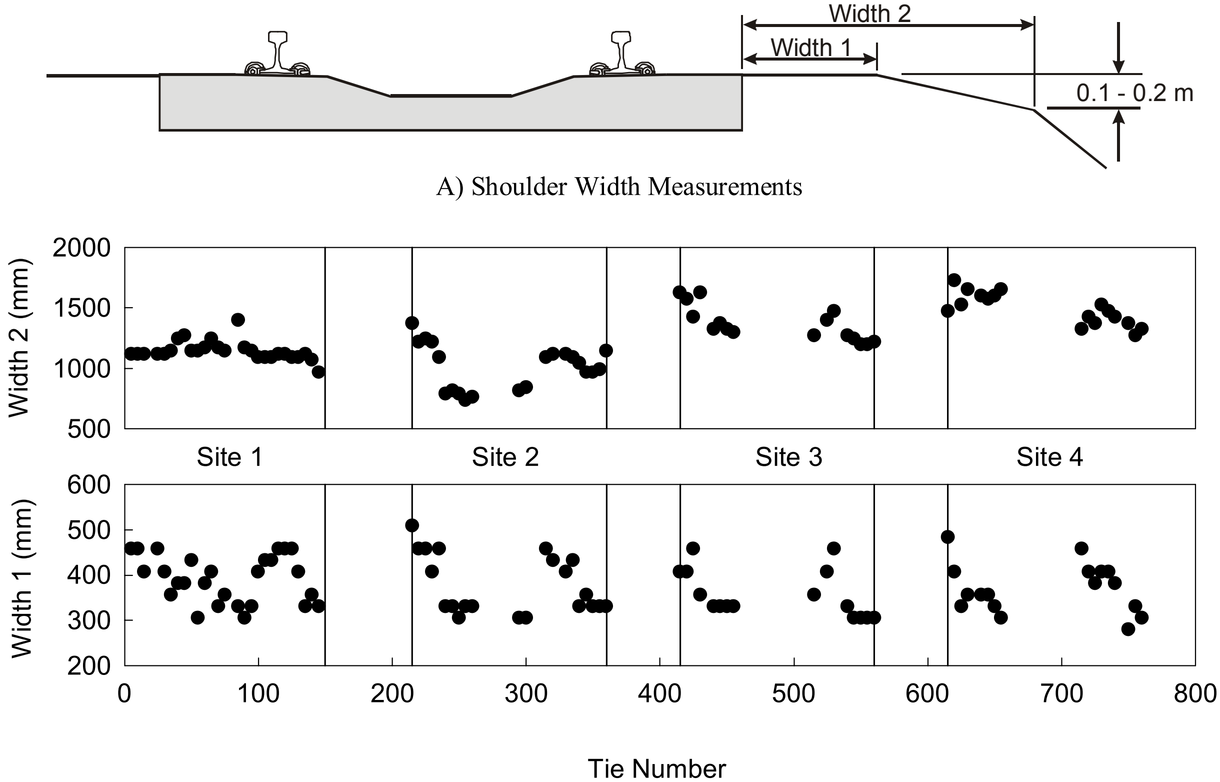


A) Layout of Test Site



B) Individual Test Zone Layout

FIGURE 3 Site Layout



B) Shoulder Width Variations

FIGURE 4 Track Shoulder Width Characteristics

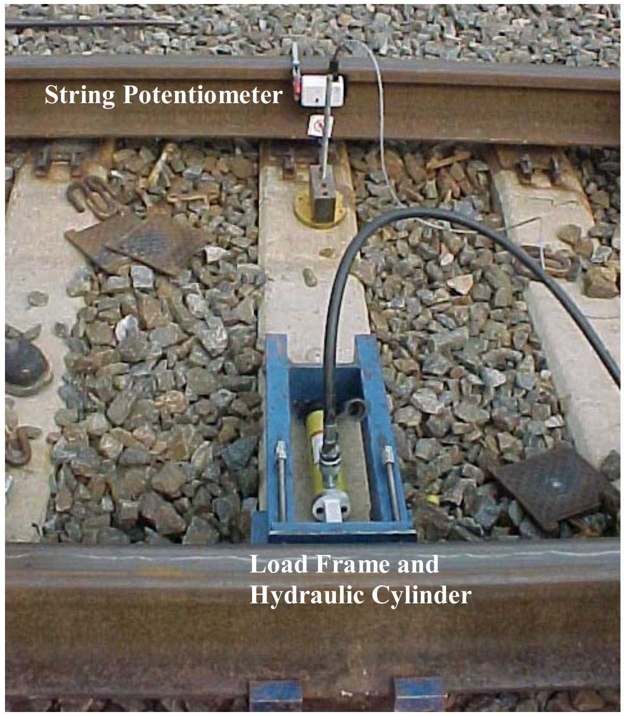
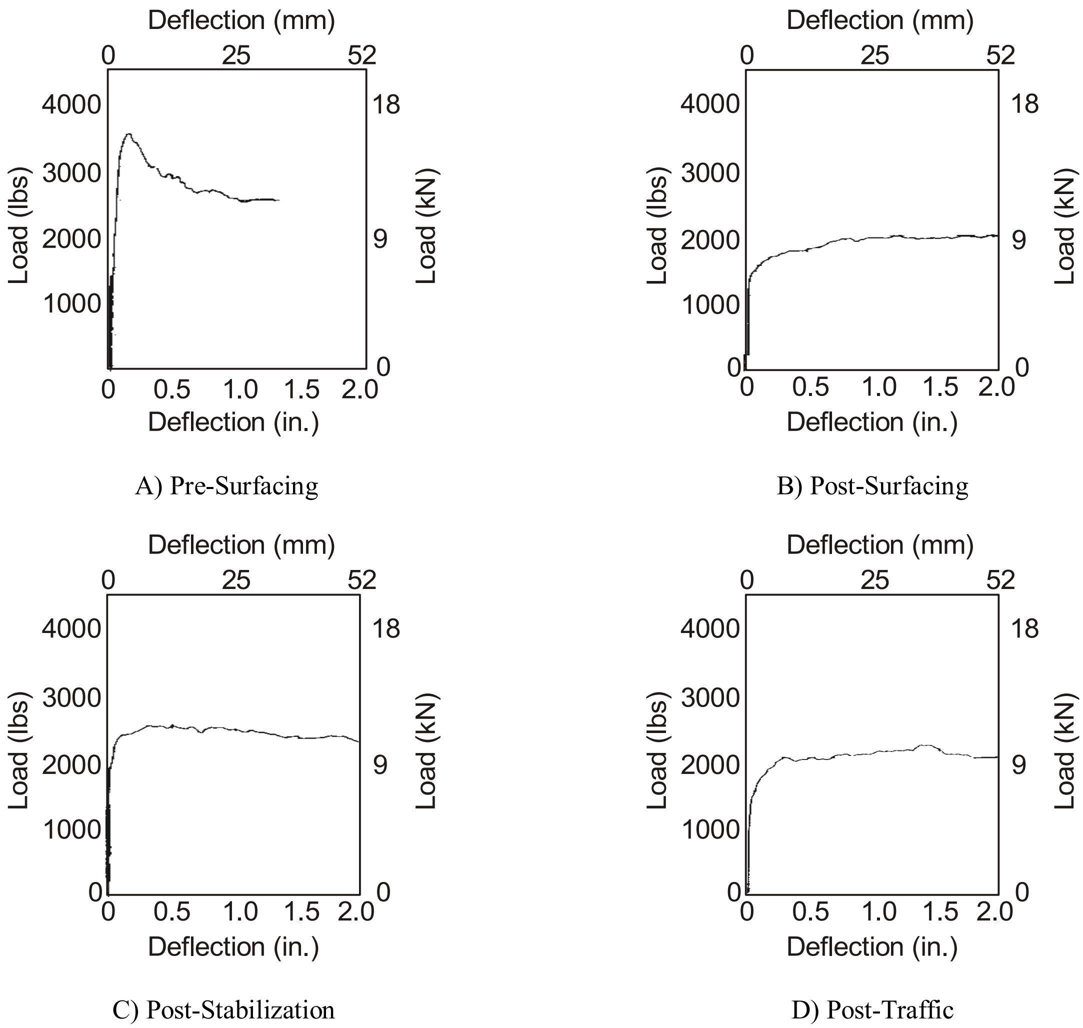


FIGURE 5 STPT Test Setup



A) Pre-Surfacing

B) Post-Surfacing

C) Post-Stabilization

D) Post-Traffic

FIGURE 6 Characteristics of Lateral Resistance Measurements

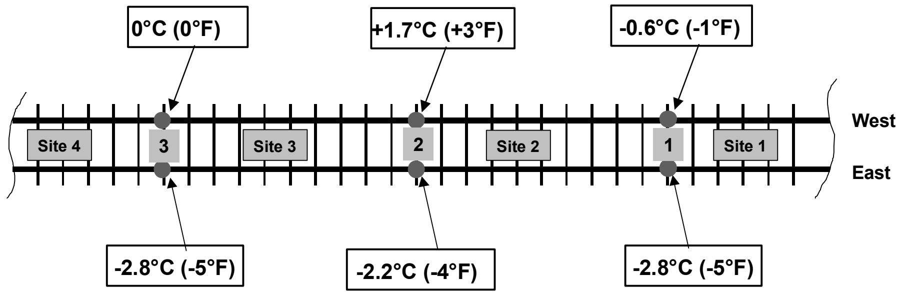


FIGURE 7 Observed Maximum Rail Neutral Temperature Variation