Laboratory Test Results of Heavy Axle Loads
On Concrete Slab Track for
Shared High-Speed Passenger and Freight Rail

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ABSTRACT

Slab track makes track safer and meets the needs of shared high-speed passenger rail (HSR) and freight rail by maintaining the strict tolerances required by HSR and reliably supporting the increasingly heavy loads of freight without the excessive maintenance of ballasted track.

Presented are the laboratory test results of a reinforced cast-in-place concrete slab track system subjected to static and repeated loads applied by hydraulic actuators to simulate vertical and lateral wheel loads of 315,000-lb freight cars. The direct fixation slab track (DFST) laboratory test section consists of a 12” thick, 10’-6” wide, 26’ long slab placed on an elastomeric pad that simulates subgrade conditions. Rail fasteners are anchored to the slab and support 136-lb/yd rails which are then loaded. The loading spectrum was modeled to induce the heavy axle loads, , in a pattern and loading similar to actual freight car loading observed on the high-tonnage loop test track at the Transportation Technology Center in Pueblo, Colorado. After over 3 million cycles and 130 million gross tons (MGT) applied in the laboratory, the data and observation show that the slab track system successfully accommodates the heavy axle freight rail loads while maintaining the required vertical and horizontal geometry.

Key Words: slab track, high-speed rail, shared corridor, direct fixation, concrete
INTRODUCTION

Slab track is a railroad track support system that uses a reinforced concrete slab pavement for support of railway track. The slab track is typically supported on a subbase over a prepared subgrade. The track rails are supported by either rail fasteners which are anchored to the slab (or an intermediate concrete block) or embedded directly into a trough cast within the slab. Slab track can be pre-cast, cast-in-place or slip-formed.

While slab track for high-speed rail (HSR) has been used for decades in Europe and Japan, its use in North America has been limited. Now, as alternative modes of public transportation become necessary and as federal funds for these projects become available, the need for a safe, reliable, durable, and economical track support system which can endure the heavy axle loads imparted by freight traffic while maintaining the stringent tolerances required for high-speed rail is essential.

Slab track makes track safer and meets the needs of shared high-speed passenger rail (HSR) and freight by maintaining the strict tolerances required by HSR and reliably supporting the increasingly heavy loads of freight without the excessive maintenance of ballasted track.

Presented are the laboratory test results of a continuously reinforced cast-in-place concrete slab track subjected to static and repeated loads to simulate vertical and lateral wheel loads of 315,000-lb freight cars. The slab track was constructed on an elastomeric pad that simulates subgrade conditions. The load spectrum was modeled to simulate actual heavy freight car loads measured on the high-tonnage loop test track at the Transportation Technology Center (TTC) in Pueblo, Colorado. After 3 million cycles and 130 million gross tons (MGT), there was no deterioration in the slab track and the required vertical and horizontal geometry was maintained.
Advantages of Slab Track

The use of concrete slab track reduces maintenance and prevents accidents because the slab track structure is much stronger and stiffer than ballasted track. Slab track has high lateral resistance which prevents buckling and reduces lateral movement at curves. Since buckling of the track is less of a concern, the rail can be laid at lower temperatures than rail for ballasted track. Installing rail at lower temperatures will prevent rail from pulling apart due to low temperatures during winter months. Another significant advantage is that the gage is held to the correct dimension because the concrete slab holds the rail fasteners very securely.

With the use of slab track, rail geometry is held within Federal Railroad Administration (FRA) and Amtrak limits even under heavy freight loads. Slab track spreads the axle loads to the soil subgrade uniformly and therefore the soil pressure is lower than in ballasted track. In addition, the slab track is able to span weak spots in the subgrade and the reduced deformations result in lower rail stresses which in turn result in longer rail life.

Slab track is impervious and therefore helps to keep water out of the subgrade directly below the concrete slab. It requires less maintenance than ballasted track. Reduced track maintenance cycles for slab track will greatly benefit train operations and reduce accidents involving track maintenance workmen.

Large quantities of slab track can be built within the cost target of 1.3 times the cost of ballasted track. In the U.S., the construction cost for Class 4 ballasted track is about $970,000/mile while the construction cost for Class 9 slab track is estimated to be $1,240,000/mile. The estimated annual maintenance costs of ballasted track on heavy tonnage routes, including train delays and reroutes, in the US are about
$50,000/mile not including the cost of tie replacement. The annual maintenance costs of slab track will likely be less than $10,000/mile. These figures result in a payback period of less than 8 years without consideration of the safety benefits of slab track.

Railroad Safety

In the *Railroad Safety Statistics Annual Report 2000* published by the Federal Railroad Administration, FRA reported that the total cost of damage from railroad accidents was $278 million and that the single largest cause, 40% of the total (or $111 million) resulted from accidents caused by track defects. The track defects causing the accidents included alignment irregularity, broken welds, fractures, and gage widening. Human error, equipment, signals and other problems caused the remainder of the accidents.

Track buckling is an alignment irregularity that is not uncommon. It is caused by large compressive forces due to thermal expansion of the rails combined with a track structure having weak lateral resistance. Every summer, US railroads have to fix thousands of buckles or “sun kinks”. In the winter, the railroads fix thousands of pull-aparts caused by tensile fractures as a result of low temperatures.

Slab Track is Not New

Concrete slab track has been tested and used in Japan and Germany for thirty years. Engineers in Japan have concluded that ballasted track is not adequate for their high-speed Shinkansen trains and have developed a well-engineered slab track system. The Canadian Pacific Railway, Long Island Railroad, and Amtrak have used slab track in tunnels, on bridges and on soil subgrade. Also, transit systems have used slab track extensively in streets shared with street traffic, in tunnels and on aerial structures. Examples of slab track use in Europe, North America, and Japan are shown in Table 1.
SLAB TRACK COOPERATIVE RESEARCH AND DEMONSTRATION PROGRAM

PCA has undertaken a research and demonstration project to substantiate that concrete slab track is an ideal track for shared freight and high speed passenger rail. PCA has submitted a proposal to the Federal Railroad Administration for joint funding of the program and are hopeful that FRA will provide the funds requested. Amtrak has committed funds providing Congress passes the High Speed Rail Investment Act. The R & D program includes development of a design methodology and recommended practice for slab track, laboratory and field tests, and a detail study of life cycle costs. Under the program, Construction Technology Laboratories, Inc. (CTL) subjected a full scale section of the slab track to 3 million cycles of a spectrum of forces caused by 39 ton axle loads.

**Slab Track Design Criteria**

To demonstrate that slab track will perform well for shared HSR and heavy axle load freight service in the U.S., slab track must be shown to have a life of 50 years or more and be capable of carrying freight cars with 39 ton axle loads, the heaviest loads in service today. Shared slab track must also accommodate high speed passenger trains at a maximum speed of 200 mph, without safety concerns and without the high maintenance cost of ballasted track.

Because of extensive experience with concrete pavements in the U.S., PCA selected a continuously reinforced concrete pavement (CRCP) for the initial slab track test. The design of the continuously reinforced concrete slab combines design methods for foundations on grade and for joint free highway pavements. The longitudinal reinforcement in the slab is designed for longitudinal bending moments and to keep shrinkage cracks very small and uniformly distributed. Transverse reinforcement in the slab is provided to resist transverse bending moments. The reinforcement is placed in top and bottom rebar mats.
Subgrade soil must have a minimum quality for the use of slab track. The subgrade soils properties for the test slab track design used soil properties equivalent to the subgrade soils at TTC. It is very important for the track designer to perform a thorough geotechnical investigation and design of soil remediation measures, if necessary, as is normal for good track design practice.

**Description of the Slab Track Test**

The slab track was constructed and tested in the structural laboratory of Construction Technology Laboratories, Inc. (CTL). The slab was constructed by CTL personnel using top-down construction methods to accurately position the fastener inserts in the concrete slab. Although other methods are employed in the construction of slab track, the top-down method was chosen because of its inherent low cost and ease of attaining the strict tolerances required for high speed rail track systems. The system was constructed in accordance with Amtrak Standard MW 100 for Class 9 Track for a maximum speed of 200 MPH. A summary of the construction tolerances is as follows:

- Track surface deviation at the mid-ordinate of a 62’ chord limited to 1/8”
- Deviation from zero cross level limited to 1/8”
- Deviation of horizontal alignment measured in a 62’ chord limited to 1/8”

The slab track test section, shown in Figure 1, consists of a full-scale reinforced concrete slab measuring 12” thick, 10’-6” wide, and 26’-0” long, and bearing on an elastomeric pad which in turn bears directly upon the laboratory floor. The laboratory strong floor is designed to resist high loads without significant displacement. The direct fixation fasteners are anchored to the slab by inserts which are cast-in-place with the slab. The fasteners, spaced at 2’-0”, support RE136 rail laid at a standard gage of 4’-8 ½” with a gage
tolerance of +1/16” and –3/32”. The rail is held to the fastener with Pandrol e-clips. The slab track laboratory specimen simulates an installation on mainline track.

The thickness of the concrete slab was set at 12” to provide space for the two mats of reinforcement and because 10” CRCP has demonstrated exceptional performance under very heavy truck traffic for over twenty years. The slab width was chosen in part to correspond to the recommendations of AREMA, Chapter 8, Part 27 and to keep the subgrade pressures at values less than 20 psi, thereby assuring exceptional performance even across small areas of poor soil. The 10’-6” width also eliminates the development of punch-out failures which are due to high edge loading and non-channelized vehicular loadings in pavements. While railroad applications always keep the train loads perfectly channelized, a narrower slab width could lead to an edge loading condition where higher concrete stresses and slab deflection are developed. The 26-foot slab length was determined by car geometry considerations to support the spacing of four freight car axles consisting of two end trucks with axle spacing of 6’-0” and an axle spacing of 7’-0” across the coupler between cars. The slab extends approximately 3’-0” at each end to run out the strains induced into the slab during testing. Two trucks were decided upon so that one is situated with the axle-loads directly over the fasteners to give maximum slab stresses while the other truck places the axles between fasteners to give maximum rail bending stresses. Fasteners were placed on 2-foot centers to correspond with spacing typically used in similar ballasted track applications in the US.

The concrete used in construction of the slab track test section was chosen for its simple mix design, availability, and ease of replication in all regions of the country. The concrete is a standard Illinois Department of Transportation mix, #D104 which is a 6-bag mix consisting of 560 lbs. of Portland cement, 150 lbs. of flyash, 964 lbs. of fine aggregate (FA-1), 1,987 lbs. of coarse aggregate (CA-11), 32 gallons of water, and water-reducing and an air-entraining admixtures in each cubic yard of concrete. Also specified
was a w/c ratio of 0.38, slump of 3-inches +/- 1 inch, air content between 4 and 7%, a maximum aggregate size of 1-inch, and an unconfined compressive strength of 5,000 psi at 28 days. The steel reinforcement was specified to be uncoated and have a yield stress of 60,000 psi.

The Acoustical Loadmaster direct fixation fasteners, supplied by Advanced Track Products, Inc., were chosen because of previous testing at the Battelle where they were tested to 450 million gross tons and experienced maximum loads simulating 39-ton axle loads. The actual fasteners supplied for the slab track tests were modified slightly to endure the extreme loads stipulated in the test protocol. Embedment anchors used were Richmond Rail Fastener Embed supplied by PTC Fastening, Inc. and were chosen for their successful installations in transit and rail projects across the country. RE136 rail have been standard for heavy haul freight lines and was therefore specified for use in the slab track test specimen. Pandrol clips were specified because of their successful use in numerous projects.

The elastomeric pad supporting the concrete slab was selected to simulate the soil conditions at the Transportation Technology Center (TTC) in Pueblo, Colorado. Different pad thicknesses were subjected to plate bearing tests in which pressure deflection relationships were measured. The relative spring constants of the material as shown in Figure 2 were compared to the subgrade properties at the TTC test site which are characterized by a tangent modulus of 10,000 to 20,000 psi. The tangent modulus measured at TTC was converted to a composite subgrade spring constant of 500 psi using the 1993 AASHTO Design Guide, and a 1-inch thick pad of 40 durometer rubber was selected to simulate the TTC subgrade in the laboratory.
Laboratory Tests

As components of the slab track system were chosen, a test protocol was developed. The protocol identified four main tests to be performed as follows:

- Fastener Tests to determine the spring constants of the fastening system for verification of k-values used in slab track design and other tests typically performed on fastener systems to confirm their structural integrity.
- Static load slab track tests to determine the response of the slab track system for comparison to structural analysis.
- Repeated load slab track tests to determine the behavior of the system under heavy repeated loads.
- A drop-hammer test to ascertain the response of the system to impact loads.
- Modal analysis test to determine the dynamic behavior of the slab track system.

Laboratory Test Set-Up

All elements of the slab track system were constructed beneath a steel loading frame in the CTL laboratory. Eight vertical actuators consisting of two hydraulic rams each were connected to a central hydraulic oil pumping system and were supported by the steel frame directly above the slab track specimen. The actuators were used to apply the simulated vertical wheel loads to the top of each rail. Two horizontal hydraulic ram actuators were connected between the two rails to apply lateral loads to the rails. See Figure 3 for locations of the applied loads. The actuators were controlled by a computer program that applied vertical and horizontal loads to simulate the forces produced by the actual TTCI test train with 315,000 pound freight cars. The original intent was to apply loads at a rate that simulated the 70 car TTCI test train traveling at 40 mph. However, because of test demands, the restricted hydraulic oil flow only allowed the laboratory to simulate a 10 to 20 mph train.
The slab track was instrumented to monitor the following parameters during the tests.

- Rail deflection at and between fasteners
- Slab deflection
- Slab strain
- Rail strain
- Subgrade pressure
- Fastener displacement

Deflection of the slab track is significant in that the slab track must satisfy the allowable deflection specified in the Amtrak high speed rail operational criterion. The locations of instrumentation for slab and rail deflection are shown in Figure 4. Rail and fastener movement are measured relative to the top surface of the laboratory floor. Instrumentation for concrete strain gages, rail strain gages, and subgrade pressure cells are shown in Figure 5. Slab strains were monitored with embedment strain gages cast inside the slab near the bottom surface and external strain gages bonded to the top of the slab. Rail bending strains were monitored with strain gages attached to the rail at the fasteners and midway between the fasteners. Figure 6 is a photo of the slab track test set up.

**Laboratory Test Loads**

The vertical and horizontal loads applied during the test were developed from a distribution of measured wheel set load data provided by TTCI for 39-ton axle freight cars operated on the High-Tonnage Loop (HTL) at the Transportation Technology Center, Inc. (TTCI). The information from TTCI included data measured at the leading and trailing axles and on both sides of the train. The highest, and thus most conservative, values were used for development of the test load spectrum. The data indicated that a
vertical wheel load of 68 kips would encompass all dynamic and static wheel loads at the TTCI HTL test track 99.99% of the time.

A goal of 3-million cycles was chosen for the repeated load test to meet industry standard goals for similar track components. To get the number of cycles to be applied in the repetitive load test, an initial test wheel load target of 39 kips was selected and the cumulative frequency of occurrence of the TTCI wheel loads equaling 39 kips or less was multiplied by 3,000,000. Likewise, higher target loads were selected (50, 54, 58, 62, and 68 kips) and the associated number of cycles was determined by summing the frequency of occurrence of loads between two target loads and multiplying by 3,000,000. The resulting laboratory load spectrum is shown in Table 2. Note that the laboratory load spectrum is a more severe than the actual wheel loads from TTCI. The last column in Table 2 shows the resultant cumulative loads in MGT.

Similar calculations were performed to determine the lateral loads to be used in the test. The resulting lateral load spectrum is shown in Table 3.

The TTCI wheel load data was also compared to wheel load data provided by ZETA-TECH Inc. for maximum wheel loads from various measurements on mainline track including Amtrak’s Northeast Corridor. The maximum wheel load from the ZETA-TECH data was for a 286,000 pound car traveling at 90 mph with a maximum quasi static wheel load of 65,700 pounds, which is in the same range of wheel loads as used in the slab track test.

In order to address very high wheel loads caused by wheel flats, out of round wheels, and rail head defects, the slab track specimen will be subjected to a very short duration high impact load.
LABORATORY TEST RESULTS

Fastener Tests

Fastener vertical static and dynamic spring rates were determined prior to the repeated load tests. During the tests the fastener exhibited variable vertical, static and dynamic spring rates as shown in Figure 7. The lateral spring rate for the fastener was also measured found to be variable and is shown in Figure 8. Other fastener tests including lateral restraint, insert anchorage, longitudinal restraint, and electrical resistance will be measured during tests following the repeated load test.

Static Load Tests

Static load testing of the slab track was completed prior to the repeated load test using a vertical load up to 68 kips at each wheel location and a lateral load up to 21.76 kips at each horizontal actuator location. Table 4 summarizes the maximum measured deflections and stresses or strains during the static load test and compares some of the measured values to the calculated values at the same location on the slab track. The calculated values are from a computer analysis using RISA 3D software and PCA MATS software to model the rail, fasteners, concrete slab, and subgrade.

Repeated Load Test Results

The repeated load test was completed in July 2002. A thorough visual examination of the slab track, rail and fasteners, performed after completion of the test revealed that deterioration of the slab track components did not occur during the 3 million repeated load cycles.
**Remaining Tests**

During August 2002 the following three remaining tests will be performed:

1. A modal analysis of the slab track will be performed to determine the response of the slab track to dynamic loads.

2. The slab track will be subjected to a full static load and the slab track response measured to determine if any degradation of the slab track occurred during the repeated load test.

3. The slab track will be subject to a short duration high impact load.

The results of these three tests will be reported during the presentation of this paper at the AREMA 2002 Conference.

**CONCLUSION**

The concrete slab track has met all predicted expectations and has performed well during the static and repeated load testing. The fairly good agreement between the measured behavior and the calculated behavior of the slab track demonstrates the validity of the method of analysis used during the design of the track. Reasonable expectations of actual installations of the slab track system would be that slab track has the strength to effectively support heavy axle loads of freight trains and the durability to maintain strict tolerances required by high speed rail operations. Slab track would therefore increase safety and keep required maintenance at a minimum.
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PCA Expert Panel

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Nathan Higgins        Hatch Mott and MacDonald
Kenneth Lane          Transportation Technology Center, Inc.
Dingqing Li           Transportation Technology Center, Inc.
Richard S. Lanyi*    Canadian National Railway
Mohammad Longi        Consultant
Gene Randich          Consultant
Nicholas Skoutelas    Amtrak
Bernard Sonneville    The Permanent Way Corporation
Shiraz Tayabji*       Construction Technology Laboratories, Inc.
Jan Zicha             Consultant

*Former panel member

Federal Railroad Administration

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Fig. 2  Simulated Subgrade Properties
**LEGEND:**

V - Vertical Wheel Load in Elevation
⊗ - Vertical Wheel Load in Plan
L - Lateral Wheel Load

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**Fig. 3 Test Load Locations**
Fig. 4 Slab Track Test Deflection Instrumentation
LEGEND:
R - Rail Strain
P - Sub-Grade Vertical Pressure
+ - Longitudinal and Transverse Top and Bottom Concrete Strain
⊕ - Transverse Top and Bottom Concrete Strain

Fig. 5 Slab Track Test Strain and Pressure Instrumentation
Fig. 7 Fastener Static and Dynamic Vertical Spring Rates
Fig. 8  Fastener Lateral Spring Rates
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<tr>
<th>Location</th>
<th>Type of Slab Track</th>
<th>Total Length of Slab Track</th>
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<td>Japan - Shinkansen</td>
<td>Precast Concrete Panels and other</td>
<td>1.211 Miles + 868 Miles in Planning</td>
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<td>22</td>
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<td>0.50%</td>
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<td>Total</td>
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### Table 4

**Summary of Static Test Observations**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measured</th>
<th>Calculated</th>
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</thead>
<tbody>
<tr>
<td>Rail Deflection</td>
<td>0.235 inch</td>
<td>0.226 inch</td>
</tr>
<tr>
<td>Rail Stress (vertical load only)</td>
<td>12,000 psi</td>
<td>14,800 psi</td>
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<tr>
<td>Slab Deflection</td>
<td>0.026 inch</td>
<td>0.0266 inch</td>
</tr>
<tr>
<td>Maximum Transverse Strain in the Slab</td>
<td>83 microstrain</td>
<td>70 microstrain</td>
</tr>
<tr>
<td>Maximum Longitudinal Strain in the Slab</td>
<td>43 microstrain</td>
<td>40 microstrain</td>
</tr>
</tbody>
</table>