Concrete Slab Track State of the Practice

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CONCRETE SLAB TRACK FOR FREIGHT AND HIGH SPEED SERVICE APPLICATIONS

A Survey of Practice

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Introduction

This report was prepared to address questions and concerns related to the large-scale application of slab track technology for freight and high-speed passenger service applications. Today, most of the railroad freight and passenger traffic in the U.S. is carried over conventional ballasted track system. However, slab track is experiencing increasing use for high-speed rail in Japan and Europe and slab track is commonly used for light rail transit in the U.S. Also, it is common in the U.S. to use direct fixation rail on concrete slabs in aerial structures and tunnels for light and heavy rail transit systems.

Railway track technology has evolved over a period of 150 years since the first rail track over timber ties was introduced. For much of this period, the conventional track system, commonly referred to as the ballasted track system, has consisted of certain components including rails, ties, ballast and the subgrade (roadbed). Ties are predominantly wood ties but concrete ties are also widely used for both transit and freight applications.

Over the last 20 years, there has been an increase in the use of concrete slab technology for transit, commuter, and high-speed train applications. Essentially, a slab track consists of a concrete slab placed on a subbase over prepared subgrade. The rails may be directly fastened to the concrete slab or the rails may be placed on concrete blocks or another slab system that is placed (or embedded in) the underlying concrete slab. A new version of the slab track, developed in the Netherlands, incorporates rails embedded in a trough in the slab and surrounded by elastomeric material. The slab track systems for passenger service applications incorporate several requirements to mitigate noise and vibration.

The concrete slab track technology has not been widely used for freight applications in the U.S. The U.S. freight trackage consists of over 177,000 miles owned by Class I railroads plus that for short line and regional railroads. The combined track mileage accounts for over 1.40 trillion ton-miles of freight. The U.S. freight trackage essentially consists of wood tie-ballasted system. During the Year 2000, it is expected that over 14,000,000 new ties will be installed of which 87% will be wood ties, 12% will likely be concrete ties, and 1% other material including plastic and steel (Ref. 1).

The slab track system for transit applications in the U.S and for and for high-speed rail in Europe and Japan has performed well over the last 20 years. Also, the limited application of slab track for mixed passenger service/freight operations has also exhibited good performance. Because of the continued increase in gross tonnage expected to be carried by railroads and the expected growth in high-speed passenger rail corridors with its smaller deviation allowed in the rail geometry, the need for a stronger track structure is apparent. At-grade concrete slab track technology will fill the need for stronger track in the U.S.

For slab track to be selected for new track construction or track renewal, the following requirements must be met:

1. The slab track system must be capable of being constructed using a combination of existing track concrete pavement construction technologies.
2. The direct fixation fastener system must be economical to install, have adequate strength and have a long life.
3. The slab track system must be practical to maintain and repair.
4. The slab track must be able to maintain rail alignment better than ballasted track
5. The life cycle cost of the slab track system must be equal to or lower than that for conventional ballasted track.

In the following sections of this report, various critical issues related to slab track technology are addressed. Also, where appropriate, a comparative discussion of ballasted track system is included. It should be noted that the issues presented are primarily based on review of available published information. Only a limited amount of contacts were made with railroad companies, track material suppliers, engineering consultants, researchers, and government agencies. This report serves as a white paper outlining various technical and economical issues and summarizes the state-of-practice related of concrete slab track technology.

Historical Development of Slab Track Technologies

Although slab track type systems have been used in tunnels and on bridges for a much longer period, the application of slab track systems for at-grade application has occurred in the last 30 years. An excellent review of the at-grade concrete slab track system for railroad and rail transit system as of 1980 is presented in Reference 2. According to this review, based on 18 slab track projects constructed by railroads and transit authorities in eight countries and reviewed in the report, the slab track projects were performing well after many years of service. The use of slab-track has further evolved over the last 20 years for transit and high-speed applications, especially in Japan, the Netherlands, Germany, and North America. However, only a limited application of slab tracks for dedicated freight service application has been reported.

Types of Slab Tracks

The types of concrete slab track systems that have been used can be classified into the following four major categories:

1. **Cast-in-place at-grade systems** – These include jointed plain or reinforced concrete slabs or continuously reinforced concrete slabs.
2. **Tie Embedded systems** – These include systems using block ties or full ties with rubber boots embedded in concrete that is placed on a concrete base
3. **Two slab layer systems** – These include a surface slab system (typically precast, but also cast in place) that is placed on a concrete base. The precast surface slab system is typically separated from the concrete base using an asphalt sandwich layer or by a cement-based grout material.
4. **Embeded rail systems (ERS)**- These include rail embedded in an elastomeric or cementitious material in a preformed trough in a concrete slab.

The at-grade systems require a good quality subbase and adequate provisions for subsurface drainage and frost protection to mitigate excessive subgrade settlement under train loading. The details of various types of slab tracks in use or tested experimentally in Japan, the Netherlands, Germany, and North America are given in the following sections. It should be noted that the most common use of slab track to date has been for passenger train operations requiring special track component features to reduce noise and vibration in urban areas, minimize track maintenance cost and maintain track geometry.

Slab Track Use in Japan

The Japanese National Railways (JNR) began production use of slab track over 30 years ago. Slab track has been used both on Shinkansen and narrow gauge lines for over 2,400 km (1500 miles) including tunnels and bridges (Ref. 3). The slab track has continued to provide excellent performance in terms of maintaining track geometry and reducing maintenance of track cost. The early criteria (developed during the early 1970's) for use of slab track by the JNR were as follows (Ref. 3):

1. The construction cost should not exceed twice as much as ballasted track.
2. The slab track should be structurally sound and have resilience equivalent to that of ballasted track.
3. The speed of construction should be reasonable.
4. The slab track should allow for adjustments in the vertical and lateral directions to account for deformations of the subbase.

After experimentation, a slab track design, referred to as Slab Track Type A, was selected for routine use for tunnels and viaducts. The variations of this design are shown in Figure 1 for open

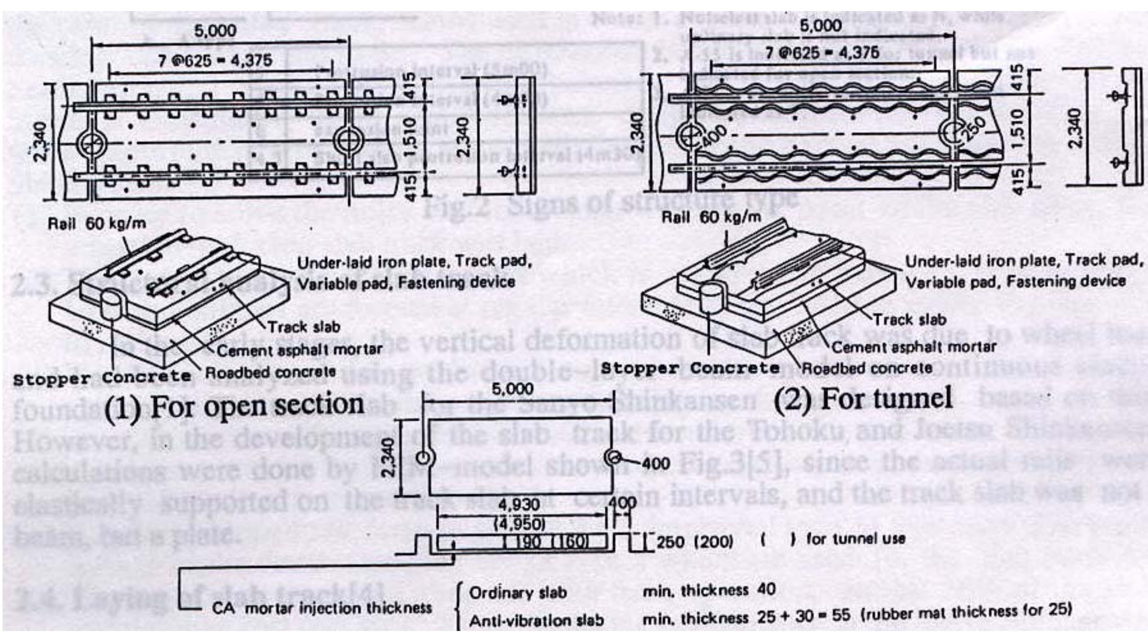

Figure 1 – Japanese Type A Slab Track (Ref. 3)

and for tunnel sections. The slab tracks consists of precast concrete slabs, 5 m (16.4 ft) long, and cement asphalt mortar (CAM) layer beneath the slab. On the roadbed concrete of a viaduct or in a tunnel, lateral stopper concrete (400 mm (15.8 in.) in diameter and 200 m (655 ft) high) is provided at intervals of 5 m (16.4 ft). The track slabs are made of pre-fabricated reinforced concrete, prestressed concrete, or prestressed resurfaced concrete. The track slab for the Shinkansen is nominally 2340 mm (92.1 in.) wide, 4930 to 4950 mm (194.1 to 194.9 in.) long, and 160 to 200 mm (6.3 to 7.9 in.) thick. One track slab weighs approximately 5 tons. Recent modifications to the slab track include use of vibration reducing grooved slab mat under the track slab.

Although, most of the slab track was initially used for tunnels and bridges, the RA type slab track, shown in Figure 2, was tried on soil roadbed during the mid-1970s. However, no large-

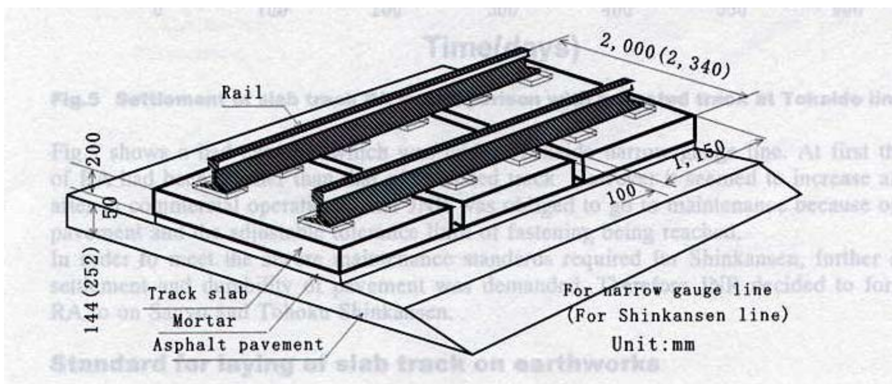

Figure 2 – Japanese Type RA Slab Track on Grade (Ref. 4)

scale installations were made of this type of track because of concerns with excessive settlements. A current version of the slab track for at-grade application, referred to as the reinforced concrete roadbed system (RCRS), is shown in Figure 3 (Ref.4). This system has been

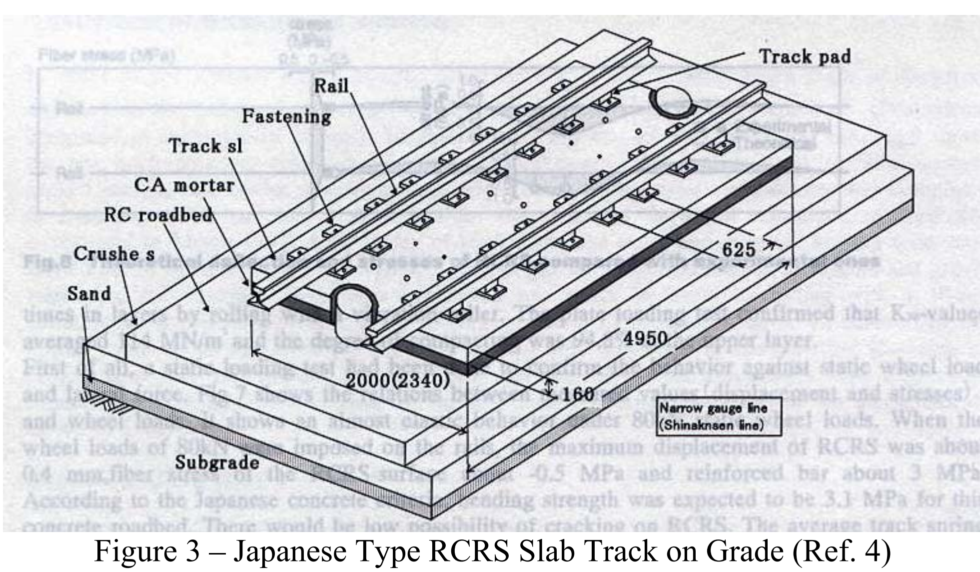

Figure 3 – Japanese Type RCRS Slab Track on Grade (Ref. 4)

undergoing experimental testing and monitoring since the early 1990s and has been used on the Hokuriku Shinkansen line from Takasaki to Nagano, which opened to service in October 1997. The cost of the RCRS type track was found to be higher than those of ballasted track by 18% in cuts and by 24% in fill sections. It was expected that because of low track maintenance, the extra costs would be recovered in about 12 years of operation. It is also expected that the workforce required to maintain the slab track would be about 30% lower than for ballasted track. The Japanese standards for constructing at-grade slab track are shown below:

Item	Standard
Final Settlement – Estimated	< or = 30 mm (1.2 in.)
Deflection	< or = 1/1800
Angular Bending	< or = 3/1000
Bearing Capacity of Bank and Cutting Bed	K_{30} > or = 110 MN/m/m/m

These standards address the serious concerns with roadbed settlement. Currently, a frame-shaped slab track is being investigated to reduce initial construction costs.

The Shinkansen slab tracks carry 10 to 15 million gross tons per year (as of 1990). Although, the overall performance of the slab track has been good, some problems have been noted. These include damage to CAM layers, cracking in the slab track due to alkali-silica reaction (ASR), and warping of slab in tunnels.

Overall, slab track maintenance was found to be much less than for ballasted track on the Shinkansen lines, ranging from about 0.18 to about 0.33 of that for ballasted track. The average construction costs of slab track is about 1.3 to 1.5 times those of ballasted track. The difference in construction cost is expected to be recovered in 8 to 12 years depending on the tonnage carried by the line.

Slab Track Use in the Netherlands

Several innovative slab track type systems have been developed in the Netherlands. These include the following:

1. Embedded Rail System (ERS)
2. Edilon Block Track
3. Deck Track

Embedded Rail System

The system, in use since the 1970s in the Netherlands, involves providing continuous support for the rail by means of a compound consisting of Corkelast (a cork/polyurethane mixture) (Ref. 5). The system shown in Figure 4 has been used on a limited basis on bridges and level crossings.

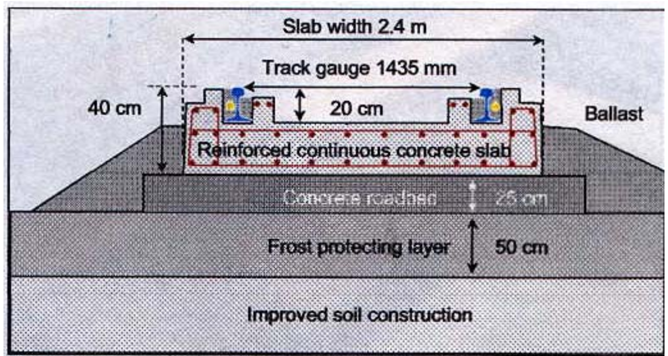

Figure 10 Embedded rail concept for 3 km test track in Holland

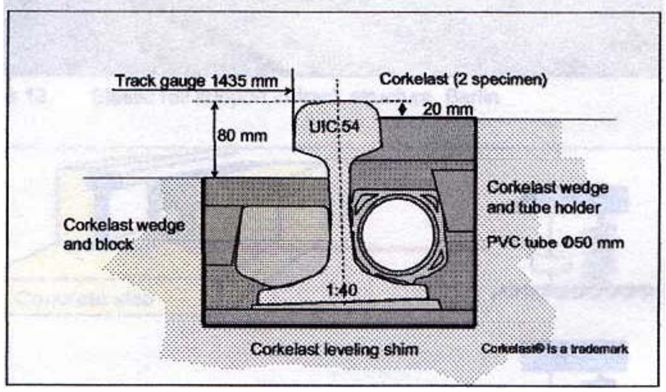

Figure 4 – Embedded Rail Slab Track System (Ref. 6)

Recently, a 3-km (1.9-mile) length of the ERS concrete slab track on grade was built in the south of the Netherlands. The structure consists of a continuously reinforced concrete slab resting on a cement-stabilized base, which was placed over a sand subbase. An advantage of this system is that the final track geometry is not influenced by the geometry of the supporting slab. The use of the ERS system for the HSL-Zuid high-speed line from Amsterdam to the Belgian border is now being considered.

Edilon Block Track

The Edilon block track is mainly used for bridges and tunnels (Ref.6). It is a "top-down" construction system. Under this system, the first step is to place the rails and blocks in position. The blocks are then cast in the concrete slab using Corkelast (to provide the necessary elastic support). This is similar to other systems in which rubber booted tie blocks are cast into the concrete (e.g., the Stedef system, the Sonneville low vibration track system, and the Swiss Walo system). The Edilon system has been used for over 100 km (62 mile) on railways and the light rail transits system in the Netherlands and over 100 km (62 mile) of the Madrid metro system.

Deck Track

The Deck Track is a recent innovation developed for use with embedded rail (Ref. 7). A schematic of the Deck Track is shown in Figure 5. A 200-m (655 ft) test section of the track was constructed during the spring of 1999 near Rotterdam and was opened to traffic during July

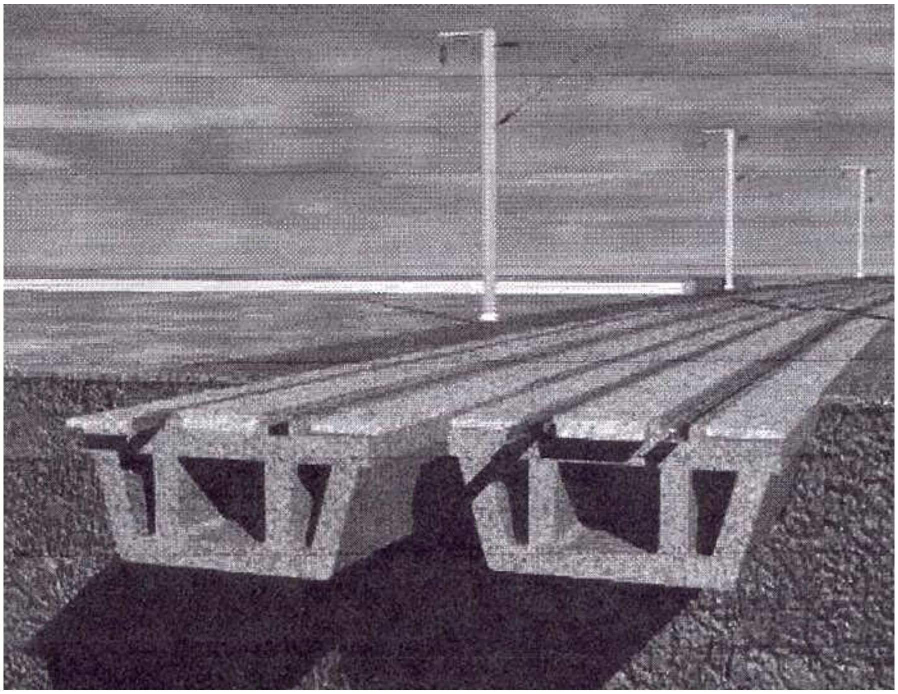

Figure 5 – Deck Track System (Ref. 7)

1999. The track is used by many heavy freight trains every day. Although it is too early to judge the performance of the track, the constructability of the track has been demonstrated. Construction cost data is not available.

Slab Track Use in Germany

Slab track use has been undergoing development in Germany for many years. In 1996, the German Railway (DB) began operating a test track in Karlsruhe consisting of seven new types of ballastless track (Ref. 8). Approximately 330 km (1,082 ft) of slab tracks has been constructed throughout the DB network. One of the best-known designs is the Rheda system. In the Rheda system, the concrete ties are cast into a continuously resurfaced concrete slab. The Rheda system, originally developed during the 1970s, is shown in Figure 6. During construction, track consisting of rail, ties, and fastenings, are assembled on the base slab. After laying and lining of the slab panels, concrete is placed into cribs and spaces below the ties. It is required that the slab track be constructed over load-bearing frost-protected subgrade and that the groundwater be greater than 1.5 m (5 ft) below the slab.

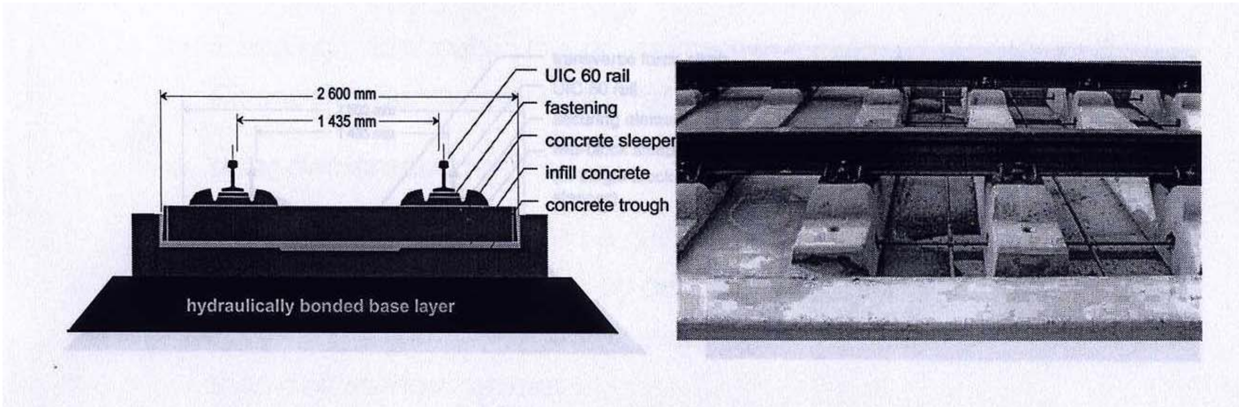

Figure 6 – The Rheda Slab Track System (Reference 8)

About 147 km (92 miles) of slab track is expected to be constructed along the new 219 km (136 mi) Cologne-Rhine/Main high-speed line. The justifiable cost factor for the slab track in Germany is considered to be less than 1.4 of that for ballasted track. It is expected that higher initial cost will be offset by future maintenance costs savings and by greater availability of the tracks due to less downtime for track maintenance.

The use of new slab tracks in the DB AG rail network is subject to licensing under public law or approval in individual cases (ZiE) from the Eisenbahn-Bundesamt (Federal Railway Office) (EBA). This certifies that the slab track is perfectly safe and technically feasible in terms of state-of-the-art technology (8). The applicant must submit a design specification, proof of static rigidity, expert opinions and the results of laboratory tests and trials along with the license application. Once the railway authorities have studied and evaluated the construction design for the slab track or its system components, they issue a general license or a license for operational testing. The license for operational testing is generally subject to a fixed period of time. In addition to the EBA license, a user declaration is required from DB AG for the slab track or its system components to be used in the rail network. This user declaration is the rail company's approval for the new system to be used in a specific case. The system can be granted a general license and introduced as a DB AG standard design when its technical suitability has been proven by operational testing over several years with at least 3 winter periods or a traffic load of not less than 150 million tons.

Slab Track Use in North America

Although slab track has been in limited use for many years, use of slab track in North America has been steadily increasing over the last 10 years. The predominant use of the slab track has been for transit systems. Early use on transit systems was for tunnel and bridge sections with systems customized to reduce noise and vibration. Some of this trackage included the floating slab design as used for the Washington, DC metro tunnel system. The embedded track system, consisting of dual tie blocks set in rubber boots and using microcellular pads locked-in with a second pour of concrete, has been used for transit systems in San Diego, Atlanta, Toronto, San

Francisco, St. Louis, and Dallas. The rubber boots and microcelluar pads provide vibration isolation and electrical isolation. A discussion of selected at-grade slab track projects follows.

Long Island Railroad Project

The most significant use of slab track on grade in the U.S. was constructed at the following three locations on the Long Island Railroad (LIRR):

1. East of the Massapequa Station on the Babylon Line
2. West Side Storage Yard
3. Richmond Hill Yard

Massapequa Station Project – This project constructed just east of the Massapequa Station consists of 1.8 km (1.13 miles) of two parallel, continuously reinforced concrete (CRC) slab tracks on an embankment section with continuously welded rail and direct fixation fasteners. The project was constructed during the late 1970s and opened for traffic in December 1980 (Ref. 9). Details of the slab track sections are shown in Figure 7. The slab track carries 12 million gross tons (MGT) per year made up of commuter passenger trains and short freight trains.

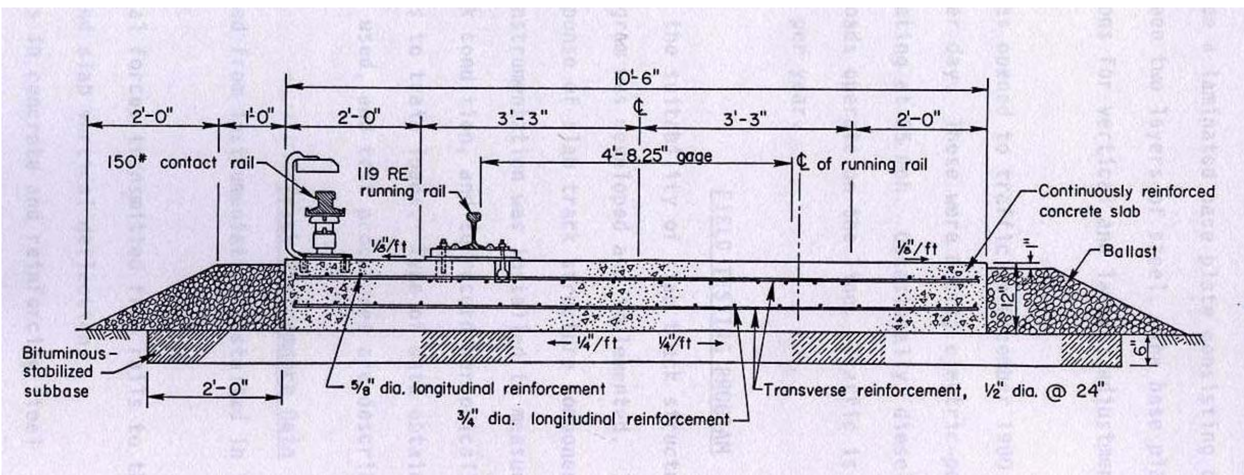

Figure 7 – The Long Island Railroad Slab Track (Ref. 10)

The slab track design incorporated the following:

- Concrete Slab (CRC)
    - Thickness – 304 mm (12 in.)
    - Slab width – 3.2 m (10.5 ft)
    - Longitudinal reinforcement – 0.9% (two layers)
    - Placement – using side forms

- Subbase
    - 152 mm (6 in.) thick and 4.4 m (14.5 ft) wide hot mix asphalt

- Fastening System
  - Spacing – 762 mm (30 in.)
  - Clips – Pandrol "e" clips
  - Base plate – 178 by 381 by 38 mm (7 by 15 by 1.5 in.) with a neoprene pad between two steel plates

- Rail
  - 119R E

- Expansion Joints at Slab Ends (at structures)

After 20 years of revenue service, the slab track is performing very well. The concrete slab exhibits no distress and the transverse cracks in the CRC slab is very tight with crack spacing ranging from 0.9 to 1.5 m (3 to 5 ft). Only minor problems have been reported with the direct fixation fasteners after 20 years of service.

West Side Storage Yard – This facility, located just west of Amtrak's Penn Station in New York, was constructed during 1984 and consists of 27 concrete slab tracks, varying in length from 244 to 366 m (800 to 1200 ft), for holding commuter trains (Ref. 10). The total length of the slab track is about 8235 m (27,000 ft). The slab track design used here was similar to that used at the Massapequa site. The slab is continuously reinforced, 3.2 m (10.5 ft) wide, and is 330 to 342 mm (13 to 13.5 in.) thick. The slab was placed over a 102-mm (4-in.) thick asphalt base, which was placed over 863 mm (34 in.) of granular subbase. The reinforcement was placed in two layers with the top layer epoxy-coated. The concrete strength was specified to be 27.5 MPa (4,000 psi) with a slump of 63 to 76 mm (2½ to 3 in.).

For slab track design, the following axle loads were used together with an impact factor of 25 percent:

1. M-1 Electric Engine – 16,250 kg (26,000 lb)
2. GP-7 Amtrak Locomotive – 37,500 kg (60,000 lb)

After 16 years of service, the slab track is performing well and has exhibited only fastener-related problems.

Richmond Hill Yard – This yard, used as a maintenance facility, contains two sets of slab tracks . One set of tracks, constructed during 1992/1993, are used for engine and car repair. Another set of track (single-track) was constructed during 1997 and is used as a wash facility with trains operating at about 3 kph (5 mph). This track includes a 12-degree curve. The unreinforced slabs at the wash track are very thick, up to 660 mm (26 in.) thick and are jointed with joint spacing of 6.1 m (20 ft). Both sets of tracks use 119RE rail. Fastener problems developed along the wash track as a result of the severe curve and intermediate fasteners were installed along the curve to provide effective fastener spacing of 381 mm (15 in.). Fastener problems have also occurred on the older repair slab tracks. Other than the fastener problems, both sets of slab tracks are performing well with no distresses exhibited by the concrete slab or the substructure.

Canadian Pacific (CP) Rail Slab Track Sections

CP Rail constructed three test sections near Rogers Pass in British Columbia between 1984 and 1988. The first section at Albert Canyon was constructed as a test section constructed in 1984, the second section is a 15.0-km (9.4-mile) single-track section in a tunnel through Mount MacDonald completed in 1988, and the third section is a 1.6-km (1-mile) single-track section through Mount Shaughnessy was completed in 1988.

Albert Canyon Test Section – This was a 283 -m (930-ft) slab track section built during late 1984 using the patented PACT-TRACK system developed by British Rail and McGregor Paving Limited in the United Kingdom (Ref. 11). The track test section was built to investigate the use of the PACT-TRACK for the 15 -km (9.4-mile) MacDonald Tunnel and simulated the tunnel track conditions. A thick concrete slab was first placed on a prepared subgrade to simulate the tunnel's floor. The slip formed continuously reinforced surface slab was then placed. U-shaped dowel bars were used to anchor the PACT-TRACK slab to the tunnel slab.

The PACT-TRACK surface slab is 229 mm (9 in.) thick and 2.43 m (8 ft) wide. Concrete is placed using a customized slipform paving machine, which rides on two rails (which are later used for the track) and which feed the concrete into the front of the paving machine using a conveyer system. After the concrete has cured, the continuously welded rail is laid on a continuous 12.7 to 15.9 mm (½ to ⅝ in.) thick rubber compound pad and clipped to inserts embedded in the slab. For the Rogers Pass projects, direct fixation Pandrol clips ("e" clips) spaced at about 304 mm (12 in.) were used with 136RE rails. Details of the PACT-TRACK system are shown in Figure 8. The top surface of the PACT-TRACK is sloped from the rail to the center of the slab and drains are provided along the center of the track.

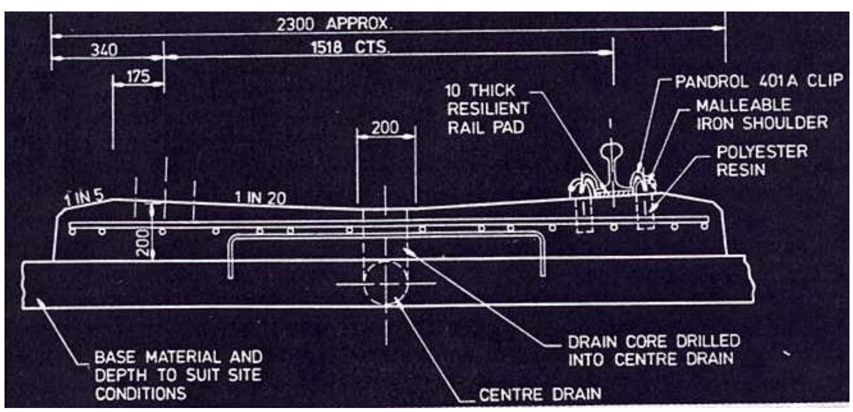

Figure 8 – The PACT-TRACK System (Ref. 11)

The operating conditions at Albert Canyon include trains with 35-ton axle loads and annual gross tonnage of about 90 million. The test track was designed for evaluation over a 2-year service period. According to reports, the test track was removed after about 3 years of operation. Slab cracking due to pumping at the transition between cut and fill portions had developed and repair was accomplished using grouts injected under pressure.

Mount MacDonald and Mount Shaughnessy Tunnel Sections – Based on the overall satisfactory performance of the Albert Canyon slab track, the PACT-TRACK system was installed along the McGregor Tunnel during 1988 (Ref. 12). The tunnel section slab track design was essentially similar to the design used for the Albert Canyon test section. It should be noted that the slab width used allows only about 381-mm (15-in.) width beyond the rail base on each side of the track. In the PACT-TRACK system, the rail is continuously supported over the pad and the slab. This requires that the finishing tolerances for the surface slab be very tight – about 1 to 2 mm (0.04 to 0.08 in.).

CPR used ballasted track with concrete ties after the rail exits the tunnels. At the transition between the slab track and the ballasted track, retaining walls 0.6 m (2 ft) deep below grade on each side of the track run parallel to the track for 6.1 m (20 ft). Also, a transition slab runs for 6.1 m (20 ft) under the ballast between the two retaining walls.

During the 12 years the slab track has been in service, surfacing and alignment of the rail have not been necessary. However, there were some problems with the slab track installation. After seven years of use, in 1995, the following four areas of PACT-TRACK started to develop cracks: (1) at the ends of the tunnel PACT-TRACK slab, (2) at the joints between the tunnel section and the cut and cover portal section, (3) at a 18.3 m (60 ft) section where excessive seepage water partially submerged the PACT-TRACK slab, and (4) at one an end of day construction joint where there was seepage water.

AT the ends of the tunnel PACT-TRACK slab, area (1), CPR determined that the deflection of the first two ties adjacent to the PACT-TRACK under train loads caused uplift on the PACT-TRACK rail fasteners resulting in loosening of the fasteners and diagonal cracking in the corners of the PACT-TRACK. Only three out of the four tunnel entrances experienced this type of problem. CPR decided that a slightly softer track modulus was needed at the tunnel entrance and replaced the concrete ties with closely spaced wood bridge ties for a small distance from the end of the tunnel.

The 16.6 km (10.4 miles) of PACT-TRACK are now in very good condition. Repairs were made to address cracking at four areas. Softening the track just outside the entrance improved the transition section and installing expansion joints at the portal section construction joint have addressed the joint problems. Coring vertical drains to provide better drainage addressed the water related problems.

Kansas Test Track Section

The test track was built in Kansas on a heavy traffic freight line of the Santa Fe under the joint sponsorship of the railroad and the Federal Railroad Administration during 1972 as part of an effort to evaluate improved track structure designs (Ref. 2). The 2440 m (8000 ft) experimental test track consisted of nine sections using various types of track construction. Several sections were built using concrete ties at various spacing, concrete beams, concrete slab, precast beams, and stabilized ballast. The slab track section was one of the experimental sections. The slab track was 2.8-m (9-ft) wide CRC slab with a slab thickness of 457 mm (18 in.). Fasteners were spaced at 762 mm (30 in.).

The test track was opened to traffic during May 1973 and closed soon after because of fastener failures in the concrete beam and slab test sections. After the fastener problem was corrected, the test track reopened to traffic during October 1974. During June 1975 the track was again removed from service because of excessive track deflection under traffic at several of the test sections resulting from the failure of the fine-grained subgrade. The degradation of the soil foundation during periods of heavy rain caused mud to be extruded around the concrete beams and through the ballast.

The progressive deterioration of the subgrade was caused by inadequate drainage causing the subgrade clay to absorb water and swell. The swelling also resulted in a loss of strength in the upper 305 to 457 mm (12 to 18 in.) of subgrade. Also, both the conventional and non-conventional track structures were essentially intact when the test was terminated. The use of the 25 to 51 mm (1 to 2 in.) ballast under the non-conventional structures was found to be inadequate in terms of drainage or load distribution to the subgrade. Non-conventional structures include the slab track and the continuous beam track.

Transit Slab Tracks

The various transit slab tracks constructed in the U.S. and Canada over the last 10 years include the floating slab tracks as well as the embedded block/tie systems, which incorporate noise and vibration attenuating features. It is reported that some of the isolators on floating slab installations have performed poorly. There have been no reports of problems with the embedded block tie and full tie systems

Slab Track Design Issues

In order to consider the slab track technology as an improvement to the conventional ballasted track system, it is necessary to understand the fundamental mechanisms of the ballast track system and the nature of problems associated with ballasted track. A brief discussion of the ballasted track design and performance issues is presented next. This is followed by a discussion of issues related to design of slab tracks.

Design Consideration for Ballasted Track

The typical ballasted track consists of rail, ties, tie-fastening system, ballast, subballast, and the subgrade. The track system must be designed so that the subgrade, subballast and the ballast provide uniform support and distribution of superstructure loadings. Design criteria that are presently used in the design of conventional tracks include the following:

1. Allowable rail bending stress.
2. Allowable rail deflection.

3. Allowable ballast stress.
4. Allowable subgrade stress.
5. Minimum track modulus.

In addition, design requirements are also established to consider the dynamic response of the track structure. A typical wheel load distribution in a conventional track structure is shown in Figure 9.

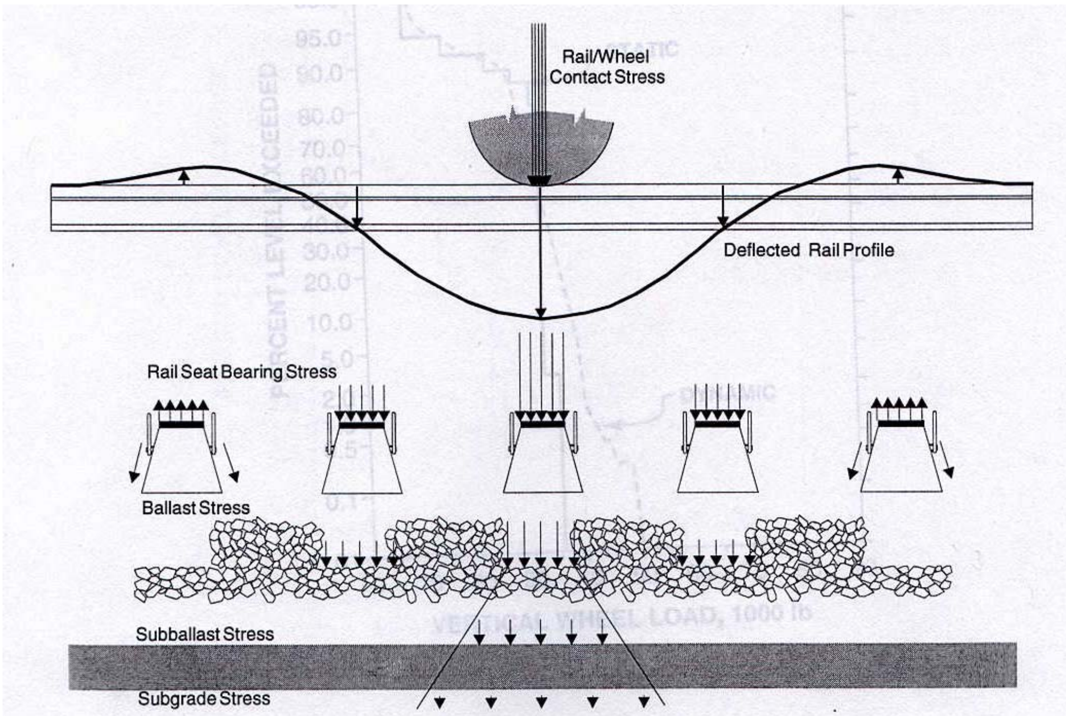

Figure 9 - Wheel Load Distribution within the Ballasted Track Structure (Ref. 13)

Track Modulus

Track modulus is a measure of overall track stiffness and track stability. It is an indicator of the load required producing a unit deflection at the rail. The track modulus, u, can be determined, using the beam on elastic foundation, analysis from the following equation (Ref. 14):

$$u = k^{4/3} / (64EI)^{1/3}$$

where: k = track stiffness (load required to produce unit deflection).
E = modulus of elasticity of the rail.
I = movement of inertia of the rail.

In the U.S., track modulus is determined in units of kg/mm/mm (lb/in./in.) and values of track modulus may range from as low as 6.9 N/mm/mm (1,000 lb/in./in.) for track in poor condition to about 27.6 to 41.4 N/mm/mm (4,000 to 6,000 lb/in./in.) for a track in very good condition. Track modulus varies non-linearly with applied load and increases as the load level increases. Higher track modulus represents better quality track and can be achieved using concrete ties instead of wood ties, using continuously welded rail instead of jointed rail, increasing ballast depth, using heavier rail, or using slab track. Higher track modulus also implies that overall rail deflections are lower resulting in low subgrade pressures and reduced rail stresses.

It should be noted that a certain amount of resilience is required in all track structures. However, conventional ballasted track normally provides too much rather than too little resilience (Ref. 14) and the resilience tends to be non-uniform as a result of non-uniform track degradation under traffic. Too much resilience results in poor ride quality and excessive rail wear.

Overall Design Requirements for Ballasted Track

The following design considerations are recommended by AREMA (Ref. 15):

Subgrade-Allowable bearing stress of 137 kPa (20 psi).

Ballast - Minimum ballast depth is determined to ensure that allowable subgrade bearing stress will not be exceeded. Several formulas exist to determine the required ballast depth. The ballast pressure under concrete tie should not exceed 585 kPa (85 psi) for high quality abrasion resistant ballast.

Wood Ties - Wood tie cross-section and length are determined as a function of anticipated loading. Wood ties are typically 177 to 228 mm (7 to 9 in.) wide and 2.4 to 2.7 m (8 to 9 ft) long.

Concrete Ties - Concrete ties may be mono-block or two-block. The ties may be reinforced or prestressed. Concrete ties are 203 to 330 mm (8 to 13 in.) wide, 152 to 254 mm (6 to 10 in.) deep, and 2.44 to 2.75 m (8 to 9 ft) long.

Tie-Pads - Tie-pads are used between the rail and concrete ties to minimize water intrusion and tie abrasion of the rail seat area and to reduce impact and vibration effects on the track structure. Dual rubber pads, with a 50 to 60 Shore A durometer on the bottom and 75 to 85 Shore A durometer reinforced rubber pad on top or equivalent pads are typically used.

Tie Spacing - Wood ties may be spaced at 457 to 609 mm (18 to 24 in.) and concrete ties may be spaced at 609 to 762 mm (24 to 30 in.).

Rail- Typical rail sections are designated by AREMA. These range from about 115RE for transit tracks to 136RE and higher for heavier freight applications. Continuously welded rail (CWR) is most commonly used now. Criteria exist to limit allowable rail bending stress (e.g., 172 MPa (25,000 psi) for CWR).

Rail Deflection- Rail deflection for heavy freight service lanes should not exceed 6 mm (0.25 in.).

In the U.S., many of the track design requirements and analysis procedures are still based on the pioneering work done by Talbot during the 1920s (Ref. 16). During the last 25 years, much progress has been made to understand ballasted track behavior using the finite element method of analysis and incorporating non-linear material characteristics for the ballast and subgrade materials (Ref. 17, 18, 19). However, these recent developments have not yet been implemented into well formulated and routinely accepted design procedures.

Conventional Ballasted Track Degradation

One of the major limitations of the conventional ballasted track is the need for frequent track maintenance. The tie-ballast system is a poor system for load distribution to the subgrade. Typical problems include ballast degradation, track settlement due to subgrade failure, ballast displacement and tie failures caused by rotting and mechanical stress . The non-uniform track degradation also results in higher rate of rail wear, rail defects, and poor ride quality. Track maintenance typically includes rail grinding, rail gage correction, tie replacement, addition of ballast, re-tamping, surfacing and localized subgrade correction. Frequent track maintenance results in excessive downtime for critical track lines and results in revenue loss for freight railroads and passenger inconvenience for passenger lines.

Out of pocket cost of Class 1 main line maintenance of track is about $15,625/km ($25,000/mile). Since heavily traveled lines may have up to 100 trains/day, maintenance window availability is difficult. Surfacing is required every 15 to 20 MGT and 1/3 of the line is surfaced every year. Because of the heavy traffic, the BNSF intercontinental line is resurfaced every 2 years and wood tie renewal is done every 6 to 7 years. Rail on tangent track is replaced because of fatigue and rail on curves is replaced because of excessive wear. Rail wear depends on the degree of curve, traffic, speed, track structure condition and lubrication.

Design Considerations for Slab Track

The focus of this section of the report, is the design of the cast-in-place at-grade slab track system.

Overall Design Requirements

Design of the at-grade slab track system requires consideration of the following elements:

1. Substructure (subbase and subgrade)
2. Concrete slab
3. Direct fixation fastener system including tie pad

4. Rail

Design criteria that need to be considered in the design of the slab track system include the following:

1. Allowable rail bending stress
2. Allowable rail deflection
3. Allowable subgrade stress
4. Allowable concrete slab stress
5. Allowable concrete slab deflection
6. Desired track modulus

Because the slab track system is a relatively stiff system, the required resiliency is provided by the tie pad. In addition, design requirements also need to consider the dynamic response of the slab track including considerations for noise and vibrations. These considerations would govern the need for incorporating resiliency in the fastening system within a narrow range. Thus, both a minimum and maximum limits on track resiliency need to be determined.

There is considerable experience available from the field of highway and airport concrete pavement technology that has been applied to the design of the track concrete slab and the substructure beneath the slab. Years of pavement experience and ballasted track maintenance have proven that a thorough geotechnical investigation and design for native soils, drainage and frost protection as required by the AREMA Manual must be performed by competent engineers to ensure adequate long term performance of slab track.

There are also no well-documented sources of information on typical failure modes of concrete slab tracks. The concrete slab may exhibit failure modes similar to concrete pavements, such as cracking, faulting (for jointed slabs), and pumping due to poor subgrade condition. The design process must ensure that the anticipated failure conditions will not occur during the 30 to 50 year design life of the track structure. The design requirements for the substructure and the rail are very similar to that for conventional ballasted track system. The subgrade needs to be uniform, well prepared, have adequate strength and be well drained. Weak subgrade soils and soils susceptible to frost heave should be removed and replaced with compacted granular soils.

A stabilized subbase is generally preferred for slab track construction. The stabilized subbase under the slab provides for a more uniform distribution of wheel load stresses reduces the subgrade stresses, and provides a degree of frost protection. The subbase also provides a platform for construction of the slab that allows the slab to be constructed to tighter tolerances than without a subbase. With respect to rail design, this aspect is based on past experience.

AREMA Slab Track Design Recommendation

During 1999, AREMA included the design of slab track in the annually published *Manual for Railway Engineering (Ref. 20)*. The design considerations are included in Part 27 of the manual. The design considerations are based primarily on the experience gained during the design of the Long Island Railroad slab track project and subsequent observation of performance at these projects. The concrete slab type addressed is the continuously reinforced concrete (CRC) slab supported on a stabilized subbase and compacted subgrade. The following design criteria are recommended:

Allowable rail bending stress – 75 MPa (11,000 psi)
Allowable rail deflection – 6 mm (0.25 in.)
Slab width – 3.2 m (10.5 ft)
Allowable stress on compacted subgrade – 137 kPa (20 psi)
Impact factor for loading – 200 percent
Concrete strength (28-day) – 27 MPa (4,000 psi)
Concrete durability – shall be addressed during the concrete mix design
Minimum modulus of subgrade reaction (k) under slab – 95 Mpa/m (350 pci)
Allowable crack width in CRC slab – 0.3 mm (0.012 in.)
Fastener spacing – not addressed, but a 762-mm (30-in.) spacing on tangent track is typically used. A closer spacing is used on curved tracks.
Minimum fastener insert pullout load – 62 kN (14,000 lb)
Toe load for elastic clips – 10 to 14 kN (2,200 to 3,200 lb)
Vertical spring rate for direct fixation fastener – 15.8 kN/mm (90,000 lb/in.) (soft pad) to 52.6 kN/mm (300,000 lb/in.) (hard pad)
Track modulus – based on fastener pad deflection. Typically, 12.7 mm (0.5 in.) thick rubber pads allow a maximum deflection of 1.9 mm (0.075 in.) (15% of pad thickness).

A schematic of a CRC slab track system is shown in Figure 10. Various loading and stress components are illustrated in this figure. It should be noted that the concrete slab develops a transverse-cracking pattern within a few days after concrete placement due to volume changes in the concrete. Additional cracking may develop after the first winter. There after, crack development progressively decreases. Cracks are held tight by the longitudinal reinforcement. Desirable crack spacing in CRC slab (based on pavement related experience) is 0.9 to 1.5 m (3 to 5 ft). This spacing is achieved by using longitudinal reinforcement of 0.7 to 0.8% of the cross-sectional area of the concrete slab and depends on concrete strength and other factors. It is desirable to have a uniform crack spacing pattern and to minimize both the closely spaced (less than 0.6 m [2 ft]) as well as the widely spaced (more than 1.8 m [6 ft]) cracking. This can be achieved by having a uniform subbase support, uniform concrete quality and favorable ambient placement conditions.

Slab Thickness Design

The AREMA document does not incorporate any specific procedure for the thickness design of the slab. Reference is made to computer programs to perform analysis of slab track systems and the procedures used for thickness design of highway concrete pavements.

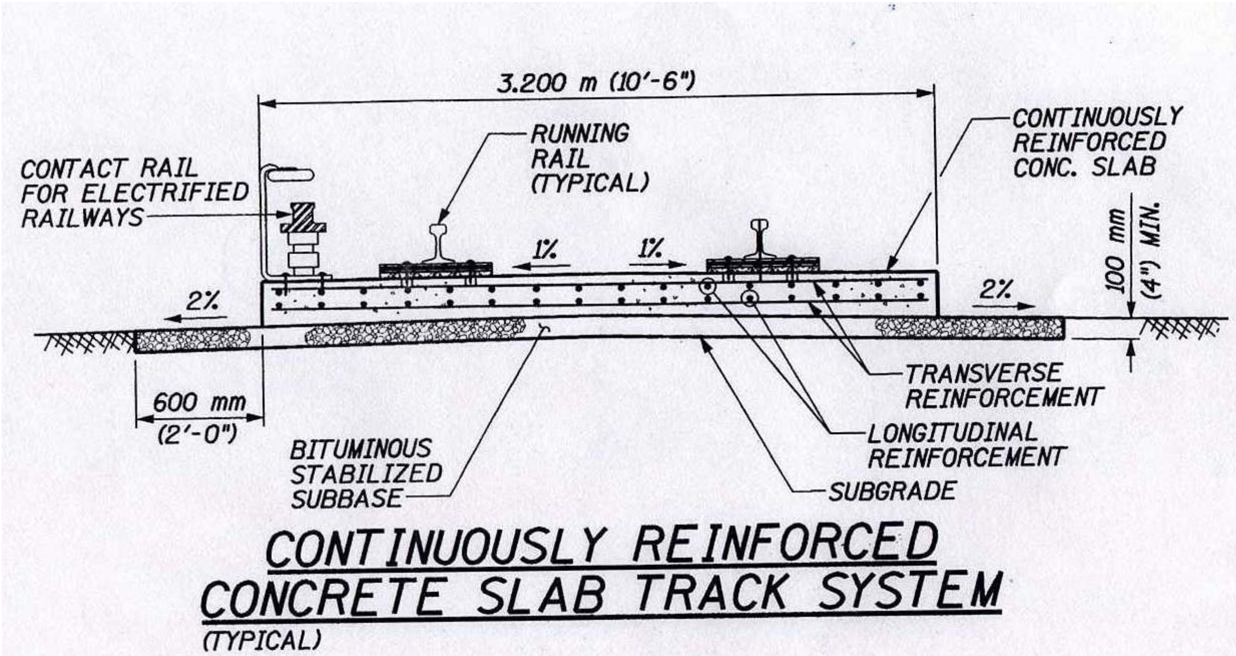

Figure 10 – Schematic of a Typical CRC Slab Track (Ref. 20)

For highway CRC pavements, the typical failure modes are punchouts and wide cracks that result in crack spalling. Punchout is a failure that develops when a longitudinal crack develops at about mid-width of the slab and between two transverse cracks as a result of "edge" loading of tracks. Under further traffic loading, the broken section further deteriorates and slab integrity is destroyed. Widened cracks develop as a result of large crack spacing caused by the use of small percentages of steel reinforcement. Essentially, the longitudinal steel yields at these locations and load transfer due to aggregate interlock at the crack is lost. This accelerates crack spalling and may also result in punchout failure.

For properly reinforced slab track, failure due to a widened crack is not expected to occur. Also, the use of a wide slab (e.g., the 3.2-m [10.5-ft] slab as recommended by AREMA) will minimize or eliminate the development of punchout failures, which are predominantly due to edge loading and non-channelized highway loadings. For the 3.2-m (10.5 ft) wide slab track, the loading under the rail is about 863 mm (34 in.) from the slab edge and this loading is considered an interior loading condition, which is far less damaging than an edge load. Also, this loading is perfectly channeled, that is, the loading is always maintained along the same location within the slab. There is no lateral wander of the loading, for example, as for highway CRC pavements. However, if the slab width were less, a concern may develop due to edge loading conditions. Edge loading conditions induce higher concrete stresses and higher slab deflections. These may lead to progressive cracking in the slab and deflection related failures such as slab settlement.

Analysis of Slab Track System Response

The following procedures are used to model the slab track system:

1. **Beam on Elastic Foundations Approach** – The rail is modeled as a continuous beam resting on an intermittent support (resilient pad), which in turn rests on a continuous beam (concrete slab) resting on another continuous uniform support (subbase/subgrade).
2. **Finite Element Analysis** – Several procedures are available and incorporate different degrees of complexities in terms of modeling and material characterization. These procedures include:
    a. Rail on discrete elastic support resting on a plate (slab) that rests on a spring (Winkler) foundation. This is an extension of procedures used for design of concrete pavements. The slab dimensions can be modeled realistically as can the wheel loadings The output is in terms of rail stresses and deflections, fastener loading and compression, and subbase/subgrade stresses. These procedures are readily available using customized software or general-purpose commercial software.
    b. Procedures similar to Item (a) above, but incorporating damping characteristics for the fastener and the subbase/subgrade support. Dynamic analysis of the track response can be performed.
    c. 3-D finite element analysis – Such analysis can be performed using general-purpose commercial software. These procedures are capable of providing static or time dependent stress and deflection response within the entire slab track system. However, only specialized analysis has been performed to date to investigate specific track component behavior. These procedures are not routinely used for design applications.

Slab track design procedures cannot entirely rely on analysis procedures until sufficient field verification and calibration have been performed using instrumented test sections and observation of field performance.

In addition to the above structural analysis procedures, there are also procedures available to determine crack spacing and cracks within a CRC slab on grade (Ref. 21). These procedures developed for highway concrete pavements can be readily applied to CRC track slab. Procedures are also available to determine the minimum amount of longitudinal reinforcement for CRC slabs (Ref. 22).

Slab Track Design Details

In addition to the structural design of the slab track system, it is also necessary to consider special design details. These details include the following:

1. Transition at structures
2. Transition to ballasted track
3. Transition at cut and fills
4. Continuity of slab track over bridge deck and tunnel invert

Transition at structures is typically achieved using multiple expansion joints near the slab end and use of a sleeper slab under the track slab for 7.6 to 15.2 m (25 to 50 ft) distance at the slab end. A typical detail for termination of a slab track at approach to a bridge is shown in Figure 11.

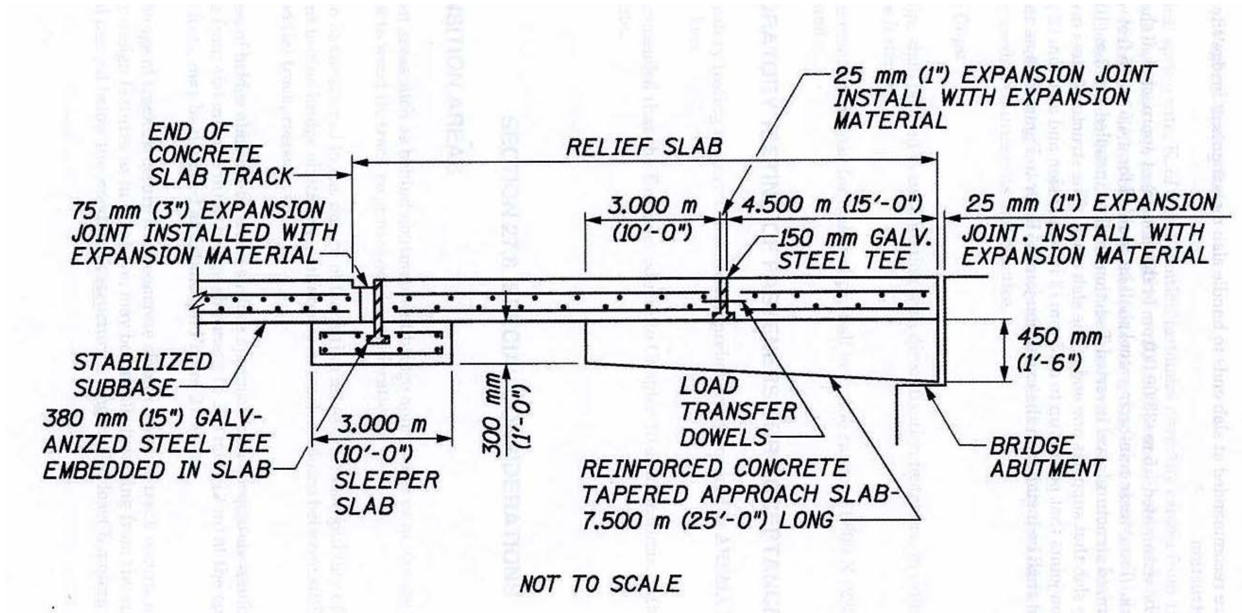

Figure 11 – Slab Track Details at Bridge Approach (Ref. 20)

Transition to ballasted track can also be achieved using a sleeper slab under the track slab, which is extended below the ballasted track for a distance of at least 6.1-m (20-ft). Transitions at cut and fill also need to be addressed carefully. This may be achieved by stabilizing the fill material or by having a thicker subbase in the fill area for a distance of 6.1 to 9.1 m (20 to 30 ft). The AREMA slab track document provides details for providing continuity of the slab track over bridge decks and in tunnels. The Japanese have performed full-scale tests of structure approach slabs on soils. For bridge decks, friction-reducing treatments (bituminous layer or polyethylene sheets) are used between the bridge deck concrete and the track slab. For tunnels, the existing invert concrete is brought to a sound condition by removing deteriorated surface concrete and replacing with concrete grouting material or new concrete to achieve the required elevation. The fasteners and rails are then placed directly on the repaired concrete surface.

Direct Fixation Fastener Requirements

Most of the slab track systems require use of a fastener system that directly attaches the rail to the concrete slab. The direct fixation fasteners provide the following functions:

1. Maintain gauge
2. Maintain alignment
3. Control longitudinal rail movement
4. Provide resilience

5. Provide electrical insulation
6. Reduce vibration and noise
7. Reduce rail stresses
8. Prevent abrasion of the concrete directly under the rail

The fastener assembly typically consists of one or two steel plates, elastomeric (rubber) pad, inserts, elastic clips, and insulators. The inserts allow the fastener to be attached to the concrete slab, the elastic clips hold the base of the rail to the fastener, the elastic pads provide the desired track resiliency, and the insulators mitigate stray electric currents. The elastic clips are also designed to exert sufficient force on the rail base to provide restraint to longitudinal movement of the rail. The fastening system in use at the Long Island Railroad's Messapequa section is shown in Figure 12.

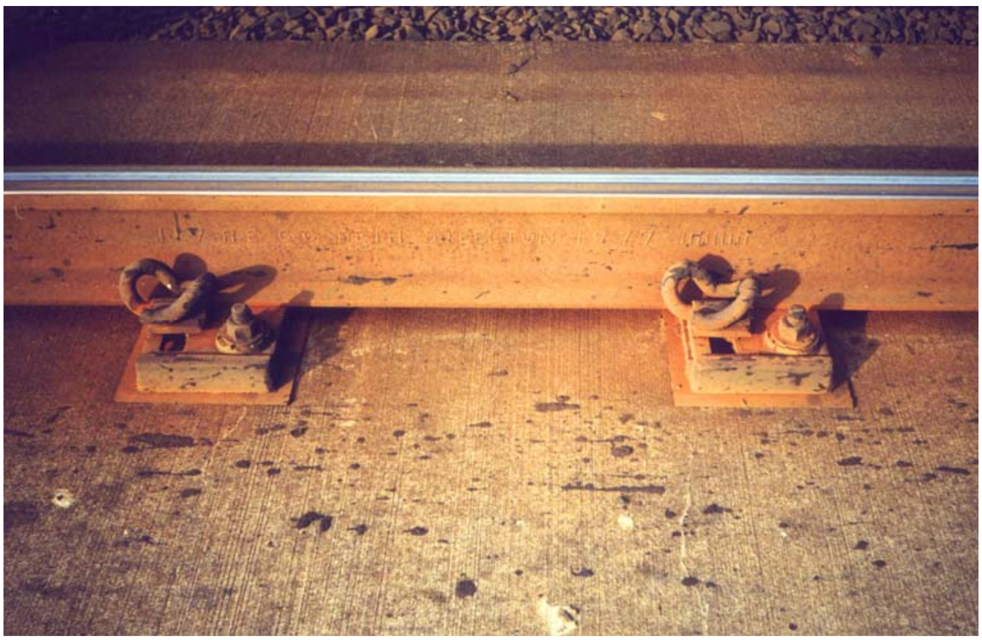

Figure 12 – Fastening System used at the LIRR Slab Track (after 20 years of service)

Fastener assemblies must meet the following requirements as verified by laboratory tests:

1. Spring rate between 14.0 to 52 kN/mm (80,000 and 300,000 lb/in.)
2. Maximum rail head lateral deflection of 7.6 mm (0.3 in.)
3. Longitudinal restraint not less than 10.7 kN (2,400 lb) per fastener
4. A dynamic to static stiffness ratio not greater than 1.5
5. A ratio of upward to downward deflection not greater than 2.05
6. No failure during 3 million cycles of simultaneously applied vertical and lateral repeated loads
7. No failure during 1.5 million cycles of upward and downward vertical loads
8. No failure during 25,000 cycles of longitudinal push-pull type load
9. Resistance to 15 kV direct current

10. Minimum resistances of 10.0 and 1.0 megohm for dry and wet fasteners, respectively
11. Minimum impedance of 10,000 ohms for wet fastener components
12. Resistance to corrosion and salt spray
13. Insert pull out resistance of 53.4 kN (12,000 lb)

Fasteners used for slab track have evolved from those used for concrete ties. The direct fixation fasteners for slab track need to allow vertical and lateral adjustment to minimize construction and maintenance effort/cost.

Proprietary products primarily developed for transit, commuter, and high-speed applications drive the direct fixation fastener market. Some of the more widely used fastener systems include the following:

1. Pandrol Systems (Ref. 23)
2. Sonneville System (Ref. 24)
3. Stedef System (Ref. 25)
4. L.B. Foster System (Ref. 26)

The Pandrol VIPA assembly uses a base plate, two studded natural rubber pads, and the Pandrol FASTCLIP and is marketed for passenger line applications. The Pandrol FASTCLIP, shown in Figure 13, is also marketed for heavy-haul concrete tie tracks. Another system marketed by

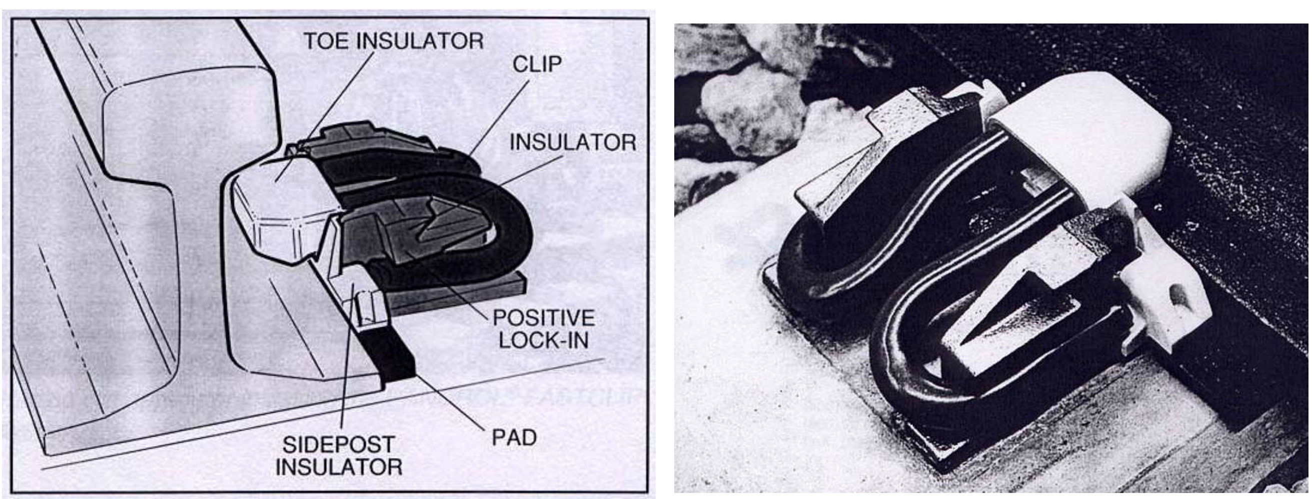

Figure 13 – The PANDROL FASTCLIP System (Ref. 23)

Pandrol for heavy haul concrete tie tracks is the Safelok System consisting of a shoulder, a clip, a pad, and an insulator. The shoulder is cast in place. The Pandrol “e” clip has also been in service for many years for concrete tie and slab-track applications. Pandrol is currently phasing out the “e” clips.

Sonneville has developed the S.75 rail fastening for use with the Sonneville low vibration track (LVT) and concrete ties. The S.75 system includes spring steel blades, cast in place inserts, nylon insulators and the "H" pad. The "H" pad has a greater bearing area on the field side than on the gauge side of the rail to minimize uneven pad wear.

Much of the direct fixation fastener development has been aimed at concrete tie systems and for slab track used for transit and high-speed rail. It is expected that significant additional development will not be necessary to produce cost-effective long-lasting direct fixation fastener systems for heavy haul slab track applications. Both the Pandrol clips and the Sonneville systems have reportedly provided acceptable service for concrete ties used on heavy haul lines. Current direct fixation fastener requirements have been developed on the basis of trial and error and experience under service conditions. The AREMA test specifications (Ref. 27) supplemented by agency developed specifications are usually specified for new projects.

Alternative Fastening Systems

A variant of the fastening systems discussed above is the technique used for the patented PACT-TRACK system. In this system, a continuous pad is used under the rail and the rail is held in place by elastic clips at discrete spacing. As a result, the load distribution under the rail is more uniform and the contact pressures lower than when pads are space at 0.6 m (2 ft). Also, rail stress is reduced when using a continuous pad and this may increase rail life.

Another unique rail fastening system is the embedded rail system developed in the Netherlands. In this system, continuous support is provided under and around the rail by means of a compound named Corkelast an elastomeric material. Other types of elastomeric and cementitious materials are also used in light rail applications.

Noise and Vibration Requirements

As noted previously, a significant developmental effort in recent years has been targeted at producing direct fixation fastener systems that are environmentally acceptable. The need to mitigate noise and vibration requires innovative solutions for fastener designs. Until recently, the noise and vibration reduction characteristics of fasteners were typically specified in terms of the fastener resiliency or elasticity. However, consistent procedures to measure fastener resiliency with respect to noise and vibration attenuation have not been available. During 1999, the European Standards Organization (CEN) published a provisional standard (ENV 1 3481-6: 1999) which sets out basic requirements for assessing the durability of vibration isolating rail fasteners as well as defining a procedure for measurement of the vibration isolation properties (Ref. 28)

For speeds up to about 300 km/h (186 mi/hr) rolling noise is predominant. Rolling noise is initiated at the wheel rail contact area because of surface irregularities, and the noise is then propagated by the wheel and the rail. Other noise sources include wheel/rail squeal on curves, aerodynamic noise, impact noise at joints and traction power noise. To mitigate rolling noise, which can be as high as 20dB(A), regular application of rail grinding, rail lubrication, track alignment maintenance, resilient rail pads and proper wheel design (19) are necessary. Concrete slab track and rail pads dampen some noise frequencies, but may reflect other frequencies, and this should be addressed in the design and maintenance of slab track.

This practice mitigates noise due to rolling, wheel/rail squeal, and impact. In Japan, the allowable noise levels for the Shinkansen lines are as follows:

Category	Standard
I – Mainly residential areas	70 dB (A) max.
II – Other areas – commercial & industrial	75 dB (A) max.

Slab Track Construction

At-grade cast-in-place slab track construction is typically a two-phase construction process as follows:

1. **Phase 1** – Construction of the slab and the substructure. This phase incorporates procedures similar to those used for concrete pavement construction. It involves the following steps:
    a. Subgrade preparation (grading and compaction)
    b. Subsurface drainage provisions, if needed.
    c. Subbase placement
    d. Form setting, if applicable
    e. Steel placement for CRC slab
    f. Concrete placement using a slip-form paver or side forms
    g. Concrete curing

2. **Phase 2** – After the concrete has cured, the rail fasteners and rails are installed, as follows:
    a. Insert locations are marked and insert holes are drilled
    b. Inserts are installed using epoxy grout. A number of inserts are tested for pullout strength as part of quality control
    c. Fastener assembly is installed and bolted to the slab using the inserts
    d. Rails are installed, aligned and secured to fasteners with elastic clips

The LIRR slab track projects were constructed using side forms for the concrete. For longer length projects and to achieve higher placement rates, slip-form paving is considered to be the most economical. Several slip-form pavers are available that can readily place narrow width track slabs (width of 2.4 to 3.6 m [8 to 12 ft]). The GOMACO Commander paver is one of these types of pavers. The PACT-TRACK construction involves use of a custom-developed slip-form paver that rides on rails and forms a sloping top surface in the slab.

Concrete Requirements

Concrete used for slab track construction is no different than that used for highway pavement construction. Therefore, material specifications developed by the local jurisdiction (State or

Provincial highway agency) can be directly adopted. The following minimum requirement should be noted:

1. Minimum 28-day compressive strength – 27 MPa (4,000 psi)
2. Minimum 28-day flexural strength – 4.1 MPa (600 psi)
3. Cement meeting requirements of ASTM C150
4. Aggregate meeting requirements of ASTM C33. A 25 to 38 mm (1 to 1½ in.) maximum aggregate size may be used. Special attention should be paid to susceptibility to freezing and thawing and alkali-aggregate reactivity.
5. Air entrainment – based on exposure conditions. Typically 4 to 7% total air content is specified for mild to severe exposure conditions.

Construction of slab track on existing roadbeds to replace ballasted track will require that the track be taken out of service. BNSF replaced 174 km (109 miles) of track at one time during the Thayer Blitz by rerouting trains over other lines. Concrete slab track can be constructed using a similar approach to that for the Thayer Blitz. Also, consideration should be given to the construction of slab track on new second or third track on heavy haul or high-speed lines.

Concrete Production

Concrete production procedures for slab track are similar to those used for concrete pavements. In urban areas, ready-mix concrete may be used. However, for larger projects and projects in rural locations, on-site plants are typically used. These mobile plants are re-located as the work progresses. Aggregate, Portland cement and water for the mobile batch plant can be economically transported by railroad car to the construction site.

Construction Tolerances

Construction tolerances are a critical issue for slab track construction. Tight vertical tolerances at the slab surface are typically required. This minimizes the need to use shims or to grind at fastener locations. The AREMA slab track document recommends vertical tolerance of +0 mm and –6.35 mm (+0 in. and –0.25 in.) for the finished concrete surface.

FRA Track Safety Standards Part 213 contains limits for track deviations from gage, uniform profile and alignment for nine classes of track based on speed. The class 9 (320 kmph (200 mph) maximum) track deviation limits are as follows:

- gage: 1.4 to 1.4 m (4 ft-8.25 in. to 4 ft-9.25 in.) with a maximum of 12.7 mm (0.5 in.) change in 9.4 m (31 ft)
- track surface: 12.7 mm (0.5 in.) per 9.4 m (31 ft) chord, 6.35 mm (0.25 in.) per 18.9 m (62 ft) chord, and 31.7 mm (1.25 in.) per 37.8 m (124 ft) chord
- alignment 12.7 mm (0.5 in.) per 9.4 m (31 ft) chord, 12.7 mm (0.5 in.) per 18.9 m (62 ft) chord and 6.35 mm (0.25 in.) per 37.8 m (124 ft) chord

Ranges of finished track tolerances used for transit track projects are listed below (Ref. 2):

1. Finished Track
   - Gauge ±2.03 to 2.54 mm (0.08 to ±0.10 in.)
   - Cross Level ±3 mm (0.12 in.) per 10 m (32.8 ft)
     ±5 mm (0.20 in.) per 20 m (65.6 ft)
   - Alignment ±4 mm (0.16 in.) per 10 m (32.8 ft)
     ±6 mm (0.24 in.) per 20 m (65.6 ft)
   - Cant ±2.54 mm (0.10 in.) per rail base
   - Twist 1:850 to 1:1000

2. Level of Track Layers
   - Subgrade ±30 mm (1.18 in.)
   - Subbase ±10 mm (0.39 in.)
   - Slab ±5 mm (0.20 in.)
   - Drilled Holes ±5 mm (0.20 in.) in any direction

The tolerance limits established for the high speed Shinkansen rail lines are given below (Ref. 3):

Track gauge	±1, -2 mm (0.04, -0.08 in.)
Cross-level	±1 mm (0.04 in.)
Longitudinal level	±2 mm (0.08 in.) per 10 m (32.8 ft)
Alignment	±2 mm (0.08 in.) per 10 m (32.8 ft)

The tolerance levels for the PACT-TRACK slab are reported to be 1 to 2 mm (0.04 to 0.08 in.) per 10 m (32.8 ft) because of the direct placement of the rail on the continuous rail pad.

Other Slab Track Construction Techniques

As discussed previously, slab track systems other than cast-in-place CRC slab tracks have been used. These include the embedded block/tie systems, the two-slab layer system, the embedded rail system variant, and several proprietary systems. The constructability of these systems has been well proven through the construction of many miles of these systems in North American, Europe, and Japan.

Slab Track Performance

Slab track technology has evolved over many years, initially through trial and error using field installation of a prototype system and in recent years through extensive laboratory testing and engineering analysis using finite element analysis techniques. Many of the early slab track systems were not thoroughly designed and properly constructed and some of these systems did exhibit early failures. However, the slab track technology has matured and the slab track projects constructed in the last 20 years and now under construction are expected to provide very low-maintenance service lives of 30 to 50 years.

A review of literature indicates that at-grade slab track systems appear to be performing well for passenger applications and for limited heavy haul railroad applications. No abnormal problems with slab track performance have been reported in recent years. A discussion of key performance related issues are presented next.

Slab Track Effect on Rail Wear

Data are not available to compare rail wear for ballasted and slab track systems. According to Dr. Ando, of the Japanese Railway Technical Research Institute, the slab track stiffness does not affect rail life negatively (Ref. 29). The use of lower stiffness rail pads or rubber mat under the top slab of a two-slab layer system mitigates rail wear. It should be noted that rail wear and rail noise and the need for rail grinding are also affected by wheel flats.

Direct Fixation Fastener Performance

The direct fixation fastener assembly is a multi-component assembly and can experience poor performance under service conditions as follows:

1. Insert pullout – not a common occurrence.
2. Tie pad degradation – older tie pads may exhibit set after many years of service and may require replacement.
3. Elastic clip failure may develop as a result of broken shoulder – not a common occurrence
4. Insulator failure
5. Concentric component failure

Fastener technology has improved greatly in recent years and commercially available fasteners that can provide long term service for high speed as well as heavy haul applications are now commonly used on concrete tie installations and are readily available.

Concrete Slab and Substructure Performance

Properly designed and constructed concrete slab can be expected to provide reasonably distress free service for 30 to 50 years. However, it is necessary that the substructure design consider provisions for drainage and frost heave. If subgrade soils are poor, unconsolidated or weak they should be removed and replaced with properly compacted backfill. One railroad geologist indicated that 90% of subgrade along the track right of way performs well and that only 10% of the subgrade require remediation. Adequate soil exploration should be conducted to locate poor subgrade soils where slab track is to be installed.

Inadequate drainage continues to be a concern for highway concrete pavements and railroad track. The case of slab track should be treated no differently. Compliance with AREMA Manual subgrade and drainage recommendations is very important. With a 3.05 m (10 ft) plus wide CRC slab track, distress typical of CRC pavements are not expected to develop and have not developed, for example, along the LIRR slab tracks. A view of the LIRR's slab track section is shown after over 20 years of service life.

Figure 14 – The LIRR Messapequa Slab Track Section after 20 years of service

Slab cracking was reported at the Albert Canyon PACT-TRACK test section in British Columbia. The cracking developed as a result of pumping at the cut/fill transition. It should be noted that the PACT-TRACK system uses a slab width of only about 2.4 m (8-ft). It should also be noted that the 15.6 km (9.8 mile) long PACT-TRACK system installed in the McGregor Tunnel during 1986 is reportedly performing satisfactorily under the 90 million gross ton per year loading.

Life Cycle Cost Considerations

The initial cost of slab track is higher than that of ballasted track. Agencies in Europe and Japan have developed criteria to properly evaluate the cost-effectiveness of slab track. The Japanese consider the slab track to be cost-effective if the initial cost is less than 1.3 times that of ballasted track. The Europeans also use similar criteria. For high speed lines, it is expected that the higher initial cost of the slab track would be recovered within 8 years of revenue service due to reduced maintenance costs and reduced downtime for the slab tracks.

It is reported that track maintenance costs for ballasted track range from $12,500 to $31,200 per km ($20,000 to $50,000 per mile). Ballast has to be tamped every 15 MGT. Rail replacement is done on a routine basis after 3 to 5 years on heavy haul railroads carrying annual 70 MGT or more. Rail grinding is also done on routine basis on passenger service lines to mitigate noise and vibration irrespective of track type. Tie replacement is done at an average rate of 38 to 62 ties per km (60 to 100 ties per mile) per year depending on service condition.

Ballasted tracks require more frequent routine maintenance to reclamp and replace ballast, to replace ties and to correct alignment. For heavy haul lines, this is a major cost item and can lead to significant revenue loss due to track down time or longer re-routing of trains. The cost of re-routing trains has been estimated as follows (Ref. 30):

Annual Tonnage (MGT/year)	Cost of Re-Routing ($/mile)
30	120,000
60	252,000
90	378,000
120	504,000

The above costs include fuel, track maintenance, and operations costs and are based on one week of track closure and re-route distance of 192 to 200 km (120 to 125 miles).

In the North American market, the cost of slab track construction on a larger scale is expected to be very favorable because of the ready availability of slab construction equipment and expertise. Because cost data for large scale at-grade slab track construction in the U.S. are not available due to lack of such projects, it is expected that initial construction costs can be kept in the range of 1.3 to 1.4 times that of the ballasted track as has been the case in Europe and Japan. In fact, for the simpler cast-in-place construction, it is possible that the slab track costs can be kept below 1.2 to 1.3 times the cost of ballasted track. Such a cost differential can be recovered within 5 to 10 years for heavy haul rail lines.

Summary

Conventional ballasted track systems have served the railroad industry well over the last 150 years. The systems are expected to also serve the needs of the industry in the future years. However, with the ever-increasing tonnage on major railroads and the demand for efficient high-speed passenger service, improved track structure systems are needed. The various types of slab track systems discussed in this report will be at the forefront of the solutions to construct the improved track structures that will be demanded in future years.

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