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Publication of this paper sponsored by Committee on Track Structure System Design.

Innovations in Track Structures on Long Island Rail Road—Rationale, Design Criteria, and Performance

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During the last 20 to 25 years, the Long Island Rail Road (LIRR) has designed or participated in the design and construction of various grade elimination projects. The earlier projects (1958-1970) entailed embankment sections with conventional track structure—wood ties, jointed rail, and ballast. The viaduct sections were cast-in-place, reinforced concrete deck with ballast, wood ties, and jointed rail. Since 1970 LIRR has embarked on various innovative track structures and their associated components, which entailed continuous welded rail, elastic fastener clips, direct fixation fastening system, and concrete slab track. Some of the considerations in selection of the new design features were availability of technology, improved ride quality, faster operating speeds, and reduced maintenance costs. Various improved track structures are discussed in this paper and the rationale, design criterion, field measurements, findings, and performance are described.

Between 1912 and 1916 concrete slabs were installed on three separate occasions on soft roadbed for the support of ordinary ballasted track. These installations were

1. Under main line crossovers in Jamaica,
2. Under main tracks on a 20-ft fill behind bridge abutments, and
3. On a silt fill at the rear of a bulkhead for loading car ferries.

The first installation entailed 73,000 ft² of cast-in-place concrete subballast slabs under 49 turnouts in the Jamaica Interlocking (1). Concrete slabs were 8-in. thick and unreinforced. A few years after construction a cave-in occurred under one of the slabs. The supporting slab held the ballast and track intact, and the traffic was only delayed slightly. After nearly 70 years of passenger and freight traffic, these installations are still performing satisfactorily.

PROJECT CORRIDOR

The Babylon branch on the Long Island Rail Road (LIRR) is the busiest. Every day it carries 33,452 commuters in the morning (6:00 to 10:00 a.m.) and 27,426 commuters in the afternoon (4:00 to 7:00 p.m.) and employs 148 commuter (revenue) trains. The average train speed is 60 mph and the maximum speed is 80 mph. The 40-mile trip from Babylon to Pennsylvania Station, central business district (CBD) of New York City, takes 53 min (minimum) travel time. Twenty-five percent of the daily commuter traffic is

on this corridor. Some freight traffic also uses this branch. Traffic is estimated at approximately 12 million tons per year. During the last 20 to 25 years the various sections of this route have been elevated, thus eliminating the accident hazard at the grade crossings between trains and vehicular traffic. The elevated structures are either earth embankments, simple span concrete viaducts, or individual bridges.

The various rail improvement projects constructed during the last 25 years are presented in this paper. The track structure elements of these projects will be emphasized. The focus is on the evolution of track structures in these projects. First conventional wood tie ballast was used, followed by direct fixation track, and finally concrete slab track structures were used.

CONVENTIONAL TRACK STRUCTURES

From 1958 through 1970, LIRR was involved in various rail improvement projects. Nearly 20 miles of double tracking was constructed on the Babylon corridor as part of grade elimination projects. The projects included elevation of railroad tracks in Nassau and Suffolk Counties of New York.

Embankment Sections

Embankment sections were an average of 17- to 20-ft high. Track structures were comprised of 12-in. standard ballast section. Wooden ties (7 in. x 9 in. x 8 ft 6 in.) at 21.25 in. center to center. The running rail weighed 115-lb in 39-ft lengths. The ends of the rail sections being joined by means of joint bars and bolts thus formed an expandable joint. The rails were attached to the wooden ties by cut spikes driven through holes in tie plates that were inserted between the base of the rail and the top of the tie. Figure 1 shows a typical wood tie track.

Concrete Viaducts

Concrete viaducts were either cast-in-place deck or prestressed beams with poured-in-place composite concrete decking. Track structure was composed of 115-lb running rail (39-ft sections fastened with

Figure 1. Wood tie track.



joint bars), two parallel 100-lb guard rails for full length of viaduct that terminated 150 ft beyond the end of viaduct structure, 7-in. x 9-in. x 8 ft 6-in. wooden ties, 12-in. ballast section with 1-ft shoulder, and rail hold-down devices made of cut spikes driven through tie plates. Every other tie was box anchored.

The specifications for track materials and construction conformed to the appropriate sections of the American Railway Engineering Association (AREA) document (2).

Bridges

Bridges were either steel stringers, floor beams and concrete deck, or prestressed concrete beams with cast-in-place composite deck. Track structures were the same as used on the viaduct structure.

Construction

To minimize settlement and associated track maintenance at the approaches and behind the abutments the track was laid on reinforced concrete approach slabs cast on subgrade. Dimensions were 10-ft wide and 10-ft long over which the ballast was installed.

Numerous improvements in design of support and superstructures of viaducts and bridges occurred over the years; however, the track structure and its components remained virtually the same. Some of the possible reasons for lack of improvements and changes in track structures are the following:

1. Current standards of track have evolved from previous practices through trial, judgment, and experience;
2. Because research in the railroad industry is lacking and railroad engineering has a low priority in academics, the railroad track has not been developed in the same manner as have most engineering structures;
3. Track engineers and maintenance supervisors are comfortable with the wood tie and ballast track structure with which they have many years of construction and maintenance experience;
4. Management and decision makers lack the initiative to introduce new track technology and hardware that have been developed and deployed in Europe and Japan; and
5. Conventional track structure, because of its inherent design and construction materials, involves standardized replaceable components (e.g., rail, ties, ballast, and hold-down devices) that are both

readily and economically available in the market. Manufacturers therefore lack financial incentive to develop and market new track components and materials unless railroads and rapid rail transit systems demonstrate commitment to design and construction of improved track structures.

IMPROVED TRACK STRUCTURES

From 1970 through 1980 LIRR in conjunction with the New York State Department of Transportation embarked on various rail improvement projects. The following projects entailed some improved and innovative track structures.

1. Amityville-Copague-Lindenhurst (ACL) Grade Elimination Project--This project included 5.0 miles of double track (10.0 track miles) in an urban environment, and 3.32 miles of two adjacent concrete viaducts with direct fixation fastening system (DFFS) and continuously welded rail (CWR). The embankment section was constructed with conventional wood tie track and ballast. Revenue traffic commenced August 1973.

2. Merrick-Bellmore (MB) Project--This project included 3.32 miles of double track (6.64 track miles). It included concrete viaduct sections nearly 1.0 mile long with direct fixation and CWR. It also included an embankment section with wood tie track. Traffic commenced in 1975. A view of precast-prestressed viaduct is shown in Figure 2.

3. Massapequa Park (MP) Project--This project included 2.3 miles of double track (4.6 track miles) and 1,400 ft of concrete viaduct with continuously welded rail and DFFS. Figure 3 shows the viaduct with direct fixation and welded rail. An important feature was 1.13 miles of two parallel, continuously reinforced concrete (CRC) slab tracks on an embankment section with CWR and direct fixation; thus, wood ties and ballast components were eliminated. The MP project opened for revenue traffic in December 1980.

Most of the improvements have occurred in the following domains of track structures:

1. Heavy CWR instead of a lighter section of jointed rail,
2. Elastic rail clips instead of conventional hold-down devices on ballasted track,
3. Concrete viaduct and bridge deck with direct fixation instead of ballast and wood tie structure, and

Figure 2. Precast and prestressed concrete viaduct.



Figure 3. Viaduct with direct fixation and welded rail.



4. Concrete slab track on embankment instead of conventional wood tie track and ballast.

119-lb Re-CWR with 12-in. Ballast Section

For the last 10 years LIRR has had an ongoing program to replace the jointed rail on existing track structures with 119-lb re-CWR, both at grade and on newly elevated structures, including embankments, viaducts, and bridges. The new rail improvement projects have as standard design, continuously welded 119-lb rail (on wood ties, embankment section, and in conjunction with direct fixation) on concrete viaducts, steel and concrete bridges, and concrete slab track.

Advantages

The advantages of the 119-lb re-CWR include lower maintenance costs compared with that for jointed rail because the joints are not continuously damaged by the wheel due to discontinuity and uneven alignment of the adjacent rails. The noise generated because of impact of wheel with joints is minimized, which is especially important in the urban environment through which LIRR traverses. Also, the ride is more comfortable for the passengers when 119-lb re-CWRs are used.

Rationale and Considerations Leading to Design

LIRR has different operating conditions because of mixed service. The same trackage has to accommodate high-speed passenger trains and slow, heavy tonnage freight. Different design and maintenance restraint are necessary to satisfy these mixed operating parameters.

Compensation for curves by providing superelevation in outer rail is generally a compromise. The outer rail is set for freight and passenger trains are run above the balanced (equilibrium) speed of the curve. Maximum authorized speed is established by taking into consideration the degree of curve and superelevation based on 1.5-in. unbalanced. Maximum superelevation is limited to 6 in.

Maximum grade is limited to the 1 percent range on the main line because of adhesion and concern for possible leaves on the tracks. In tunnels grade is limited to approximately 3 percent (maximum).

LIRR standard conventional track requires 12-in. minimum ballast section below the bottom of the tie. Although the conventional track could be reduced to 8 or 10 in., because of the need to permit

free drainage, to permit adequate depth for tamping, and to prevent contamination of ballast, the 12-in. depth is considered cost effective.

AREA recommends that the deflection of the rail not exceed 0.25 in., and that maximum rail bending stresses be less than 11,000 psi (2). LIRR's standard is 119-lb re-CWR on the main line track. Theoretically by allowing an increase in rail deflections the stresses in rail could be decreased; however, a corresponding increase in track deterioration can occur. Moreover, contact stresses in rail are more critical than bending stresses. Further optimization on rail weight is not considered justifiable because the savings in weight would be outweighed by an increase in maintenance costs, a decrease in stability against track buckling, and an increase in rail wear, especially on curved trackage.

Nearly 60 percent of the LIRR's main line tracks are electrified by third (contact) rail. The running rails are also used as negative returns for power. By using a 119-lb rail and not a lighter section of rail, which may satisfy the stresses and deflection criteria, LIRR is able to optimize on substations spacing (average 1.5 miles) and save on the cost of additional cable as return along the running rail.

The LIRR standard requires that rail temperature of CWR be raised to between 80 and 105 degrees at the time of anchoring. If rail temperature is below this range, a rail heating device must be used. If rail temperature exceeds 105 degrees, rail should be cooled by applying water. This is required because of concern for possible track buckling.

Performance

Performance can be summarized as follows:

1. The use of 119-lb rail as standard weight on the main line tracks has reduced track deterioration and maintenance,
2. The stability against track buckling has increased, and
3. In combination with 12-in. ballast and CWR, ride comfort has increased and the problem of noise has been minimized due to elimination of joints.

Elastic Rail Clips on Ballasted Track

During a 10-year period most of the main line trackage has been or is in the process of being rehabilitated by replacement of cut spikes and plate as rail hold-down devices with elastic fastener clips and plates on wooden ties. Figure 4 shows a wood tie track with elastic fastener clips.

Considerations and Advantages

1. The problem associated with spike kill of timber ties is greatly reduced by use of a resilient rail clip;
2. By increasing toe load (2,200 lb per fastener) longitudinal rail creep can be controlled and, in case of rail failure, the pulling apart of rails can be kept to a minimum;
3. Because the base of rail is anchored positively the clips cannot loosen and so less maintenance is required;
4. Installation requires only simple tools and unskilled labor; and
5. Elastic rail clips facilitate the operation of distressing CWR; elimination of the expansion joint in rails because of CWR results in development of internal stresses in the rail attributable to thermal changes.

Figure 4. Wood tie track with elastic clips.



Performance

Rapid mechanical tie wear under the tie plate was a significant track maintenance problem. The use of elastic rail clips and special tie plates held to the ties by lock spikes has kept the problem of tie wear to a minimum. Thus, the average tie life has been increased by at least a few years from the current average of approximately 28 years on main line track.

DFFS

Some of the track components that require periodic renewal or replacements are the ballast and wood ties. By eliminating these components on bridges and viaducts and replacing them with rail directly attached through fasteners to the concrete deck, the following could be achieved:

1. Reduced maintenance costs,
2. Improved reliability of track and faster operating speeds, and
3. Less interference to operations of revenue traffic because of less track time required for maintenance.

Design Objectives

Rail fasteners for installation of rails on continuous structures, such as bridges or viaducts, must satisfy the following objectives:

1. Maintenance of rail alignment,
2. Control of longitudinal rail movement,
3. Electrical insulation for electrified railroad,
4. Control of vehicle motions,
5. Control of structural loads,
6. Provision for vertical and lateral adjustment of rail (LIRR specifies ± 0.5 in. and ± 1 in., respectively),
7. Provide resilience to help reduce the effect of dynamic impact on track structure, and
8. Exhibit resistance to weather and oil.

The normal procedure is for each section of welded rail to be heated at installation to pretension to ensure that the rail will remain in tension for most temperatures. Thus, the rail does not expand or contract as long as the fastener also remains stationary. On a bridge or viaduct, how-

ever, the fastener will move (or attempt to move) as the spans of the deck expand or contract under temperature changes. Thus, the rail should be allowed to slip in the fastener once the load exceeds that needed to retain the rail under breaking or tractive efforts. Typical values for maximum longitudinal force that can be resisted without slipping of the rail in the fastener are approximately 3,000 lb.

In addition, if a fastener that is not resilient has an excessive toe load that prevents movement of the rail in the fastener, then this force can be transferred adversely into the concrete deck and possibly cause structural distress or even failure. On the other hand if toe load is not adequate then, in the case of rail breakage (winter conditions), the fastener may be unable to hold the pull-apart forces in CWR and a potential derailment condition is created.

Installation and Fastener Details

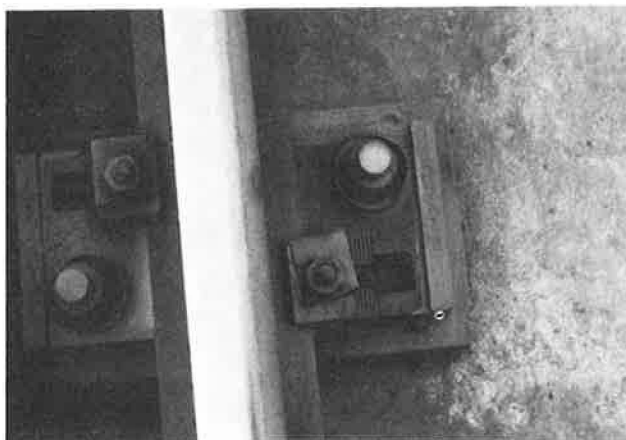
The laboratory testing and evaluation of test results included the following tests:

1. Static load tests--vertical load test, lateral load test, and longitudinal restraint test;
2. Repeated load test--vertical repeated load test; and
3. Elastomer test.

The first direct fixation track was installed on the ACL project in 1973 on nearly 3.32 miles of concrete viaducts along with CWR. Concrete viaducts were simple span, prestressed concrete beams that have 8-in. reinforced, cast-in-place composite decks. This installation entailed 119 lb re-CWR fastened to the concrete slab with elastic rail fasteners installed at 30-in. spacing. Rail fasteners included 7 x 15 x 1.5-in. laminated base plate made of a neoprene sheet sandwiched between two layers of steel. The base plate provides for vertical and lateral adjustments of 0.5 and 1.0 in., respectively. The fastener was installed on a concrete grout pad and is of the same design mix as the concrete deck (4,000 psi). The grout pad was 17 x 17 in. and varied in height from 0.5 to 1.5-in. Figure 5 shows original DFFS on the grout pad. The fastener was held to the slab by a spider and stud arrangement. The final hold-down was a nut and a standard lock washer. The rail was secured to the fastener by the standard bolted rail clip.

The second installation was part of the MB project on 1.0 mile of concrete viaduct that opened for

Figure 5. Original DFFS on grout pad.



revenue service in 1975. The third installation was part of the MP project opened for traffic in 1980. DFFS was installed by using presetting of anchor bolts on 1,400 ft of concrete viaduct and by coring after placement of concrete in a 1.13-mile long concrete slab track. In this installation the design was modified with the following variations. The fastener was installed directly on the viaduct and slab track instead of being placed on the grout pad. A 1/8-in. thick polyethylene pad (17.25 x 9.25 in.) was laid between the base of fastener and the top of slab. Its function was to act as shim for vertical adjustment and also as an insulator. The original nut and lock washer holding the base of rail were replaced by a casting and elastic clip that fit into the same slot in the top of the fastener plate as the original bolted clip. Figure 6 shows DFFS with elastic clip on the polyethylene pad.

Problems, Performance, and Modifications

In mid-1978 at the first two installations that had been in service for 3 and 5 years, respectively, the rail-holding clips were found to be loose even after repeated tightening on a considerable number of spans. An emergency program of design modification and replacement was instituted. The replacement was a casting developed by the manufacturer in order to fit an elastic fastener clip. The casting slipped into the original hole in the fastener, and the action of the fastener clip locked the casting to the top of the fastener, thus behaving like a shoulder and providing the necessary longitudinal and lateral restraint to the rail. Figure 7 shows modified DFFS on the grout pad.

By mid-1981, when nearly 70,000 clips and adapter castings had been installed on these two projects, no failure, distress, or loosening had occurred. The third installation at the MP project with the modified fastener has performed satisfactorily since commencement of revenue traffic in 1980. In addition, because of elimination of the ballast due to direct fixation, the clogging of viaduct and bridge drains has been eradicated as a maintenance problem and expenditure.

Concrete Slab Track

A slab track system consisting of a concrete slab supported on a subbase and well-compacted subgrade is one example of an improved track structure. In December 1980 LIRR opened for revenue traffic, two nearly parallel, 1.13-mile-long concrete slab tracks

Figure 6. DFFS with elastic clips on polyethylene pad.

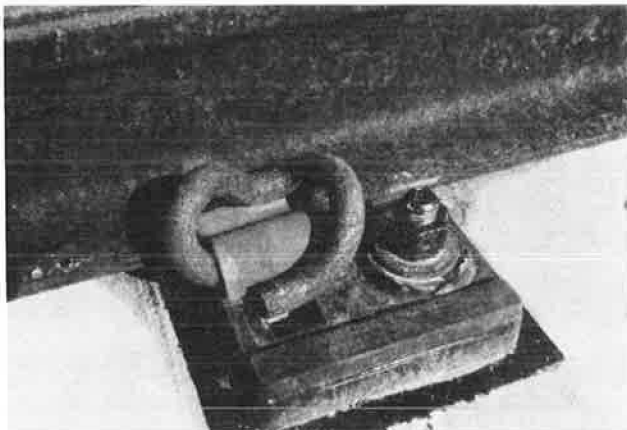


Figure 7. Modified DFFS on concrete grout pad.

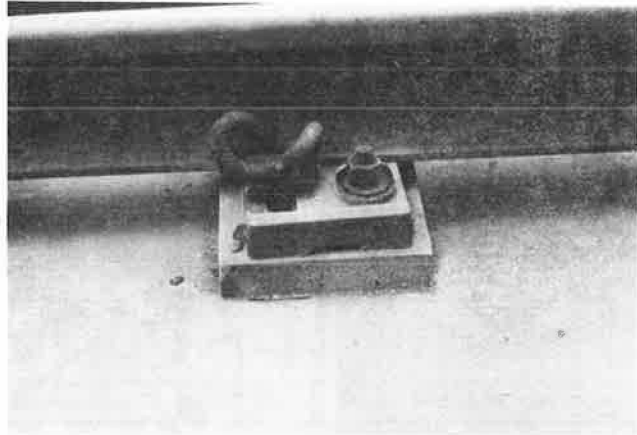
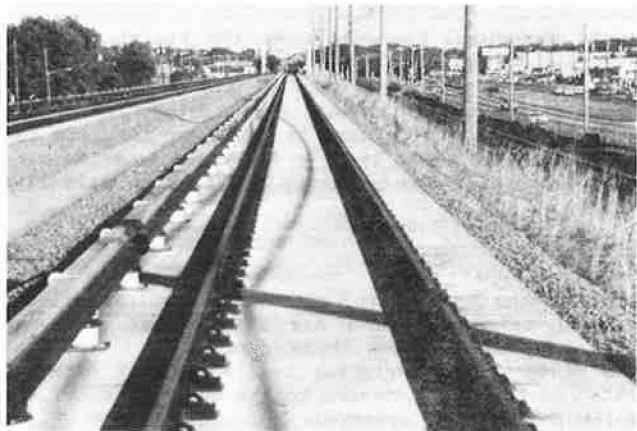


Figure 8. View of slab track.



as part of the MP grade elimination project. A view of this slab track is shown in Figure 8.

Considerations for Selection of Slab Track System

Considerations for the selection of a slab track system include the following (2):

1. Elimination of ballast, ties, and associated maintenance,
2. Use of rail fasteners with better lateral and longitudinal restraint characteristics,
3. More uniform load distribution on the subgrade so that settlement is reduced,
4. Maintenance of proper lines and surfaces to reduce the need for frequent surfacing and lining,
5. Improvement of ride quality and faster operating speeds when combined with CWR,
6. Less disruption of traffic because of reduced maintenance, and
7. Less wear and tear, and thus maintenance, for the rolling stock because of improved track conditions.

Rationale, Design Considerations, and Details

Based on current practices, the following criteria were used for track design (3):

1. Subgrade pressure not to exceed 20 psi,

2. Rail deflection not to exceed 0.25 in.,
3. Rail bending stress not to exceed 11,000 psi, and
4. Direct bearing pressure not to exceed 30 psi.

The following slab track requirements were studied and established for track design:

1. Track must be structurally adequate and capable of maintaining alignment and profile,
2. Fastening assembly must possess the capability for lateral and vertical adjustments, and
3. Slab must have provision for attaching contact rail assembly.

The design and construction specifications of CRC slab track were developed by using the existing construction technology available in North America for CRC highway and airfield pavements. This ensured that the initial cost of the slab track was economical (4).

The design life (50 years) and possible maintenance to the track structure were paramount considerations. The solution was to design and construct a track structure that can eliminate most maintenance costs. Hence, the life-cycle costs of the system were to be optimized.

The design was formulated by using the subgrade modulus of reaction (K) and the elastic theory analytical techniques. The track structure involved three distinct materials. The compacted subgrade (cohesionless, sandy, or granular material) has a low stiffness, overlain by a 6-in. thick stabilized, bituminous layer and then the 12-in. reinforced concrete slab track that is stiff material. Hence, the transition from the low stiffness material to the stiff concrete material is gradual. This ensures that the stresses induced by the rolling stock are minimized in the various layers, thus the entire guideway performs satisfactorily.

The thickness of the concrete slab was established by considering both the fatigue effect and static wheel load of a 50-year cycle of E-72 Cooper Railway repetitive loading by using a 25 percent impact factor (5). Slab thickness of 12 in. was computed as being adequate and rigid enough to withstand (a) warping stresses (temperature differential of the top and bottom of the slab), (b) bending stresses produced by wheel loads, and (c) longitudinal stresses induced as a result of anchoring CWR to the concrete slab.

Adequate reinforcement was provided to ensure that cracks are held tightly closed together (0.012-in. maximum) so that the passage of water or moisture to reinforcement is prevented and potential corrosion concerns are eliminated.

Steel reinforcement had to be sufficient to maintain aggregate interlock for transfer of the load at the crack locations. Analytical computations revealed that the stresses in the reinforcement at the crack location during winter could reach close to the yield stress (60,000 psi) merely because of temperature (weather) effects. In addition, live loads from the train could cause the yield stress to be exceeded. Therefore, a higher percentage of reinforcement (0.9 percent) was used than the general practice of 0.6 percent reinforcement for CRC highway pavements.

Slab Track Details

Details of the slab track are as follows:

1. Slab dimensions: 10 ft 6 in., 12 in. thickness at rails;

2. Reinforcing steel: Longitudinal 0.9 percent of gross section--18 No. 6 bars spaced 7-in. apart on the bottom layer and 18 No. 5 bars spaced 6- to 9-in. apart on the top layer; splices must be at least 24-in. long; at construction joints 10-ft long No. 5 bars (12 bars on top and 9 on the bottom) are added; transverse--No. 4 bars spaced 24-in. apart at top and bottom;

3. Compressive strength of concrete at 28 days: 4,000 psi;

4. Bending stiffness (EI): 6.95×10^{10} lb-in.² (6);

5. Subbase: 6-in. thick stabilized bituminous course extending 2 ft at each end, total width 14 ft 6 in.;

6. Running rail: 119-lb AREA CWR. Field welds required about every 650 ft;

7. Resilient fastening assembly: Fastener 7 in. x 15 in. x 1.5 in., anchor bolts 7/8-in., torqued to 200 ft-lb, elastic clip holding rail down, and 1/8-in. thick polyethylene pad under fastener;

8. Contact rail: 150-lb;

9. Track gauge: 4 ft 8.25 in.;

10. Maximum curve: 0 degree 30 min.;

11. Concrete cover: 3 in.;

12. Ballast: 3.0-ft shoulder for additional lateral restraint; and

13. Embankment: Average 17.0-ft high.

A cross section of slab track is shown in Figure 9.

FIELD MEASUREMENTS AND FINDINGS

LIRR has a track geometry car to ensure that the LIRR's track parameters are in compliance with FRA track safety standards. FRA stipulates minimum track standards based on operating speeds for both the condition of components and the track surface and line. FRA inspects and enforces certain track standards that must be maintained by the railroads in order to continue operations at posted speeds.

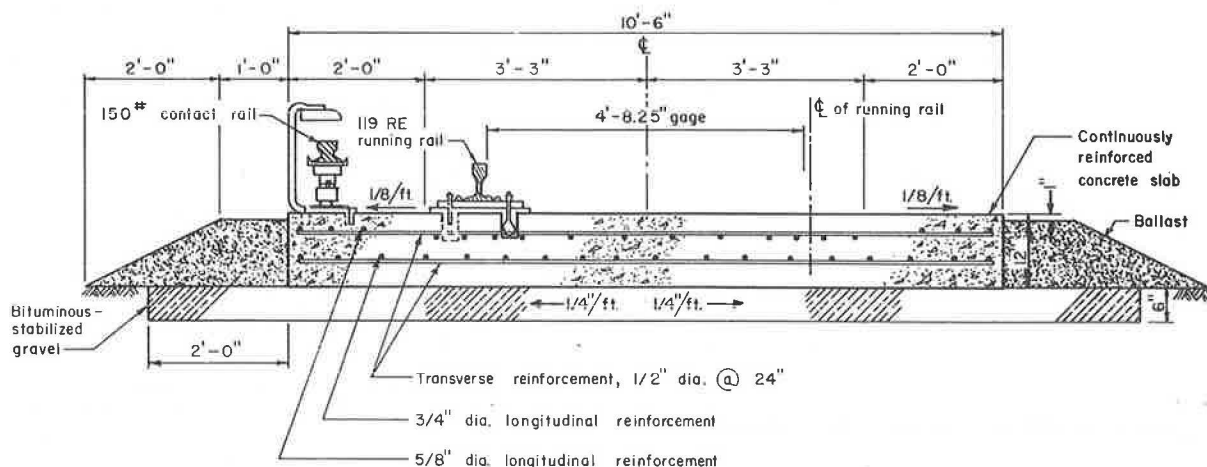
The MP slab track project also involved an extensive instrumentation and field measurement program from 1980 through 1982. The objective of the testing program was to determine adequacy of design and suitability of this advance track structure for possible future projects.

Track Geometry Car Measurements

LIRR is primarily a commuter passenger operation that has some freight traffic. The track geometry car operates and records track measurements, including track gauge, cross level, and twist, over the main line tracks on a quarterly basis and in the yards and sidings on a semiannual basis.

Since the track geometry car began operation in 1976 on these improved track structures, no deterioration of track geometry has been found. Moreover, with the experience gained in maintaining track standards as established by FRA, LIRR has instituted somewhat tighter threshold values in the exception tables of the computer software. FRA allows the gauge of curved track for speeds up to 60 mph to be 1.25-in. wide; however, LIRR has stipulated that the criterion not exceed 0.75-in. wide. Our experience has been that the track can be maintained to this requirement with little additional effort. The track car is used to identify, measure, and document the track geometry conditions that need corrective action. It is also used as a tool for input into the planning of a track maintenance program and maintenance-of-way budget.

Figure 9. Cross section of slab track.



Slab Track Field Measurements and Findings

Field Testing Program

A measurement program was formulated and instituted in collaboration with the Portland Cement Association to evaluate the adequacy and justification of the slab track structure. The program involved the recording of data on the response of slab track assembly to dynamic loading and environmental exposure. Instrumentation was installed to measure seasonal and long-term changes in track condition and to record periodically the dynamic response of track components to train loads.

Track Performance Data

Data obtained from instrumentation installed in the track included the following (7):

1. Vertical forces transmitted from the rails to the fasteners and slab,
2. Rail and slab vertical deflections,
3. Strains in concrete and reinforcing steel,
4. Pressures on subbase and subgrade,
5. Slab and subgrade settlements,
6. Changes in concrete crack width, and
7. Slab temperature.

Instrumentation installed in track at two sites to record response of slab track structure components to rolling stock and environment included the following:

1. Strain gauges,
2. Pressure cells,
3. Displacement transducers,
4. Specially designed and instrumented fasteners,
5. Thermocouples,
6. Joint width measurement plugs, and
7. Settlement targets.

Traffic Load

Wheel loads for the diesel locomotive and electric cars were 33.8 and 13.1 kips, respectively. Tests were performed with test trains at selected speeds of 10, 30, and 55 mph (diesel) and 65 mph (electric) for the prerevenue and first service testing. Portions of the first revenue service test and the entire second test were performed under operating con-

ditions by recording the revenue service trains. Diesel test equipment is shown in Figure 10.

Test Results and Findings

Tests were conducted in the field during construction. The plate bearing load tests indicated modulus of subgrade reaction (K) value for the embankment and subbase as approximately 450 and 700 pci, respectively. The pull-out tests on fastener anchor bolts revealed that the bolts withstood incremental loading to a pull-out force of 14 kips without any distress or failure in bolts, epoxy, or concrete.

Concrete specimens were taken during construction and tested in the laboratory. At 28 days the results were as follows: the average compressive strength (5,480 psi), flexural strength (628 psi), and modulus of elasticity (4.9 million psi). At 2 years of age the results were average compressive strength (9,270 psi), average flexural strength (531 psi), and modulus of elasticity (4.8 million psi). Table 1 gives the concrete test data.

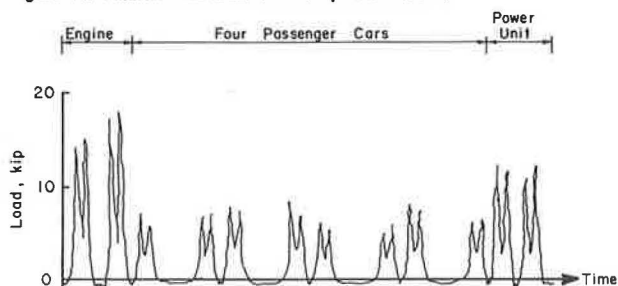
Test results revealed that neither train speed nor accumulated traffic had an apparent effect on track response to traffic loads. This can be attributed to the good track condition and the short duration of the test program.

Maximum vertical loads transmitted from wheels to the slab through the fasteners were 20.5 and 13.5

Figure 10. Diesel test equipment.



Figure 11. Fastener-slab load for diesel-powered train.



kips for the diesel- and electric-powered trains, respectively. Figure 11 shows fastener-slab load for diesel-powered trains. Rail deflections ranged from 0.054 to 0.126 in. for the diesel engines and from 0.047 to 0.131 in. for the electric trains. Maximum slab deflections were 0.012 and 0.008 in. for the diesel and electric trains, respectively.

Concrete stresses due to traffic loads were generally small. Maximum measured stress midway between fasteners was 140 psi. However, theoretical calculations indicate that stresses under fasteners could be 50 percent higher. Distribution of transverse concrete stresses is shown in Figure 12. Re-

Table 1. Concrete test data.

Age at Test	Specimen	Compressive Strength, psi	Flexural Strength, psi	Modulus of Elasticity, million psi
28 Days	1	5,460	703	4.8
	2	5,740	567	4.8
	3	5,250	615	5.2
	Average	5,480	628	4.9
1 Year	1	6,850	593	4.8
	2	6,730	707	4.8
	3	6,810	560	4.9
	Average	6,800	620	4.8
2 Years	1	9,520	536	4.7
	2	9,280	515	4.8
	3	9,000	541	4.0
	Average	9,270	531	4.8

Figure 12. Distribution of transverse concrete stresses.

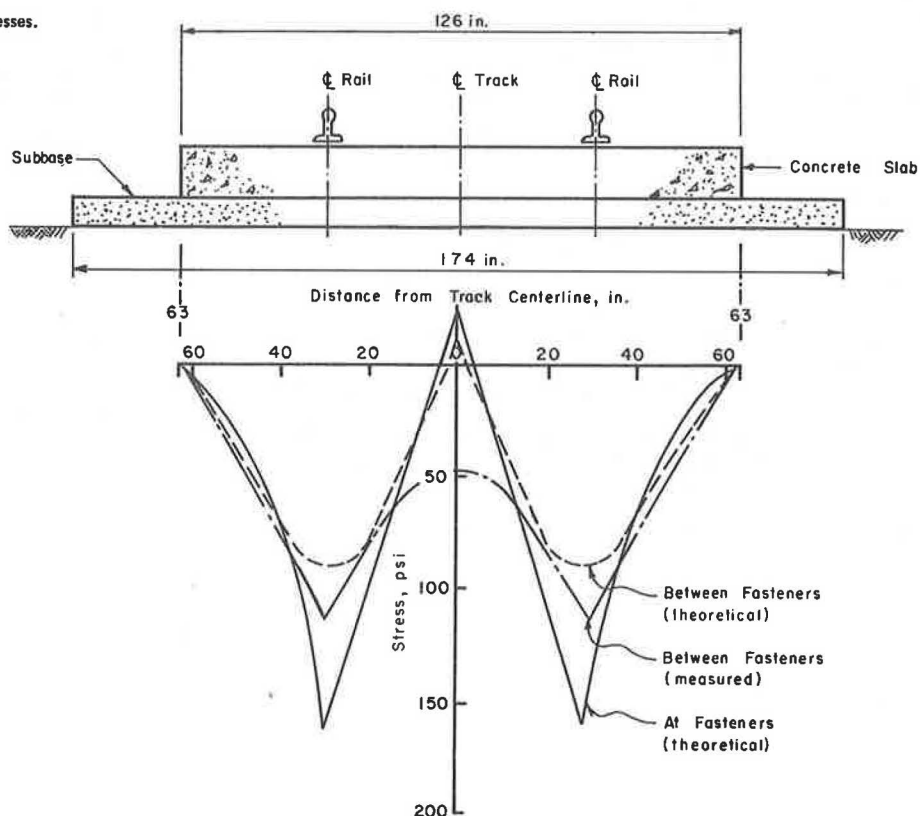
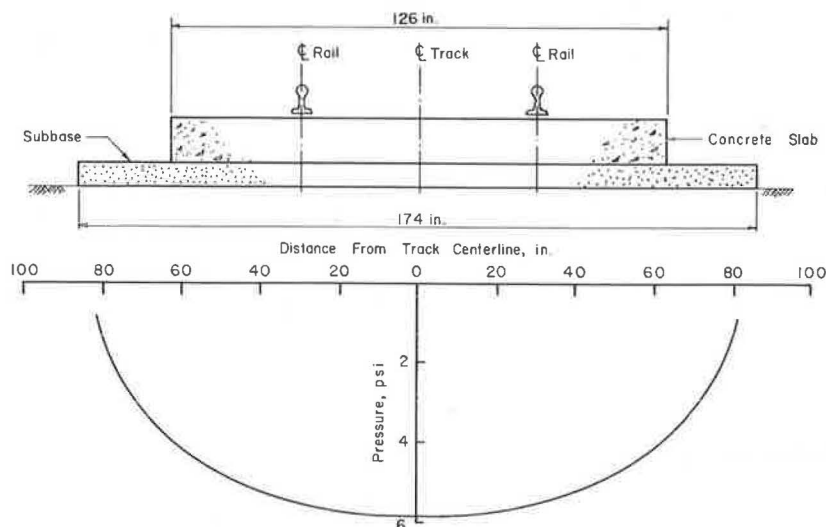


Figure 13. Subgrade pressure distribution.



inforcing steel stresses were small and the maximum measured value was 1,218 psi.

Measured pressures at the slab-subbase interface were generally small, with random variation and no specific trends. Measured pressures at the subbase-subgrade interface were small. Maximum measured pressures were 7.4 and 5.2 psi for the diesel and electric trains, respectively. Figure 13 shows the distribution of the subgrade pressure.

No significant settlement of slab or subgrade occurred after nearly 1 year of revenue service. A maximum elevation change of 0.05 in. was measured. Also, no significant changes in crack width occurred between tests.

Test results indicate that traffic-induced stresses and pressures in track structure components are relatively low. Also, no significant slab settlement occurred during 1 year of service. Results of this test program indicate that the slab track structure as designed and constructed is performing satisfactorily. However, in order to evaluate the long-term performance and optimization of design for possible future projects, additional measurements should be continued for at least the next few years.

With this objective in mind, an application and subsequent formal request for a research grant were made and accepted by UMTA. The test program was continued for 1983 and possibly into 1984.

CONCLUSIONS

Since 1973, when the first direct fixation track structure on viaducts and bridges was opened for traffic, not a single derailment attributable to the track structure has occurred on these installations. The ride quality and reliability of the system have improved significantly versus the wood-tie-ballast track structure.

The high initial cost of CWR, direct fixation, and concrete slab track is offset by low and infre-

quent maintenance without costly interruption to LIRR's high-density commuter traffic. The structure is capable of maintaining track geometry and is suitable for heavy axle loads and fast speed. LIRR intends to continue the monitoring and evaluation of these improved track structures and associated components in order to optimize the design for future rail improvement projects.

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Publication of this paper sponsored by Committee on Track Structure System Design.