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TECHNICAL AND ECONOMIC FEASIBILITY STUDY OF AT-GRADE CONCRETE SLAB TRACK FOR URBAN RAIL TRANSIT SYSTEMS

Amir N. Hanna

CONSTRUCTION TECHNOLOGY LABORATORIES
A Division of Portland Cement Association
5420 Old Orchard Road
Skokie, IL 60077

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FINAL REPORT

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16. Abstract This report was prepared as part of an ongoing research by the Transportation Systems Center in Support of the Urban Mass Transportation Administration to investigate improved track support systems. The report presents work conducted to evaluate the technical and economic feasibility of using concrete slab track systems for at-grade transit track. The functions of a rail transit track system are to guide railway vehicles and provide a safe and acceptable ride to passengers. Traditionally, a track system with cross ties and ballast has been used for at-grade construction. Such track systems utilize wood, monoblock concrete, or two-block concrete ties. These track systems undergo permanent deformation during loading due principally to consolidation and degradation of ballast that occurs during track life. Therefore, maintenance operations are required periodically to provide proper surface and alignment. Improved track systems with superior capabilities to those of conventional track provide possible solutions to problems of continuing and costly track maintenance. A slab track system consisting of a continuous concrete support, sub-base, and compacted subgrade, is one example of such improved track system. Rails are secured to the concrete support using fasteners that provide restraint to rail movements and therefore, ensure proper gage and alignment. Experience with concrete slab track systems in foreign countries has shown that such track systems result in decreased maintenance and increased reliability of service. This experience has also indicated a generally higher initial cost of slab track. This report presents a world-wide review of details and performance of slab track projects and compares features of slab track systems with those of conventional ballasted track. Methods of constructing slab track systems and a cost comparison between slab and ballasted track systems are discussed. Recommendations for future research efforts related to the development of at-grade concrete slab track systems are also presented.

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PREFACE

This report was prepared by the Construction Technology Laboratories, a division of the Portland Cement Association, under contract No. DOT-TSC-1765 to the Transportation Systems Center, Cambridge, Massachusetts in support of the Office of Rail and Construction Technology, Office of Technology Development and Deployment, Urban Mass Transportation Administration of the U.S. Department of Transportation to investigate improved track support systems.

The overall objective of this contract is to evaluate the technical and economic feasibility of using concrete slab systems for at-grade rapid transit track.

The report presents a world-wide review of details and performance of slab track projects. Also, it compares features of slab track systems with those of conventional ballasted track. Methods of constructing slab track systems are also discussed. In addition, a cost comparison between slab and ballasted track systems is presented. Finally, recommendations for future research efforts related to the development of at-grade concrete slab track systems are presented.

Mr. P. Witkiewicz of the Transportation Systems Center was the technical monitor for the work reported herein. His cooperation and suggestions are gratefully acknowledged. Mr. C. O. Buhlman of the American Public Transit Association and representatives of several transit properties and engineering firms also deserve recognition for their assistance and suggestions.

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Finally, acknowledgment is due to Mr. D. R. Burns for performing much of the work on the economic comparison between slab and conventional tracks and Mr. B. E. Colley for reviewing the text of the report.

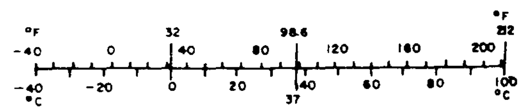
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The functions of a rail transit track system are to guide railway vehicles and provide a safe and acceptable ride to passengers. Traditionally, a track structure with cross ties and ballast has been used for at-grade construction. Such track systems utilize wood, monoblock concrete, or two-block concrete ties as shown in Figures 1-1, 1-2, and 1-3, respectively. These track systems experience permanent deformation under loading due principally to consolidation and degredation of ballast that occurs during track life. Therefore, maintenance operations are required periodically to provide proper surface and alignment.

Improved track systems with superior capabilities to those of conventional track provide possible solutions to problems of continuing and costly track maintenance. A slab track system consisting of a continuous concrete support, subbase, and compacted subgrade, as shown in Figure 1-4, is one example of such improved track system. Rails are secured to the concrete support using fasteners that provide restraint to rail movements and thus ensure proper gage and alignment.

Experience with concrete slab track systems in foreign countries has shown that such track system results in decreased maintenance and increased reliability of service. This experience also has indicated a generally higher initial cost of slab track.

To evaluate the technical and economic feasibility of using concrete slab track systems for at-grade rapid transit track in the United States, a study was initiated by the Transportation Systems Center of the Research and Special Programs Administration in support of the Urban Mass Transportation Administration of the U.S. Department of Transportation. The study encompasses the following work items:

1. Identification of details and features of slab track projects in the U.S. and abroad

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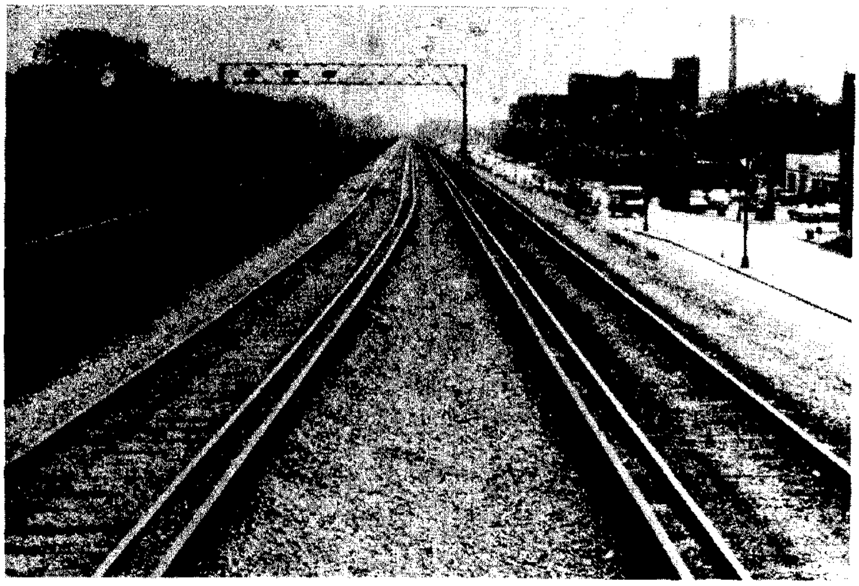

FIGURE 1-1. WOOD TIE TRACK

FIGURE 1-2. MONOBLOCK CONCRETE TIE TRACK

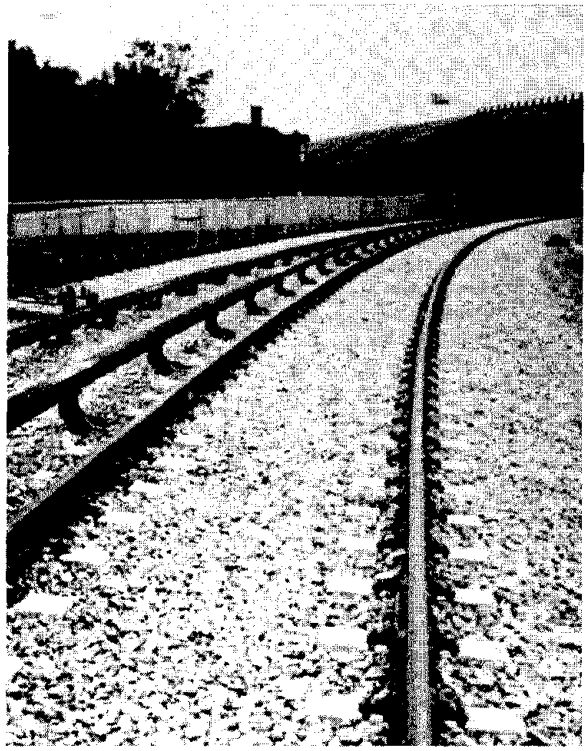

FIGURE 1-3. TWO-BLOCK CONCRETE TIE TRACK

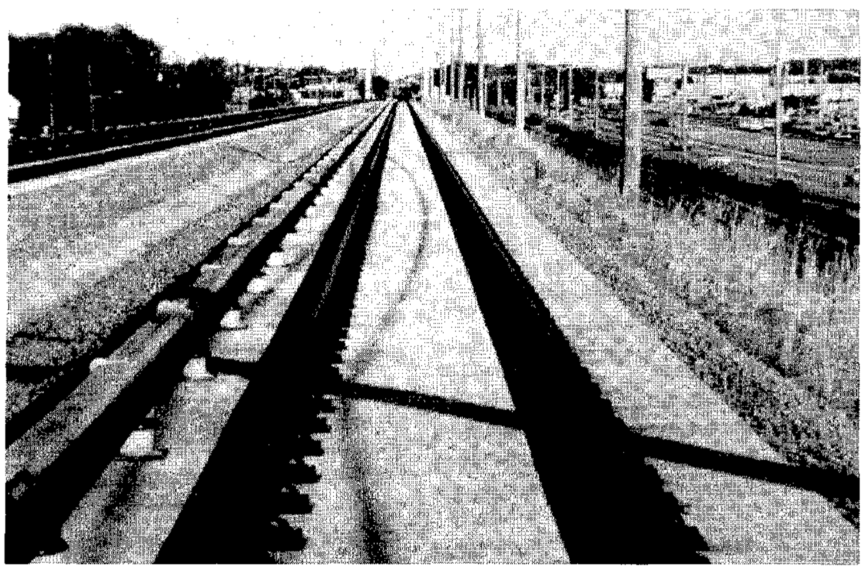

FIGURE 1-4. CONCRETE SLAB TRACK

2. Performance investigation of concrete slab track installations in the U.S. and abroad
3. Evaluation of advantages and disadvantages of using at-grade slab track for rapid transit purposes in the United States
4. Economic evaluation to compare service-life costs of at-grade slab track with those of conventional wood tie and concrete tie ballasted track

This report summarizes work performed in these items and recommends future research to aid development of optimum slab track designs for U.S. transit conditions.

2. SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

Experience with concrete slab track systems in foreign countries has shown that such track system results in decreased maintenance and increased reliability of service. This experience also has indicated a generally higher initial cost of slab track.

To evaluate the technical and economic feasibility of using concrete slab track systems for at-grade rapid transit track in the United States, a study was initiated by the Transportation Systems Center of the Research and Special Programs Administration in support of the Urban Mass Transportation Administration of the U.S. Department of Transportation. A summary of work performed in this study and recommendations for future research are presented.

2.1 SUMMARY

The study included a literature review, inspection of slab track installations, evaluation of advantages and disadvantages, and an economic analysis. Results and findings of these work items are summarized.

2.1.1 Slab Track Projects

In the past 25 years, 18 concrete slab track projects were built by railroads and transit authorities in eight countries. These projects utilized different concrete slab and precast unit designs, subbase materials, and rail fastening systems.

Precast pretensioned frames and ladder units have been used. Types of concrete slabs used have included the following:

1. Cast-in-place plain, reinforced, and continuously reinforced
2. Cast-in-place post-tensioned
3. Precast reinforced
4. Precast pretensioned

Subbases used have included crushed stone, cement- and asphalt-treated materials, lean concrete, and expanded polystyrene concrete. However, in a few cases, no subbase was provided. Generally, subbases have been placed on the compacted subgrade, although in some cases the top subgrade layer was stabilized with cement.

Rails were fastened to the slab by different methods, including the following:

1. Rail fasteners with inserts embedded in the slab during construction
2. Rail fasteners with inserts secured to prestressed or reinforced concrete ties set into the slab during construction
3. Rail fasteners with inserts secured to precast concrete blocks set into the slab during construction
4. Elastomeric blocks to secure rails in grooves built in the slab

2.1.2 Rail Fasteners

In slab track systems, fasteners were used to secure rails either directly to the concrete slab or precast concrete ties or blocks set into the slab. Several types of rail fasteners have been used. These fasteners are classified into three categories:

1. Fasteners having no provisions for adjusting rail level or track gage
2. Fasteners capable of adjusting either rail level or track gage
3. Fasteners capable of adjusting both rail level and track gage

Generally, vertical adjustment is accomplished by inserting shims between fastener base plate and concrete slab or tie, or between fastener base plate and rail. Lateral adjustment is accomplished by lateral shimming or by means of an eccentric cam or tie plate adapter.

Experience has shown that vertical and lateral adjustment capabilities are desired to maintain the design accuracy of line and level during construction and service.

2.1.3 Methods of Construction

Construction of cast-in-place slabs have been performed using conventional paving methods.

Installation of precast concrete slabs and ladder units has been accomplished using cranes. In this case, preassembled track panels were held at proper gage and alignment with special jigs. Then, cement mortar or concrete was introduced under the precast concrete units. Installation of track with ties partially embedded in cast-in-place slabs has been performed in a similar manner.

Also, precast concrete blocks have been installed in freshly-placed concrete by vibration.

Subgrade preparation and subbase construction have been performed with methods similar to those used for highway construction.

2.1.4 Performance

Most slab track projects evaluated in this study have performed satisfactorily and provided the desired objective of substantially reducing maintenance. Generally, there has been no significant change in level and alignment. However, there were a few exceptions.

In one project, several problems were encountered. These included loosening of fastening inserts, differential slab settlement, and large thermal cracking. These problems were attributed to the method of installing fastening inserts and lack of a subbase.

In another project, fastening anchorages worked loose from the concrete and excessive deflections and mudpumping occurred. These problems were attributed to inadequate fastening insert length, weak subgrade, and lack of subbase.

Generally, officials of railroads and transit properties using at-grade slab track have reported better performance of slab track as compared to cross tie ballasted track.

2.1.5 Advantages and Disadvantages

Experience with slab track in several countries indicated that use of slab track for at-grade construction provided numerous advantages over cross tie track. However, it introduced a few undesired features.

In comparison with ballasted track, slab track provides the following principal advantages:

1. Ballast and ties and associated maintenance are eliminated.
2. Proper line and surface are maintained thus reducing need for frequent surfacing and lining.
3. Rail fasteners with better lateral and longitudinal restraint characteristics are used thus improving track stability.
4. Because of reduced maintenance, less traffic disruption occurs.
5. With certain designs, less track damage occurs in the event of a derailment.

In addition, possible energy savings and reduction in rolling stock maintenance would result from the improved track condition.

However, in comparison with ballasted track, slab track provides the following undesired features:

1. Construction cost is generally higher.
2. Because of ballast elimination, higher noise levels are generated.
3. It provides less flexibility for future layout alterations.

2.1.6 Cost Analysis

An economic life comparison of concrete slab and ballasted tie tracks was made using the present worth method. Costs associated with track construction and maintenance were considered. Maintenance cost items were distributed over a 50-year period, escalated by an inflation factor and then discounted to present worth. Comparison was made for constructing a new transit system and for the partial renewal or extension of an existing ballasted track.

Evaluation indicated that construction cost of slab track is higher than that of ballasted track. However, maintenance cost for track slab is less than that for ballasted track. Evaluation indicated that depending on prevailing economic conditions and specifics of the project under consideration, concrete slab track may provide a cost advantage over ballasted track.

2.2 RECOMMENDATIONS FOR FUTURE RESEARCH

Experiments with concrete slab track in the past 25 years have demonstrated its superiority over ballasted track. However, life-cycle analysis of maintenance and construction costs of concrete slab and ballasted tracks indicated that slab track is not always less expensive. This economic analysis is based on assumptions of service life, time and extent of maintenance operations, and other factors.

Experience has shown that concrete slab track systems performed satisfactorily under various traffic conditions that generally differ from those encountered on U.S. transit systems. To identify slab track designs suitable for the traffic and environmental conditions encountered on U.S. transit systems and to obtain reliable comparison of track alternatives, more studies and field experiments are needed. The following research areas are recommended:

1. Analytical studies to develop criteria and methods for the design of concrete slab track systems
2. Laboratory evaluation of track components to help identify those systems suitable for track use

3. Laboratory evaluation of full-scale track sections under simulated traffic conditions to help identify those designs suitable for track use
4. Field testing of selected ballasted and slab track designs under transit traffic and environmental conditions to obtain long-term data of track performance, maintenance, and other factors required for a comparison of track alternatives.

Results from the recommended research effort can be used to develop optimum slab track designs. Thus, advantages of slab track systems could be better utilized to benefit the U.S. transit industry.

3. SLAB TRACK PROJECTS

In the past 25 years, 18 concrete slab track projects were built by railroads and transit authorities in eight countries. These projects utilized different concrete slab and precast unit designs, subbase materials, and rail fastening systems.

Precast pretensioned frames and ladder units have been used. Types of concrete slabs used have included the following:

1. Cast-in-place plain, reinforced, and continuously reinforced
2. Cast-in-place post-tensioned
3. Precast reinforced
4. Precast pretensioned

Subbases used included crushed stone, cement- and asphalt-treated materials, lean concrete, and expanded polystyrene concrete. However, in a few cases, no subbase was provided. Generally, subbases have been placed on a compacted subgrade, although in some cases the top subgrade layer was stabilized with cement.

Rails were fastened to slabs using the following:

1. Rail fasteners with inserts embedded in the slab during construction
2. Rail fasteners with inserts secured to prestressed or reinforced concrete ties set into the slab during construction
3. Rail fasteners with inserts secured to precast concrete blocks set into the slab during construction
4. Elastomeric blocks to secure rails in grooves built in the slab

A summary of recent slab track projects is listed in Table 3-1. Details of these projects are described thereafter.

TABLE 3-1. FEATURES OF SLAB TRACK PROJECTS

Country	Date	Location	Total Length, ft	Slab Details				Subbase			Remarks
				Type	Length, ft	Width, ft	Thickness, in.	Type	Width, ft	Thickness, in.	
England	1968-69	Radcliffe-on-Trent	944	Continuously reinforced		8.5	10.7/13.3	Lean concrete		5.9	Four, 236-ft long sections fitted with different fastening systems
			236	Continuously reinforced		8.5	16.0	Lean concrete		5.9	Rubber-booted two-block ties embedded in slab
			236	Precast units		8.3		Lean concrete		5.9	Prestressed precast longitudinal beams set into slab units
	1972	Radcliffe-on-Trent	197	Continuously reinforced		7.9	7.9/14.4	Granite stone			
			230	Continuously reinforced		8.9/ 15.7	9.8/15.0	Granite stone			Turnout on slab
	1972	Duffield	5,940	Continuously reinforced		7.9	7.9/10.8	None			
	1975	Radcliffe-on-Trent	180	Prestressed, precast	30.0			Asphalt		9.0	Ladder units
			120	Prestressed, precast	30.0			Crushed stone			
			120	Prestressed, precast	30.0			Asphalt		9.0	
Germany	1967	Hirschaid	374	Prestressed, precast	17.0	7.9	7.1	Expanded polystyrene concrete	13.1	5.9	
			187	Prestressed, precast	17.0	7.9	7.1	Lean concrete, sandy gravel	11.5 11.5	3.1 8.7	
			191	Prestressed precast	21.3		14.2	Lean concrete, sandy gravel	11.5 11.5	3.1 6.7	Ladder units
	1972	Rheda	2,297	Continuously reinforced		9.2	5.5	Expanded polystyrene concrete, cement-stabilized subgrade	11.5	7.9 5.9	Monoblock ties embedded in slab

TABLE 3-1. FEATURES OF SLAB TRACK PROJECTS (Cont.)

Country	Date	Location	Total Length, ft	Slab Details				Subbase			Remarks
				Type	Length, ft	Width, ft	Thickness, in.	Type	Width, ft	Thickness, in.	
Germany (cont'd)	1972	Oelde	2,133	Continuously reinforced		9.2	16.5	Expanded polystyrene concrete, Lean concrete, crushed stone	12.3 13.3 13.3	7.9 7.9 5.9	Two different fastening systems
			682	Reinforced concrete	13.1-16.4	8.5/17.7	8.7	Lean concrete	11.8/21.0	17.7	Two turnouts on slab
	1977	Karlsfeld	1,313	Prestressed, precast	15.6	9.1	7.9	Cement-stabilized gravel	12.5	7.9	
			1,213	Prestressed, precast	24.1	7.9	16.5/17.3	Cement-stablized gravel	11.2	7.9	Ladder units
			1,411	Continuously reinforced		8.5	7.9	Cement-stabilized gravel	11.8	7.9	Monoblock ties set into slab
			820	Continuously reinforced		8.5	7.9	Cement-stabilized gravel	10.8	7.9	Precast units set into slab
			820	Continuously reinforced		8.5	7.9	Cement-stabilized gravel	10.8	7.9	Rubber-booted monoblock ties set into slab
	1978	Munich-Nordring	164	Cast-in-place	9.8	9.2	11.0	Cement-stabilized gravel	11.5	11.0	31.5 x 9.8 x 4.7 in. precast blocks set into slab
France	1970	La Grillere	410	Reinforced concrete	23.0	11.8	5.9	Crushed stone	11.8	7.9	Rubber-booted two-block ties set into slab
			410	Reinforced concrete	23.0	11.8	5.9	Crushed stone	11.8	7.9	
	1970	Neuilly-sur-Marne	948	Prestressed concrete	328.0	9.2	7.1	Lean concrete, coarse sand, fine sand		3.9 3.9 3.9	Rubber-booted two-block ties on slab
Spain	1975	Ricla-Calatorao	13,451	Continuously reinforced		7.9	9.4/11.4	Lean concrete	13.1	5.9	
The Netherlands	1976-77	Deurne	820	Precast, reinforced concrete	19.7	7.4	21.7	Concrete	7.4	12.0	

TABLE 3-1. FEATURES OF SLAB TRACK PROJECTS (Cont.)

Country	Date	Location	Total Length, ft	Slab Details				Subbase			Remarks
				Type	Length, ft	Width, ft	Thickness, in.	Type	Width, ft	Thickness, in.	
United States	1979-80	Massapequa Park, New York	5,939	Continuously reinforced		10.5	12.0	Asphalt-treated		6.0	Double track
	1979-79	Atlanta, Georgia	1,200	Reinforced concrete	50.0	9.5	9.0	Crushed Stone	18.0	12.0	Two, 600-ft long double track sections in stations
			1,268	Reinforced concrete	50.0	9.5	9.0	Crushed Stone	18.0	12.0	Six double track sections ranging in length from 50 to 350 ft
			383	Reinforced concrete	50.0		9.0	Crushed Stone		12.0	Turnout on slab
	1972	El Dorado, Kansas	545	Continuously reinforced		9.0	18.0				Track removed in 1974
Canada	1976-77	Toronto	1,200	Plain concrete	15.0	10.0	11.0	Cement-treated, crushed stone	12.0 14.0	6.0 3.0	Double track
Soviet Union	After 1955			Precast, prestressed concrete	20.5	8.5	11.8				
				Precast, prestressed concrete	13.6	8.5	9.8				
				Precast, prestressed concrete	8.1	8.1	9.4				Frame units
				Precast prestressed concrete	8.1	7.4	8.3				Frame units

3.1 ENGLAND

Several slab track projects were built in England between 1968 and 1975. Principal projects are those at Radcliffe-on-Trent and at Duffield. Details of these projects are described below.

3.1.1 Radcliffe-on-Trent - Phase I

This experimental project was built in 1968-69 on a tangent section of the Grantham-Nottingham line between Bingham and Racliffe-on-Trent stations.(1) Track was opened to traffic in April 1969. Traffic averaged 8,000 tons per day and included trains with 25-ton axle loads operating at 60 mph speed.

The test track consisted of six, 236-ft long sections each built with a different fastening system, as illustrated in Figure 3-1. Fastening systems employed were those used by the following railways:

1. London Transport (LTE)
2. Netherlands Railway (NS)
3. French Railways (SNCF)
4. Swiss Railways (CFF)
5. British Railways Direct Laying Track (BRDL)
6. British Railways Channel Tunnel Track (BRCT)

Slabs were built on existing ballast and subballast of an abandoned freight line. However, approximately 5.9 in. of old ballast were removed throughout the test length to provide the required elevation. Remaining materials consisted of a 9.1-in. thick ballast layer and a 5.9-in. thick subballast layer placed on a clayey subgrade. Ballast and subballast consisted of ash and slag combination.

Subbase and abutments were built prior to slab construction. A 5.9-in. thick lean concrete subbase was placed over the entire length. End abutments were built about 5.9 ft into the embankment to restrain longitudinal movements. Intermediate abutments were built at level changes to resist moments caused by thermal and shrinkage forces. Abutment reinforcement extended into the slabs.

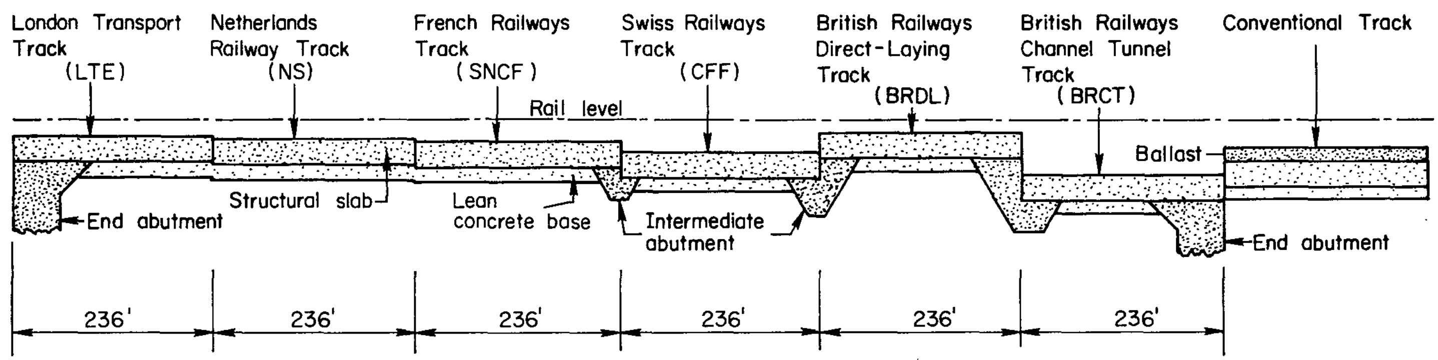

FIGURE 3-1. LAYOUT OF SLAB TRACK SECTIONS AT RADCLIFFE-ON-TRENT

The slab was placed with a slip-form paver. Specified 28-day cube compressive strength was 5,080 psi. Slab width was 8.53 ft. Slab thickness for the British Railways direct laying track varied from a maximum of 13.3 in. at rail seats to a minimum of 10.7 in. at center, as shown in Figure 3-2. Slabs for London Transport, Netherlands Railway, and French Railways fasteners had essentially similar cross section with horizontal seating and crowned slab center for drainage, as shown in Figure 3-3. Swiss Railways fasteners were provided through reinforced two-block ties embedded in the slab, as shown in Figure 3-4.

Slab reinforcement consisted of two layers of longitudinal and transverse reinforcement of 60 ksi deformed alloy steel bars welded into cages. All cages were welded to one another to provide continuous reinforcement for the entire slab length. Longitudinal reinforcement was 0.62% of concrete cross section.

The Channel Tunnel track system, shown in Figure 3-5, consisted of large precast base units that were grouted into a cast-in-place slab. Unit width and height were 8.3 ft and 23.0 in., respectively. Prestressed longitudinal track beams were placed in channels built in the base units. These beams were supported on continuous microcellular rubber pads. Polysulphide material was poured in spaces between track beam sides and base units to provide lateral support.

For all sections, rails were continuously welded. For the BR direct laying and Channel Tunnel sections, rails were supported continuously on flexible rubber-bonded cork pad. Pad thickness was 0.39 and 0.18 in. for the BR direct laying and Channel Tunnel sections, respectively. Other sections utilized discrete pads at fastener locations.

Figures 3-6 through 3-11 show views of the different slab track sections.

3.1.2 Radcliffe-on-Trent - Phase II

This test track is located at Radcliffe-on-Trent on the Nottingham-Grantham Line just to the east of the concrete slab

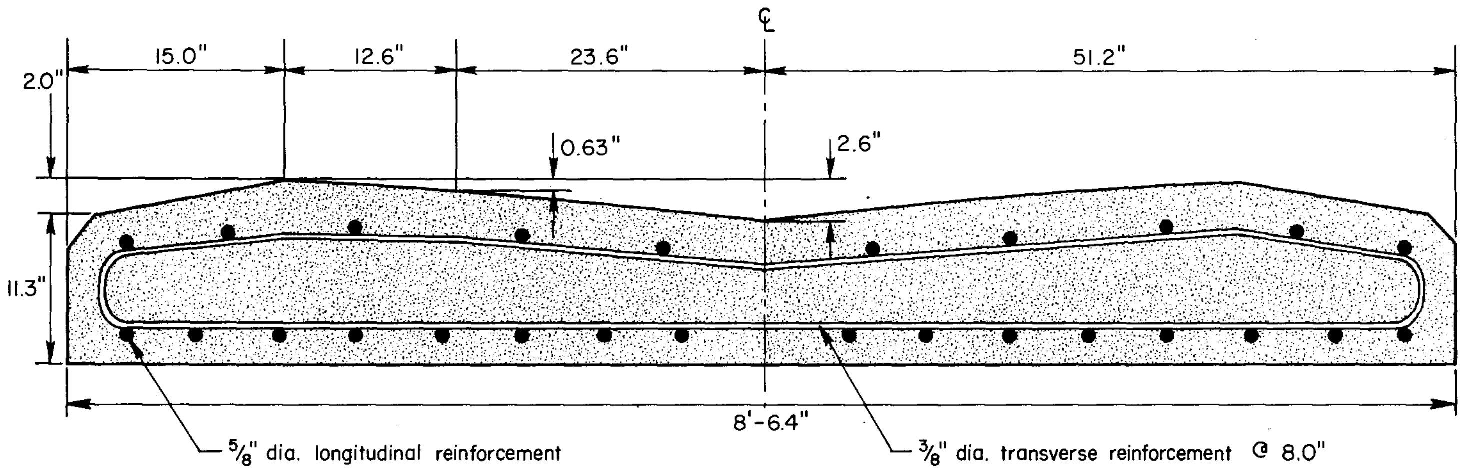

FIGURE 3-2. SLAB CROSS SECTION OF BRITISH RAILWAYS TRACK

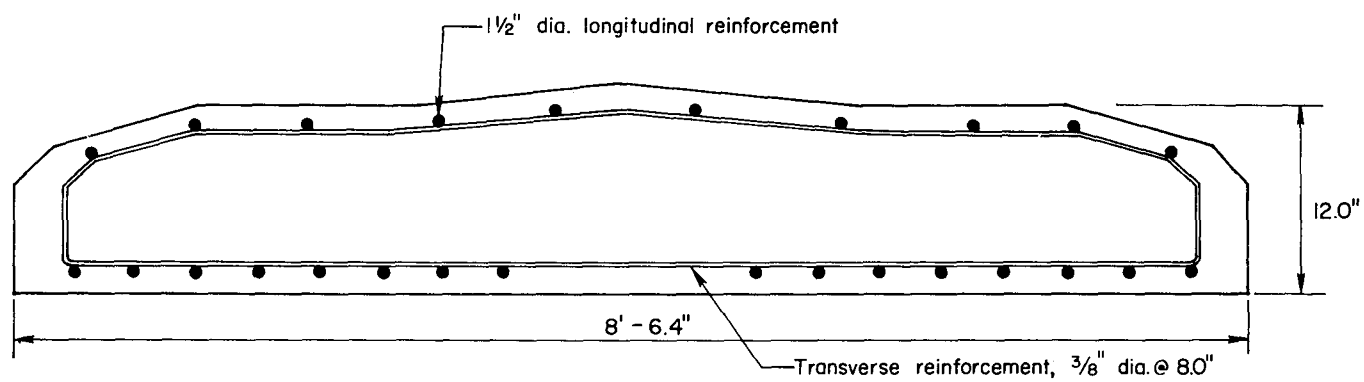

FIGURE 3-3. SLAB CROSS SECTION OF LONDON TRANSPORT, NETHERLANDS RAILWAY, AND FRENCH RAILWAYS TRACKS

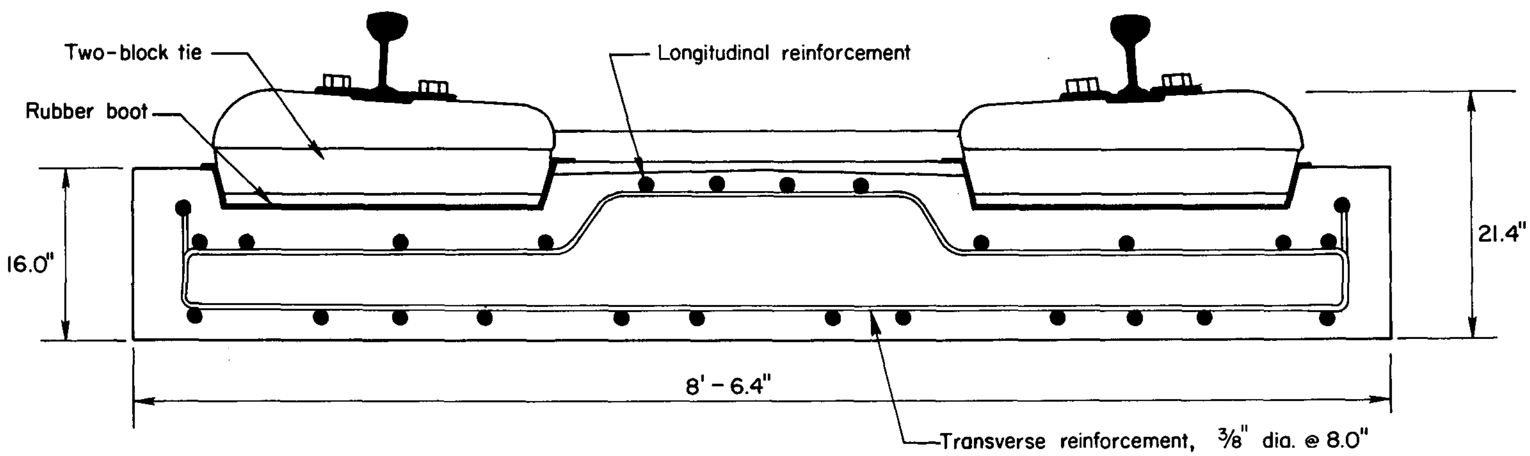

FIGURE 3-4. SLAB CROSS SECTION OF SWISS RAILWAYS TRACK

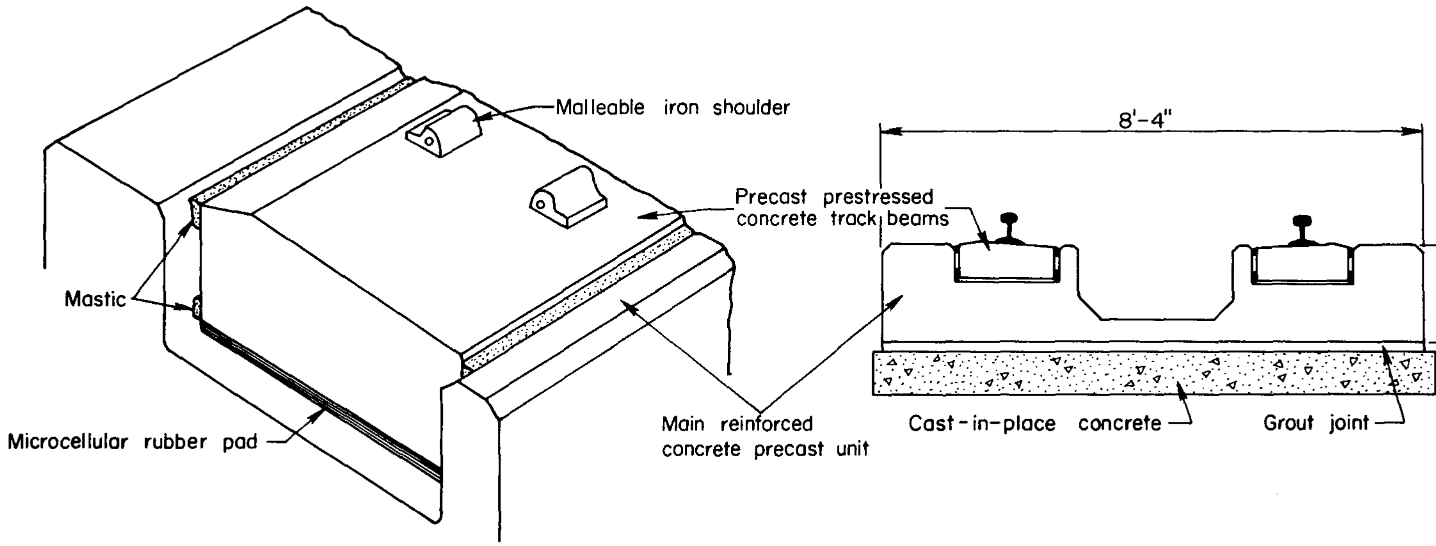

FIGURE 3-5. CHANNEL TUNNEL TRACK SYSTEM

FIGURE 3-6. LONDON TRANSPORT TRACK

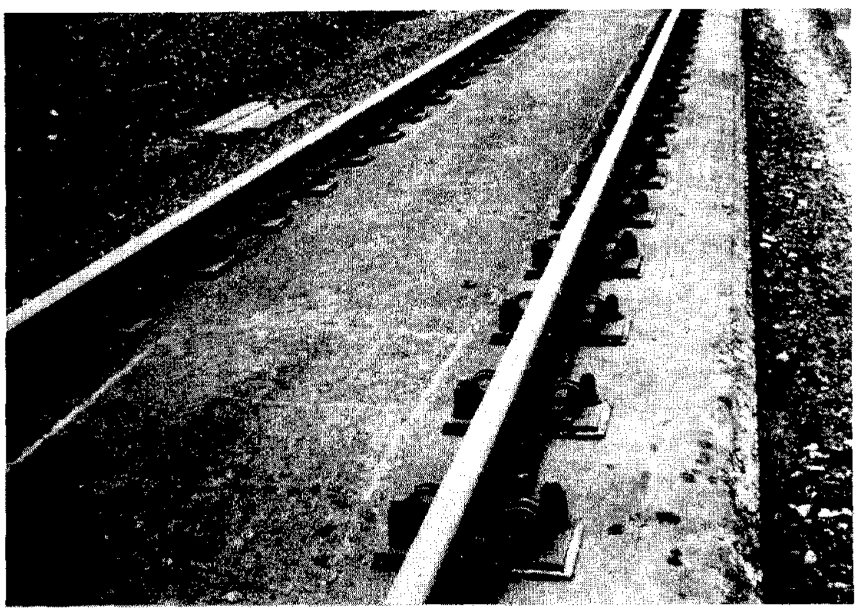

FIGURE 3-7. NETHERLANDS RAILWAY TRACK

FIGURE 3-8. FRENCH RAILWAYS TRACK

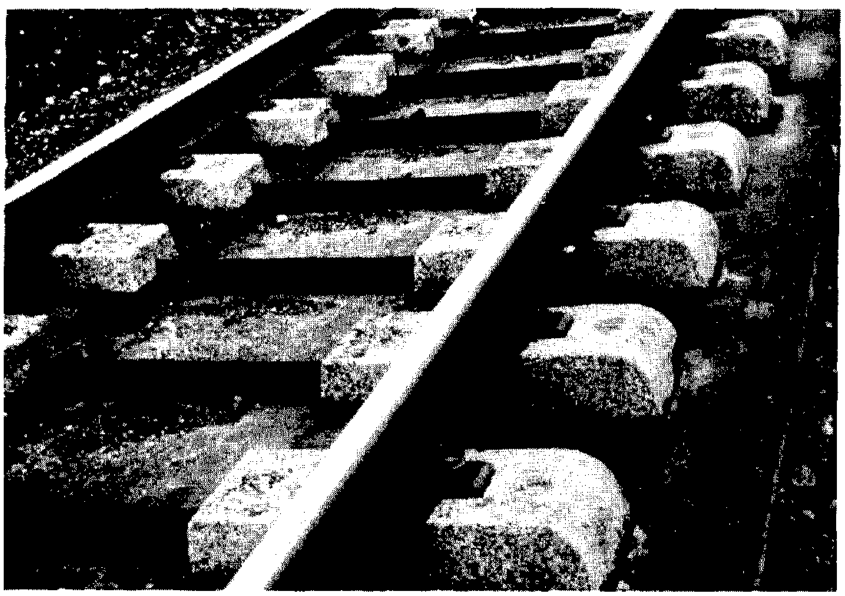

FIGURE 3-9. SWISS RAILWAYS TRACK

FIGURE 3-10. BRITISH RAILWAYS DIRECT-LAYING TRACK

FIGURE 3-11. BRITISH RAILWAYS CHANNEL TUNNEL TRACK

track laid in 1969.[2,3] The 1,155-ft long track was connected to the old track by a 623-ft long concrete tie track. Track was opened to traffic on June 4, 1972. Traffic averaged 2.5 million tons per year and included trains with 25-ton axle loads operating at 60 mph speed.

Track incorporated seven different construction types. These included two systems typical of at-grade slab track construction and five systems representing tunnel construction. Those systems pertinent to at-grade slab track work are described.

3.1.2.1 BR Direct Laid Slab - This 196.9-ft long slab section was slip-formed on prepared subgrade. Alignment included a 2,110-ft radius curve and a spiral. Fastening inserts were placed in predrilled holes using epoxy resin. Rails were supported on resilient pads.

The 7.88-ft wide slab was slip-formed with a center trough, as shown in Figure 3-12. Thickness was 7.9 in. and 14.4 in. at slab center and under rail seats, respectively. Two layers of longitudinal and transverse reinforcement were used. A view of the slab track section is shown in Figure 3-13.

3.1.2.2 Turnout on Slab - A 230-ft long turnout slab was built on a 4,000-ft radius curve. Slab was laid directly on the prepared subgrade. One slab side was slip-formed while the other was placed using road forms. A longitudinal trough was incorporated in the paved profile.

Slab width varied from 8.86 ft at the toe to to 15.7 ft at the nose. Thickness varied from 9.8 in. at center to 15.0 in. at rail seats. Two layers of longitudinal and transverse reinforcement were used. A cross section is shown in Figure 3-14. A view of the turnout is shown in Figure 3-15.

Between heel and nose points, rails were continuously supported on rubber-bonded cork pad and fastened to the slab with elastic-type fasteners. However, between the toe and heel points, discrete pads were used at fastener locations.

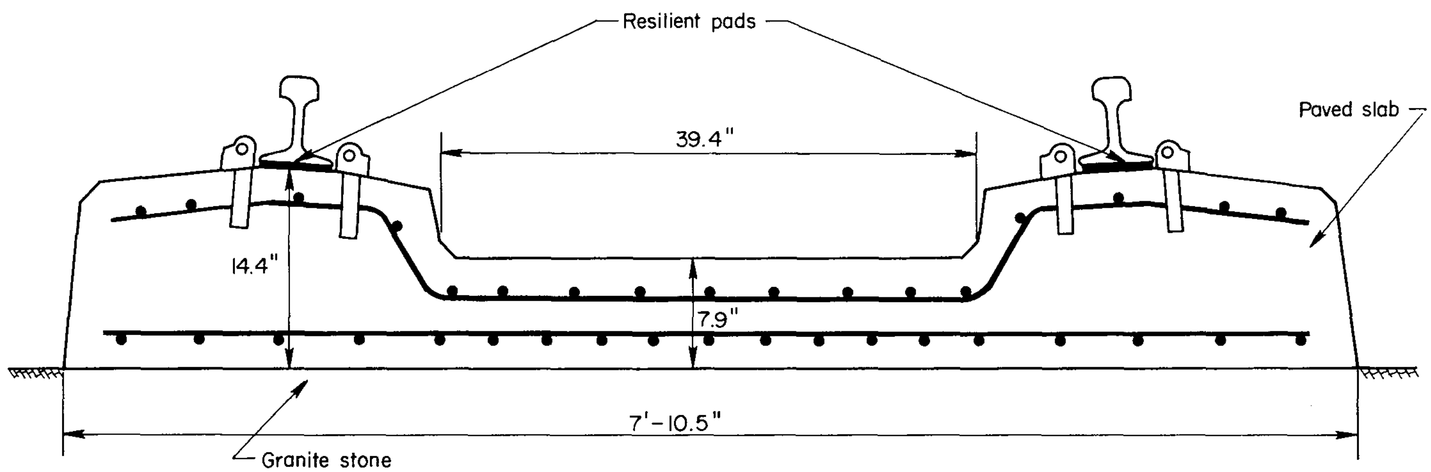

FIGURE 3-12. SLAB CROSS SECTION OF BRITISH RAILWAYS DIRECT-LAID TRACK

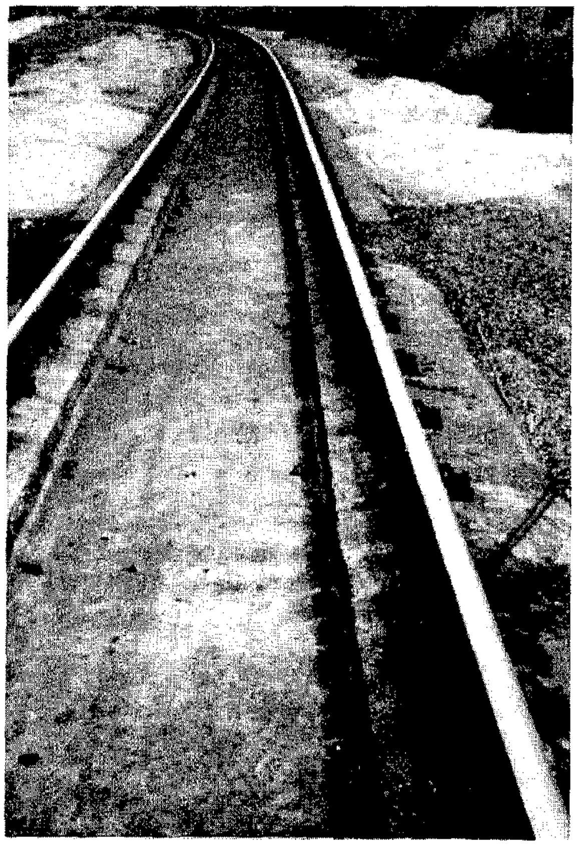

FIGURE 3-13. BRITISH RAILWAYS DIRECT-LAID
TRACK AT RADCLIFFE-ON-TRENT

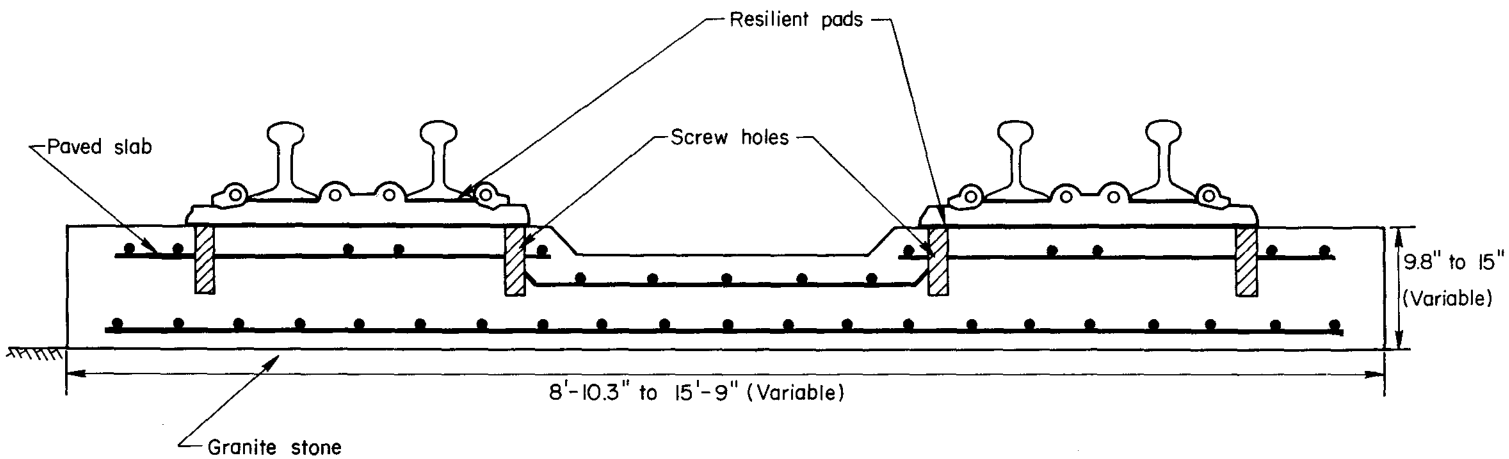

FIGURE 3-14. CROSS SECTION OF TURNOUT SLAB AT RADCLIFFE-ON-TRENT

FIGURE 3-15. TURNOUT ON SLAB AT RADCLIFFE-ON-TRENT

Transitions between slab track and conventional cross tie track were provided at both ends by prestressed longitudinal beams and cross connections forming 14.8-ft long ladder units, as shown in Figure 3-16. A view of this transition is shown in Figure 3-17.

3.1.3 Radcliffe-on-Trent - Phase III

In 1974, additional test sections were built at Radcliffe-on-Trent on the Nottingham-Grantham Line.(4) These included two precast prestressed concrete slab track systems.

3.1.3.1 Precast Concrete Slabs - This 240-ft long section consisted of eight, 30-ft long precast prestressed concrete slabs. Four slabs were placed directly on subgrade and four were placed on a 9-in. thick asphalt base. A view of this section is shown in Figure 3-18.

3.1.3.2 Precast Ladder Units - This 180-ft long section consisted of six, 30-ft long precast prestressed concrete ladder units. Units were supported on a 9-in. thick asphalt layer. Units were bonded to the asphalt base using a polyester resin mortar. Openings in ladder units were filled with sand asphalt. A view of this section is shown in Figure 3-19.

3.1.4 Duffield

This test track was built at Duffield on the Sheffield-Derby mainline.(5,6) Track design was based on BR's experience with slab track built at Radcliffe-on-Trent in 1969.

Track was built on the embankment of an abandoned freight line adjacent to the mainline. After completion of construction, test track was connected to the mainline. Track was opened to traffic in August 1972. Traffic amounted to about 15 million gross tons per year and included trains with 25-ton axle loads operating at 80 mph speed.

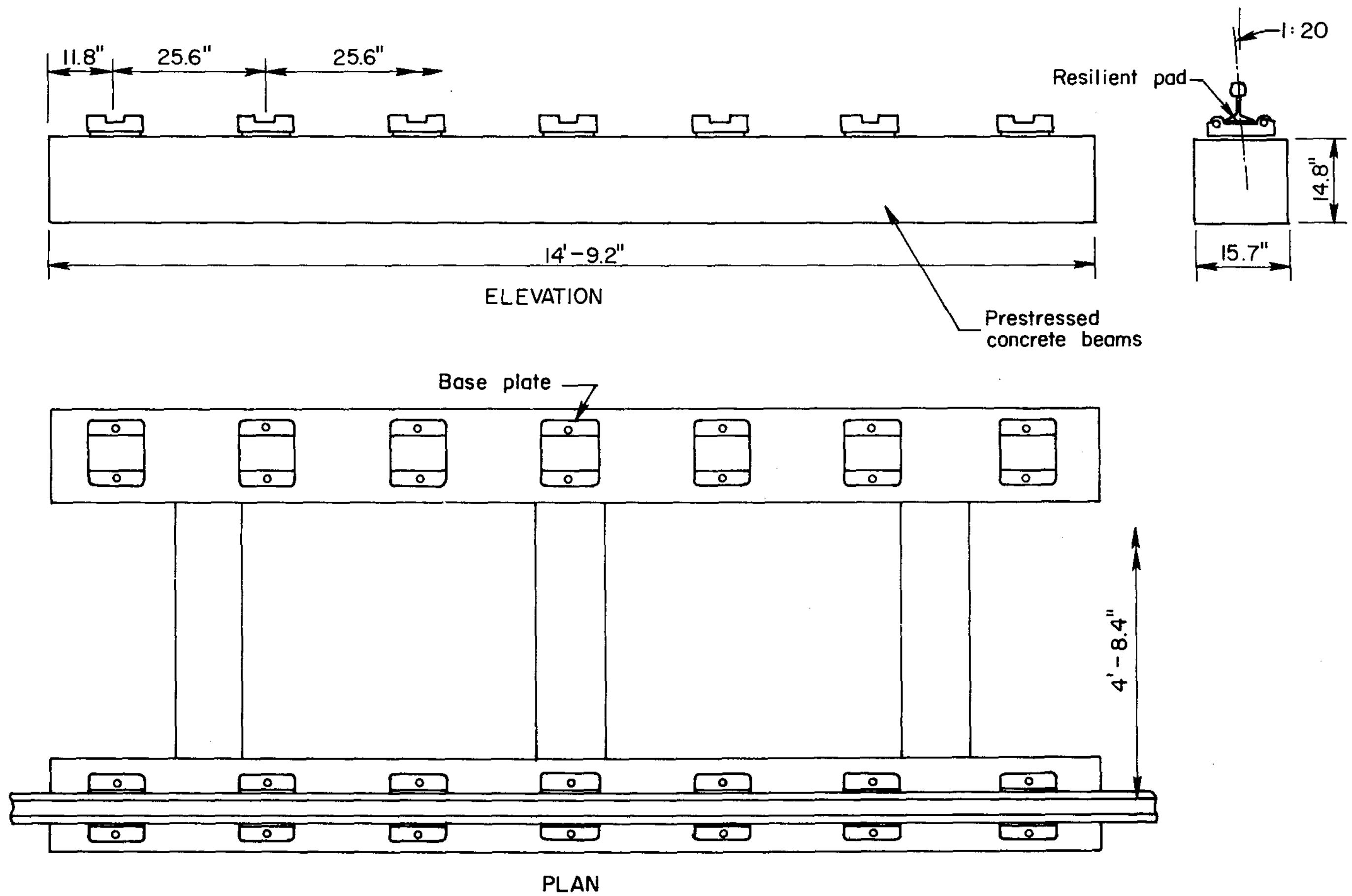

FIGURE 3-16. DETAILS OF TRANSITION BETWEEN SLAB TRACK AND CROSS TIE TRACK

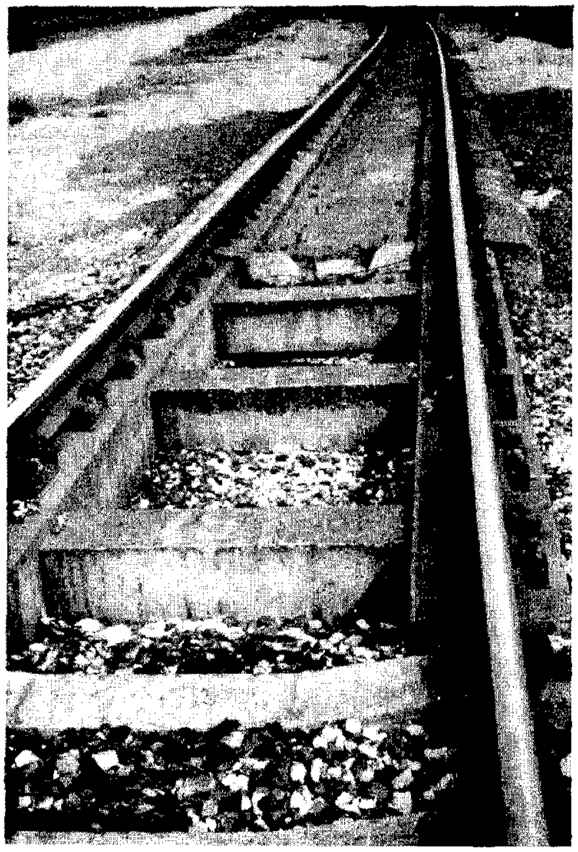

FIGURE 3-17. TRANSITION AT RADCLIFFE-ON-TRENT

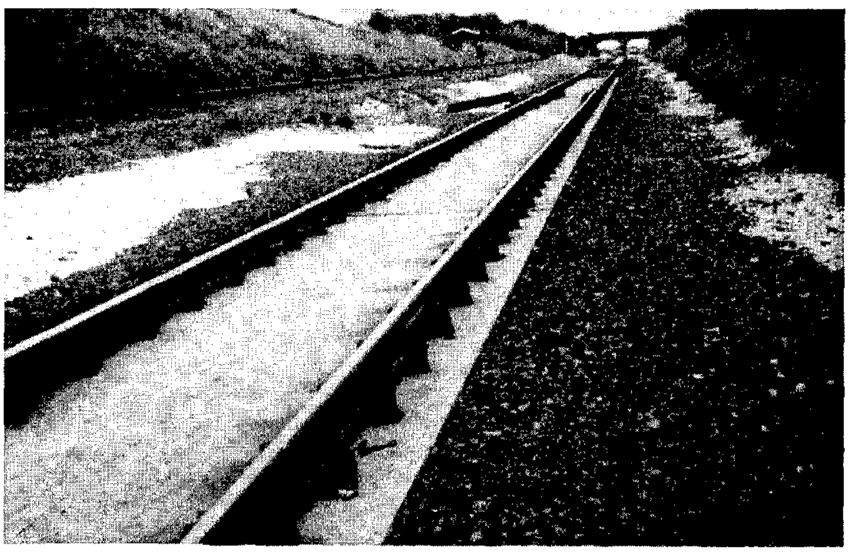

FIGURE 3-18. PRECAST CONCRETE SLABS AT RADCLIFFE-ON-TRENT

FIGURE 3-19. PRECAST CONCRETE LADDER UNITS AT RADCLIFFE-ON-TRENT

The 1.125-mile long track included an S-shaped curve with a 9,120 ft radius and a 820-ft long intermediate tangent section.

Slab was built using a special paving machine similar to road paving equipment. The machine was designed to build a 656-ft length at a time and consisted of four units. These included a paver, two reinforcement carriers, one each for top and bottom reinforcement, and an end feeder. In addition, a special machine was used to set holes for fastening inserts in the newly paved concrete. Specified 28-day concrete cube compressive strength was 5,510 psi.

The slab was 7.87 ft wide. Thickness varied from 7.9 in. at center to 10.8 in. at rail seats, as shown in Figure 3-20. Two layers of longitudinal and transverse reinforcement were used. Longitudinal reinforcement was 0.67% of concrete cross section.

End abutments and two cross walls were located at each end of the paved length to provide longitudinal restraint. Similar abutments were provided at both sides of a bridge along the track.

Transitions between slab track and conventional cross tie track were provided at both ends by prestressed concrete ladder units similar to those used at Radcliffe-on-Trent.

Elastic type rail fasteners were used. Inserts were installed at a 27.6 in. spacing using epoxy polyester resin or specially formulated cement grout. Rails were supported on 0.39-in. thick continuous rubber-bonded cork pads having a neoprene backing on the top surface. Pads were attached to the concrete slab using 0.47-in. wide strips of bituminous elastic tape. A view of this section is shown in Figure 3-21.

3.2 GERMANY

Several slab track projects were built in Germany between 1967 and 1978. These projects are described below.

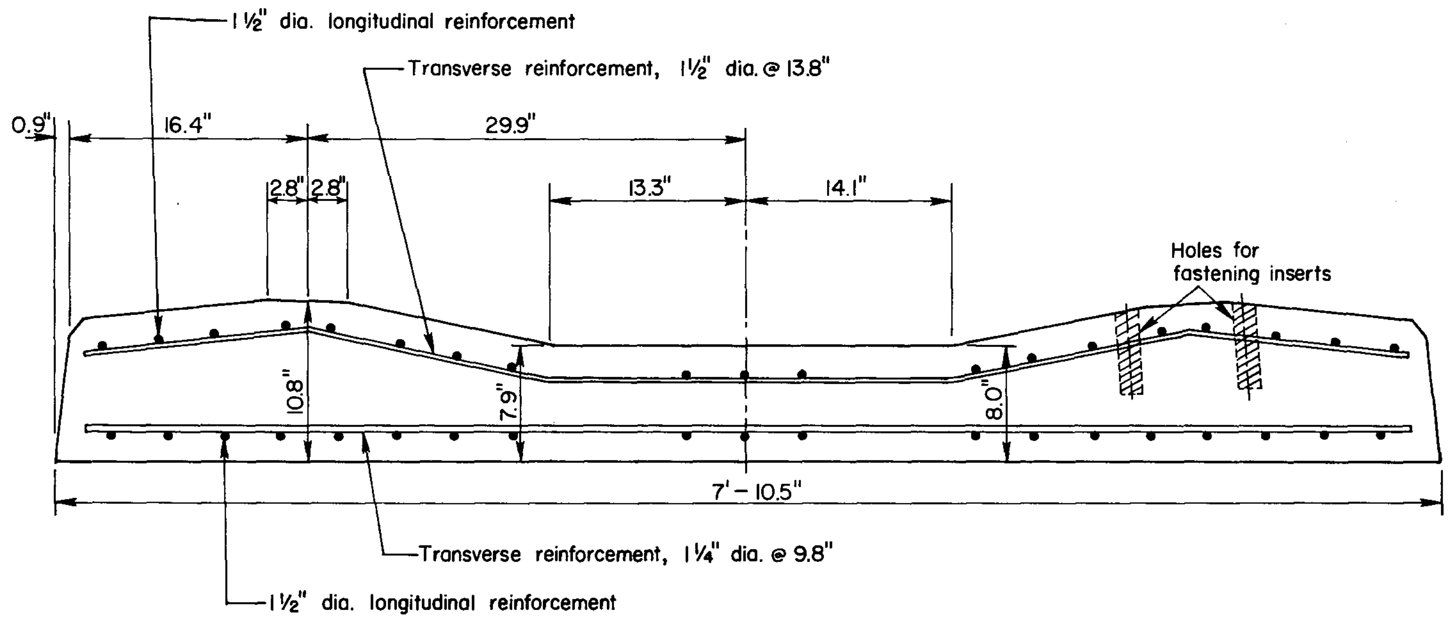

FIGURE 3-20. CROSS SECTION OF SLAB AT DUFFIELD

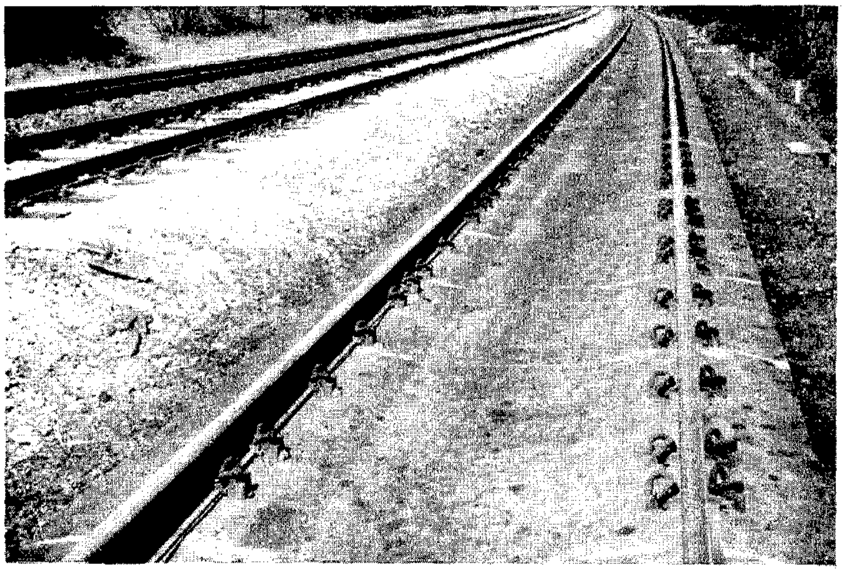

FIGURE 3-21. SLAB TRACK AT DUFFIELD

3.2.1 Hirschaid

This test section was built in 1967 at Hirschaid on the Forchheim-Bamberg mainline.[7,8,9,10] It consisted of three sections utilizing precast prestressed concrete units. Two sections had concrete slabs while the other had ladder units.

3.2.1.1 Slabs on Expanded Polystyrene Concrete Subbase - Slab track, shown in Figure 3-22, consisted of 17.0-ft x 7.9-ft x 7.1-in. precast prestressed concrete slabs. Longitudinal and transverse prestress were 435 and 231 psi, respectively. Slab continuity in the longitudinal direction was provided by four dowels encased in epoxy sealed joints.

Slabs were supported on a 13.1-ft wide, 5.9-in. thick expanded polystyrene concrete subbase. Subbase portions that extended beyond the slab width were sealed with a bituminous-lime coating and covered with ballast. Slabs were installed in position using cranes operating on guide rails.

3.2.1.2 Slabs on Sandy-Gravel Subbase - Slab track, shown in Figure 3-23, consisted of 11 slabs having same dimensions and prestress as those placed on expanded polystyrene concrete subbase. However, slab continuity in the longitudinal direction was provided by six prestressing rods encased in thermit-welded jackets.

Slabs were supported on a 11.5-ft wide, 3.1-in. thick lean concrete layer that was laid on a sandy-gravel subbase having an 8.7 in. average thickness. Deep subgrade drains were used to lower the ground water table. Installation of precast slabs was performed using cranes.

3.2.1.3 Ladder Units - This section consisted of 9 ladder units of precast prestressed longitudinal and transverse beams as shown in Figure 3-24. Each unit was 21.3 ft long and weighed 8.35 tons. Units were supported on a 11.5-ft wide, 3.1-in. thick lean concrete layer that was laid on a sandy-gravel subbase having a 6.7 in. average thickness. Deep subgrade drains

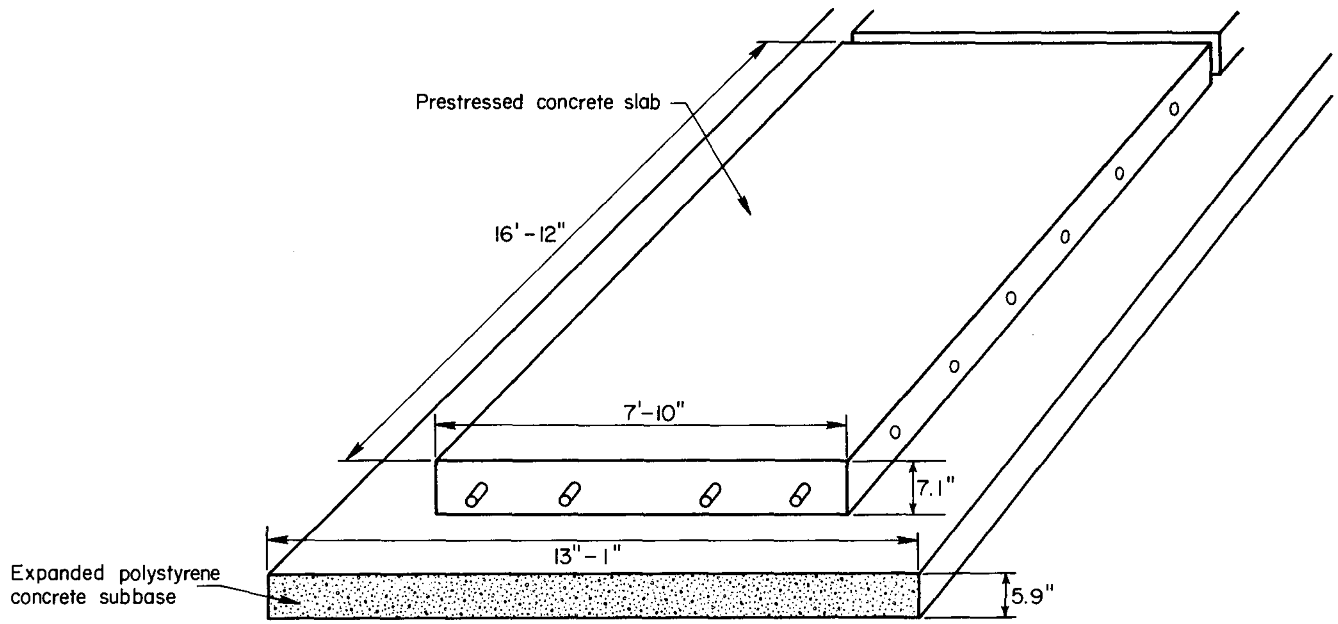

FIGURE 3-22. PRECAST CONCRETE SLABS ON EXPANDED POLYSTYRENE CONCRETE SUBBASE AT HIRSCHAID

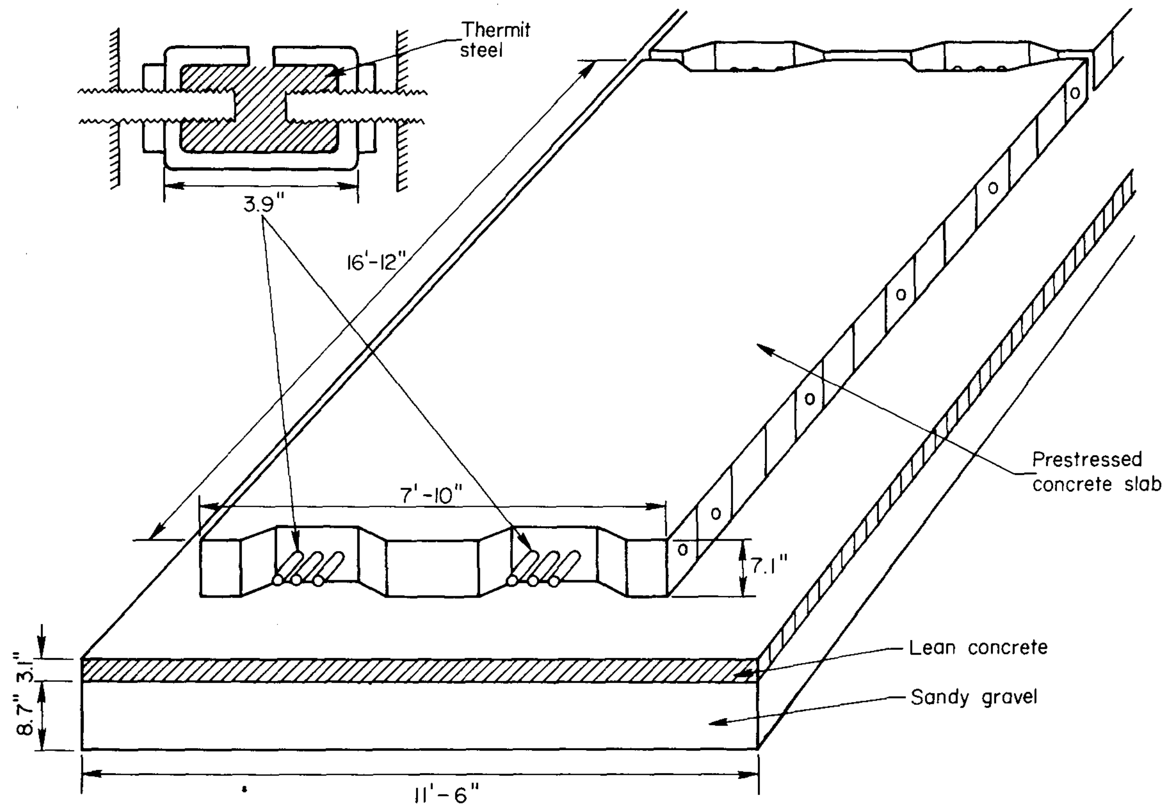

FIGURE 3-23. PRECAST CONCRETE SLABS ON SANDY-GRAVEL SUBBASE
AT HIRSCHAID

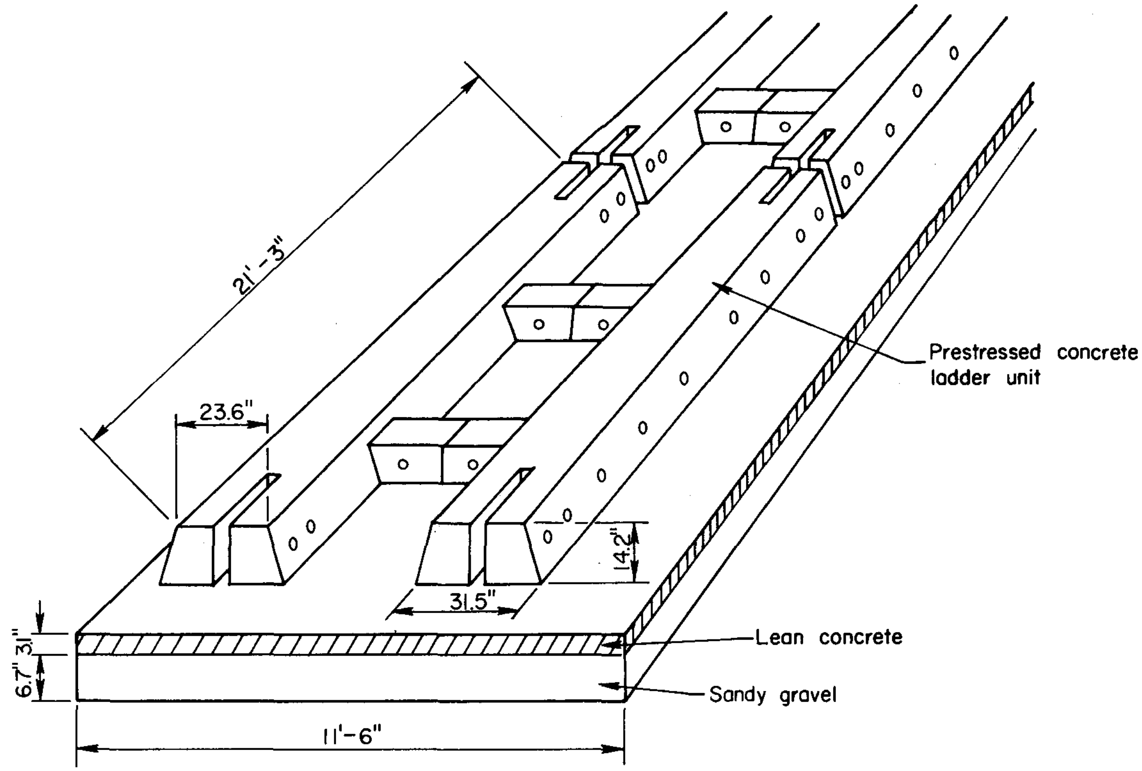

FIGURE 3-24. PRECAST LADDER UNITS AT HIRSCHAID

were used to lower ground water table. Ladder units were installed using cranes.

Ladder units were connected with prestressed joint bars. Space between longitudinal and transverse beams was filled with ballast. The upper layer of ballast was bituminous-treated to facilitate drainage.

Reinforced concrete abutments were built at ends of sections utilizing ladder units and slabs on sandy-gravel subbase, to resist longitudinal forces caused by temperature changes.

An improved version of a fastening system used by the German Federal Railway for securing rails to concrete and steel bridges was used for all sections at Hirschaid. To obtain accurate alignment, holes for fastening bolts were drilled on the site after installation of precast units.

3.2.2 Rheda and Oelde

Two large scale tests of slab track were built in 1972 between Bielefeld and Hamm in the areas of Rheda and Oelde stations.[10,11,12,13,14,15] Details of these projects are described.

3.2.2.1 Rheda - This 2,297-ft long section incorporated a tangent, a 0.3-degree curve with a 2.0-in. superelevation and a transition spiral. Daily traffic consisted of 76 trains representing about 20,000 gross tons. Average speed was 100 mph. However, test runs were made at speeds up to 156 mph.

Track consisted of prestressed concrete ties partially embedded in a continuously reinforced concrete slab. The 8.5-ft long ties were placed in position after casting the concrete slab. The slab was 9.2 ft wide and 5.51 in. thick. Ties were spaced at 23.6 in. center to center. The slab was supported on a 7.9-in. thick, 11.5-ft wide expanded polystyrene concrete subbase to provide thermal insulation and frost protection. The upper 5.9 in. of subgrade was stabilized with cement. Longitudinal and cross sections of track are shown in Figures 3-25 and 3-26, respectively. A view of this section is shown in Figure 3-27.

Reinforcing steel with a 61,000 psi yield strength was used. Longitudinal reinforcement consisted of 15, 0.63-in. diameter reinforcing bars. Transverse reinforcement consisted of 0.32-in. diameter reinforcing bars spaced at 19.7 in. center to center.

The slab was built with projecting stirrups. During construction, track panels consisting of rails, ties, and fastenings were assembled on the slab. Then, longitudinal reinforcing bars were inserted into predrilled holes in the ties and fastened to those stirrups projecting from the slab. After laying and lining of track panels, concrete was placed into cribs and spaces below ties.

A fastener system capable of providing vertical and lateral adjustments was used.

Abutments were built at slab ends to restrain slab movements due to temperature changes. These abutments were 55.1 in. deep and 23.6 in. wide. Also, deep drains were provided at track sides. Transitions between slab track and conventional cross tie track were provided at both ends using concrete ties placed at reduced spacing.

This project incorporated two turnouts installed at station ends. Turnouts were supported on 321- and 361-ft long reinforced concrete slabs. The 8.7-in. thick slabs were built with a width varying from 8.5 to 17.7 ft. Reinforcement consisted of a layer of welded wire fabric placed 2.4 in. below the slab surface. Load transfer devices consisting of 19.7-in. long, 1.10-in. diameter dowels placed at slab mid-depth were used at 13.1 to 16.4 ft spacing. Joints were formed by sawing 0.3-in. wide, 1.4-in. deep grooves.

Turnout slabs were placed on a 17.7-in. thick lean concrete subbase built with a width varying from 11.8 to 21.0 ft. To control subbase cracking, joints were sawed at a 13.1 to 16.4 ft

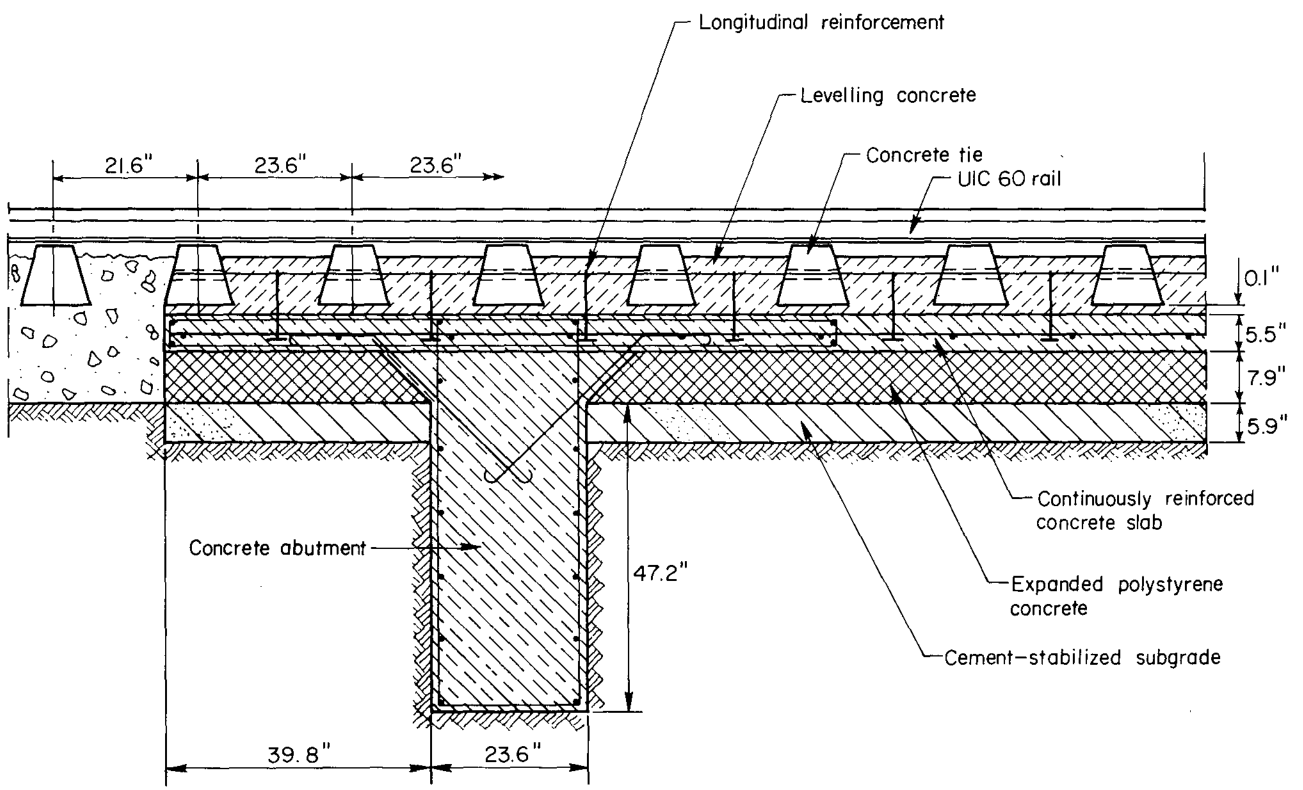

FIGURE 3-25. LONGITUDINAL SECTION OF SLAB TRACK AT RHEDA

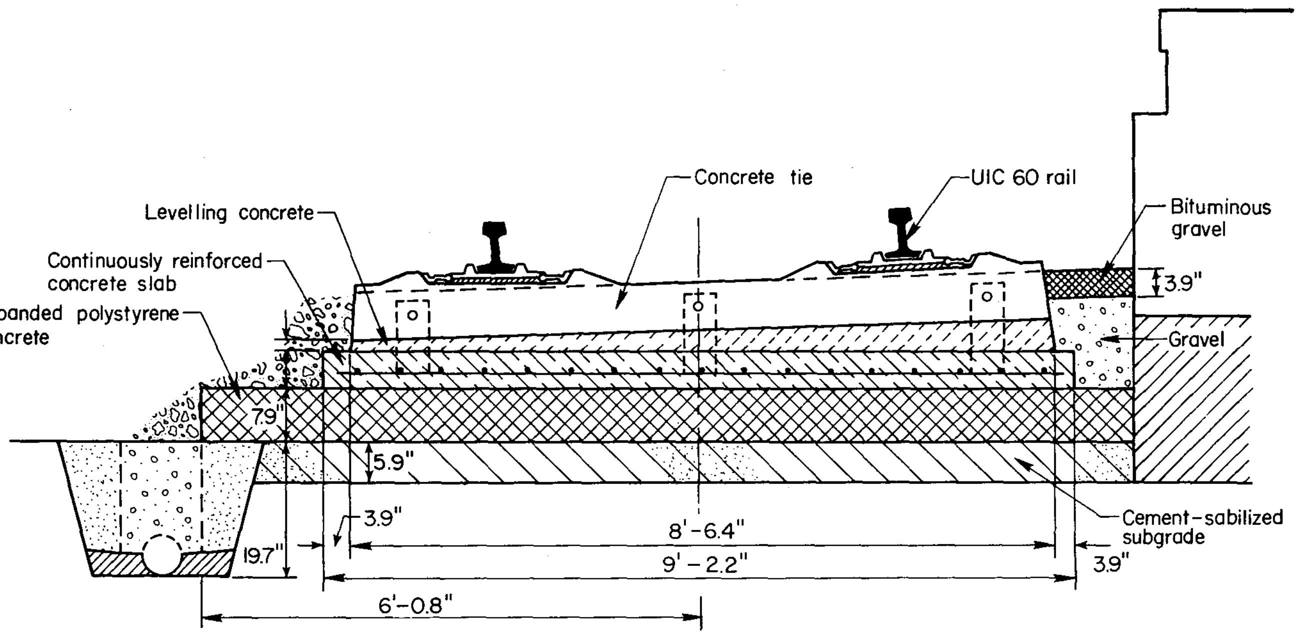

FIGURE 3-26. CROSS SECTION OF SLAB TRACK AT RHEDA

FIGURE 3-27. SLAB TRACK AT RHEDA

spacing. Subbase was placed on 1.2-in. thick expanded polystyrene boards to provide thermal insulation and frost protection. These boards were placed on a 1.2- to 2.0-in. thick layer of fine sand. Deep drains were provided on track sides. A cross section of turnout slab track is shown in Figure 3-28.

3.2.2.2 Oelde - This 2,133-ft long section incorporated a tangent, a 0.3-degree curve with 1.57-in. superelevation, and transition spirals. Daily traffic consisted of 76 passenger trains representing about 20,000 gross tons. Average speed was 100 mph. However, test runs were made at speeds up to 156 mph.

Track consisted of a 9.2-ft wide, 8.7-in. thick continuously reinforced concrete slab with controlled crack formation. Slab was supported on a 12.3-ft wide, 7.9-in. thick expanded polystyrene concrete subbase. The subbase was built on a 13.3-ft wide, 7.9-in. thick lean concrete base overlaying a 5.9-in. thick crushed stone layer. Longitudinal and cross sections of track are shown in Figures 3-29 and 3-30, respectively.

Longitudinal reinforcement consisted of twelve 0.63-in. diameter steel bars with a 61,000 psi yield strength. Transverse reinforcement consisted of 0.55-in. diameter deformed bars spaced at 11.8 in. center to center. Crack control was accomplished by coating longitudinal reinforcing bars at 9.8 ft intervals with bitumen and saw cutting of 0.16-in. wide, 1.6-in. deep joints. Bituminous coating was applied over a 23.6 in. length to prevent bond between steel and concrete in crack region and to provide a form of elastic coupling.

Two types of direct fixation fasteners capable of providing vertical and lateral adjustments were used. A German type fastener was used over a 1,476 ft length. A Dutch type fastener was used on the remaining 656 ft length. Fasteners were installed by drilling holes for anchoring blots at 23.6 in. spacing. Bolts were installed in position using epoxy grout.

Abutments were built at slab ends to contain longitudinal forces caused by temperature changes. These abutments were

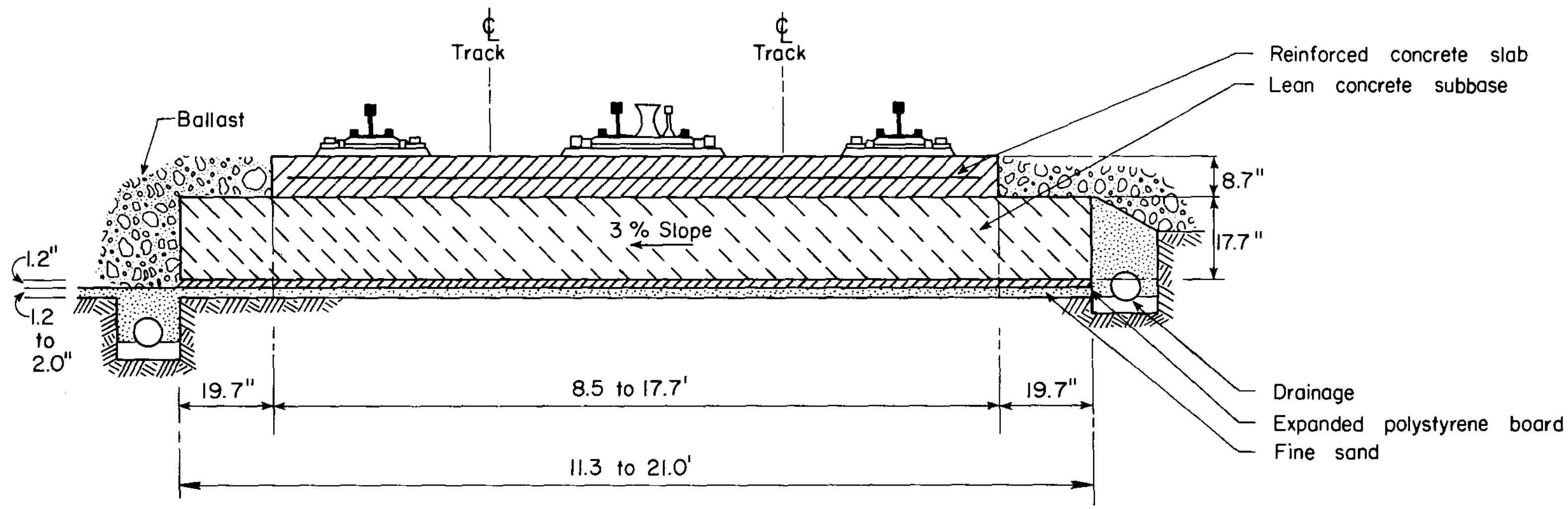

FIGURE 3-28. CROSS SCETION OF TURNOUT ON SLAB AT RHEDA

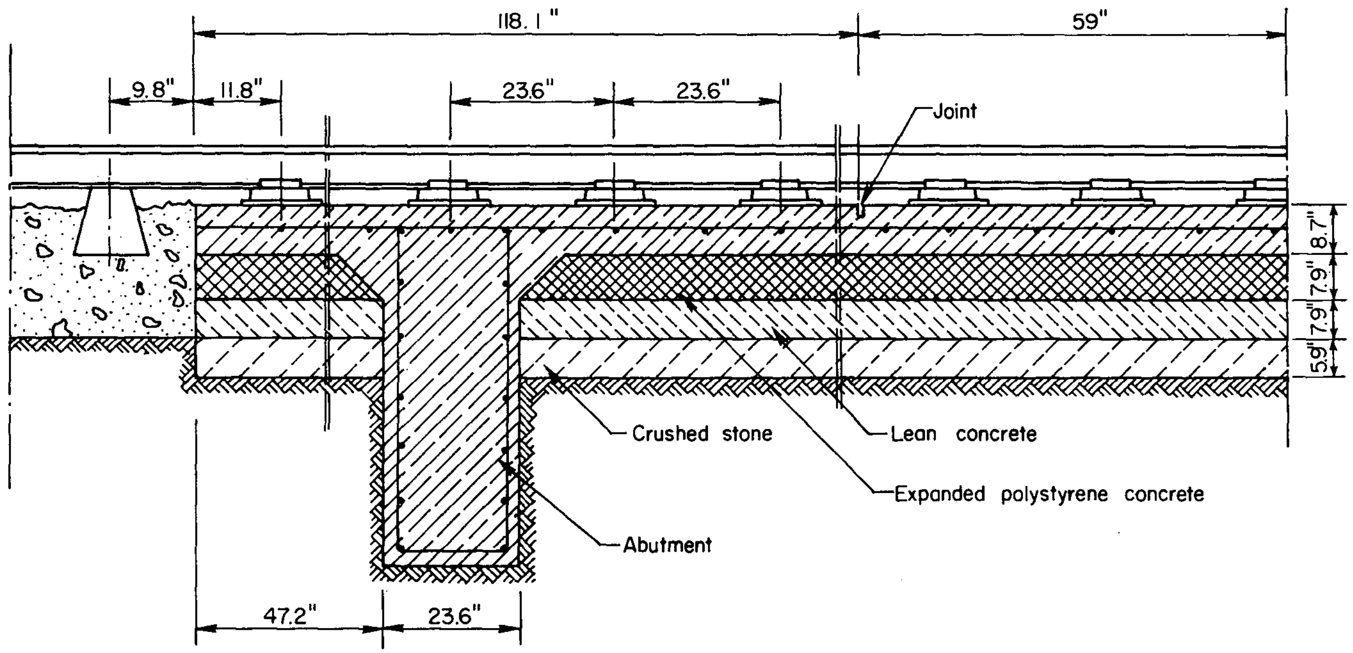

FIGURE 3-29. LONGITUDINAL SECTION OF SLAB TRACK AT OELDE

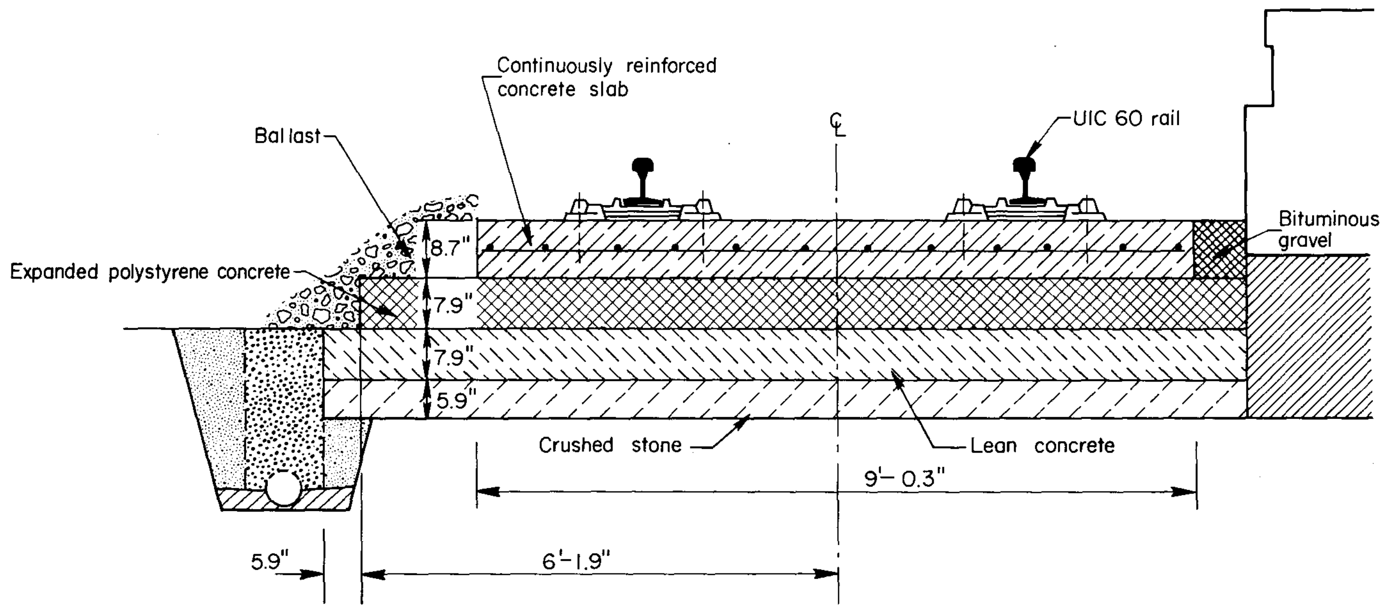

FIGURE 3-30. CROSS SECTION OF SLAB TRACK AT OELDE

55.1 in. deep and 23.6 in. wide. Also, deep drains were provided on track sides to minimize any reduction of subgrade strength by moisture. Transitions between slab track and conventional cross tie track were provided using concrete ties installed at reduced spacing.

3.2.3 Karlsfeld

This project was built in 1977 on a tangent section of the Ingolstadt-Munich mainline between Munich and Treuchtlingen.[16,17] Daily traffic was estimated at 57,000 gross tons. It included freight and passenger trains operating at 100 mph.

The 5,577-ft long test track included five different designs of slab track. These are described.

3.2.3.1 Precast Concrete Slabs - The 1,312-ft long section, shown in Figure 3-31, consisted of 9.1-ft wide, 15.6-ft long, and 7.9-in. thick slabs supported on a 12.5-ft wide, 7.9-in. thick cement-stabilized gravel subbase over a compacted subgrade. An asphalt interlayer was placed on top of the subbase to obtain the required slab elevation. A cross section is shown in Figure 3-32.

3.2.3.2 Precast Concrete Ladder Units - The 1,214-ft long section, shown in Figure 3-33, consisted of 24.1-ft long, 7.9-ft wide, and 17.3-in. thick prestressed concrete ladder units supported on an 11.2-ft wide, 7.9-in. thick cement-stabilized gravel subbase over a compacted subgrade. Units were placed on a bituminous interlayer to obtain the required slab elevation. A cross section is shown in Figure 3-34.

3.2.3.3 Concrete Ties Set into Cast-in-Place Slab - The 1,411-ft long section, shown in Figure 3-35, was constructed in a similar manner to that used at Rheda Station in 1972. It consisted of prestressed concrete ties set into cast-in-place continuously reinforced concrete slab. The slab was 8.5 ft wide and 7.9 in. thick. Ties were placed at 23.6 in. center to center. Slab was placed on an 11.8-ft wide, 7.9-in. thick

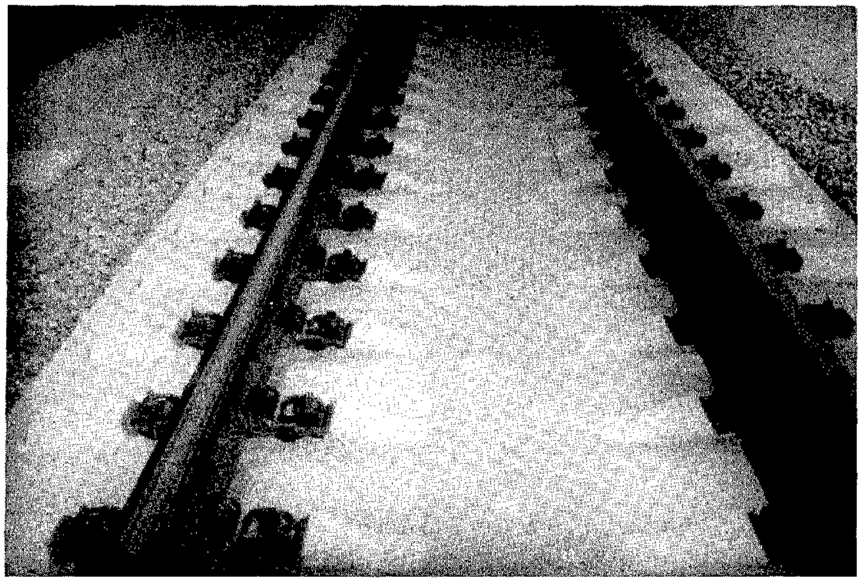

FIGURE 3-31. PRECAST CONCRETE SLABS AT KARLSFELD

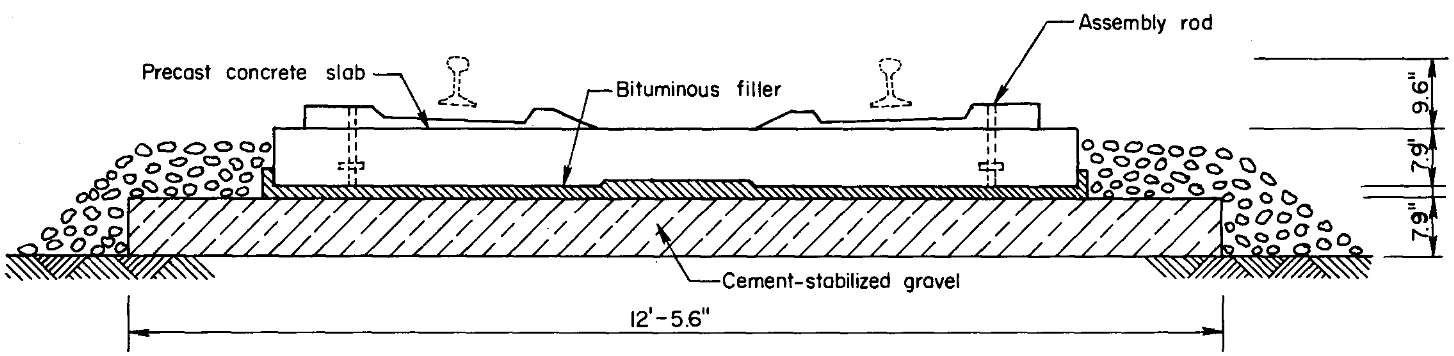

FIGURE 3-32. CROSS SECTION OF TRACK WITH PRECAST CONCRETE SLABS

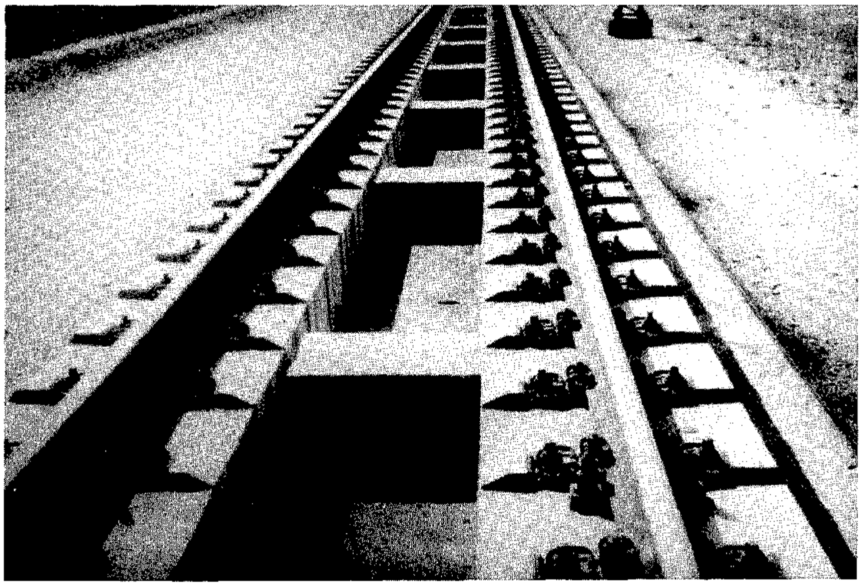

FIGURE 3-33. PRECAST CONCRETE LADDER UNITS AT KARLSFELD

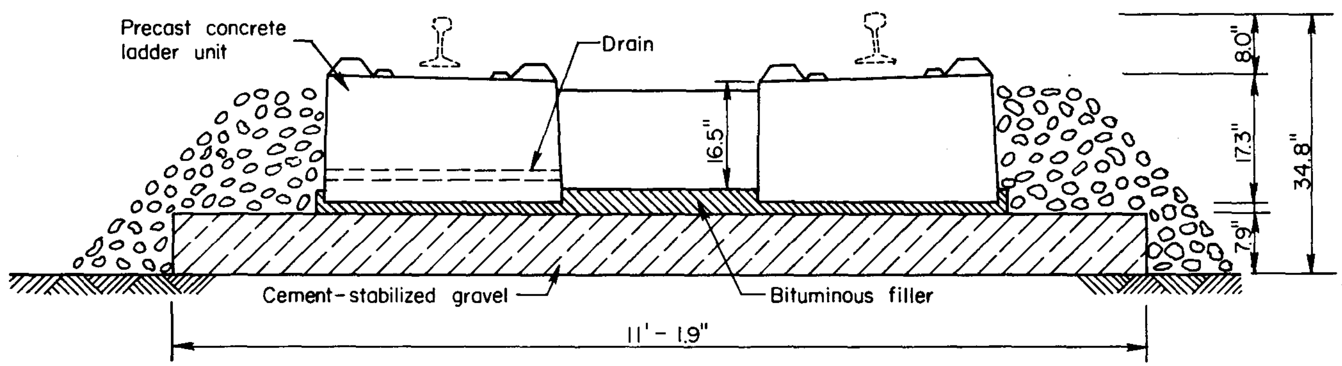

FIGURE 3-34. CROSS SECTION OF TRACK WITH PRECAST CONCRETE LADDER UNITS

FIGURE 3-35. CONCRETE TIES EMBEDDED IN SLAB AT KARLSFELD

cement-stabilized gravel subbase over a compacted subgrade. A cross section is shown in Figure 3-36.

3.2.3.4 Precast Concrete Blocks Set into Cast-in-Place Slab - The 820-ft long section, shown in Figure 3-37, was an 8.5-ft wide, 7.9-in. thick cast-in-place continuously reinforced concrete slab. The slab had longitudinal recesses at rail seats. Precast concrete units were placed in the recesses at 23.6-in. spacing using grout. The slab was placed on a 10.8-ft wide, 7.9-in. thick cement-stabilized gravel subbase. A cross section is shown in Figure 3-38.

3.2.3.5 Rubber-Booted Ties Set into Concrete Slab - The 820-ft long section, shown in Figure 3-39, was an 8.5-ft wide, 7.9-in. thick cast-in-place continuously reinforced concrete slab. The slab had longitudinal recesses at rail seats. Monoblock prestressed concrete ties, fitted with rubber boots at both ends, were set into the recesses using cement grout. Tie spacing was 23.6 in. The slab was supported on a 10.8-ft wide, 7.9-in. thick cement-stabilized gravel subbase. A filler material was used to adjust elevation. A cross section is shown in Figure 3-40.

3.2.4 Munich-Nordring

The 164-ft long section, shown in Figure 3-41, was built in 1978 near Munich.[16,17] It consisted of 32.5 x 9.8 x 4.7-in. prefabricated blocks set into a freshly cast-in-place reinforced concrete slab by vibration. The 9.2-ft wide, 11-in. thick slab, was built with 9.8 ft joint spacing. Slab was supported on a 11.5-ft wide, 11.0-in. thick cement-stabilized gravel subbase. A cross section is shown in Figure 3-42.

3.3 FRANCE

Two slab track projects were built in France in 1970. Details of these projects are described below.

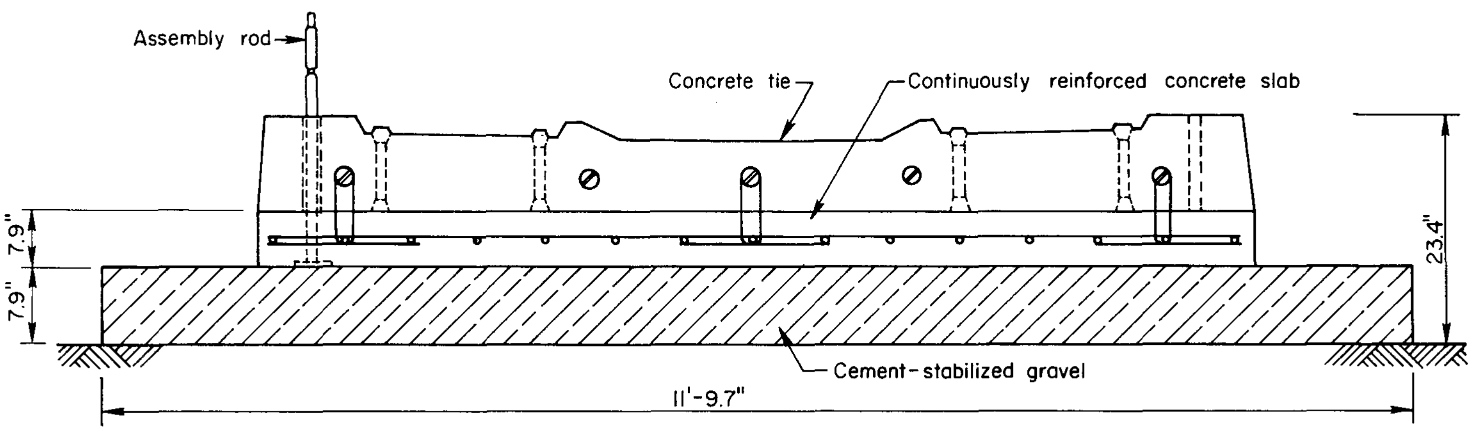

FIGURE 3-36. CROSS SECTION OF TRACK WITH CONCRETE TIES EMBEDDED IN SLAB

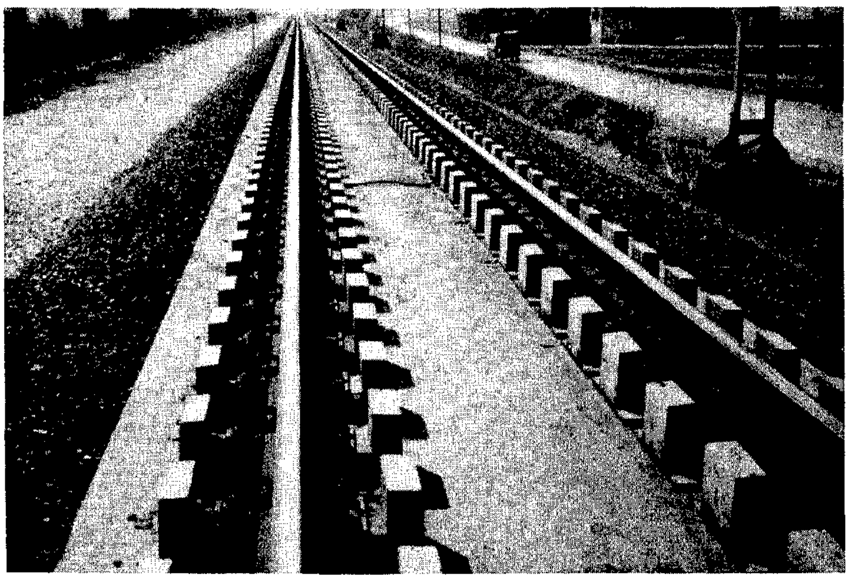

FIGURE 3-37. CONCRETE BLOCKS EMBEDDED IN SLAB AT KARLSFELD

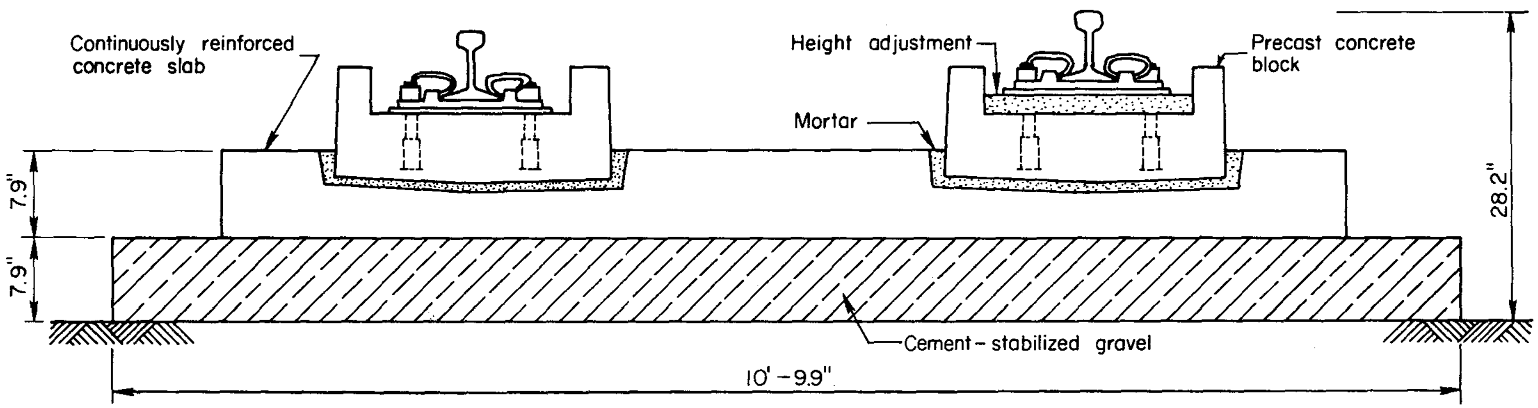

FIGURE 3-38. CROSS SECTION OF TRACK WITH CONCRETE BLOCKS SET INTO CAST IN-PLACE SLAB

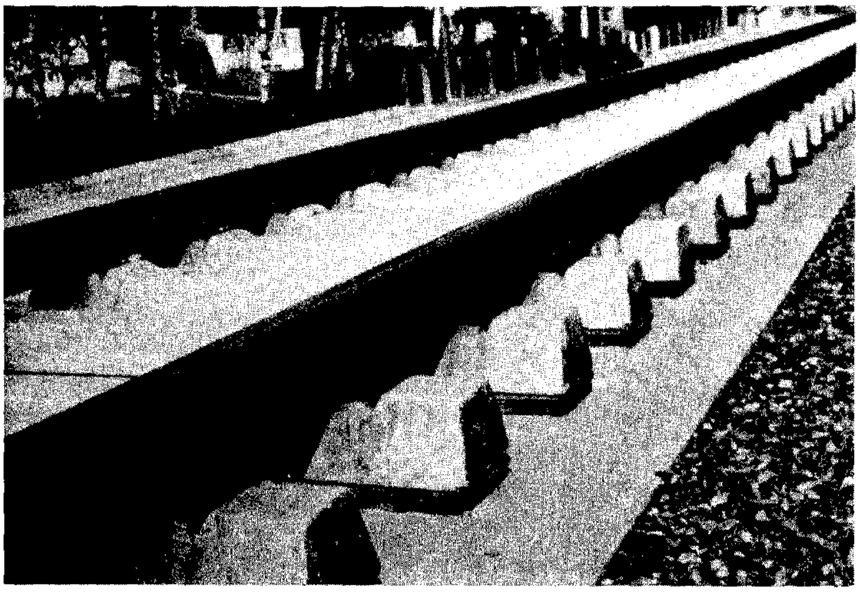

FIGURE 3-39. RUBBER-BOOTED CONCRETE TIES SET INTO CONCRETE SLAB AT KARLSFELD

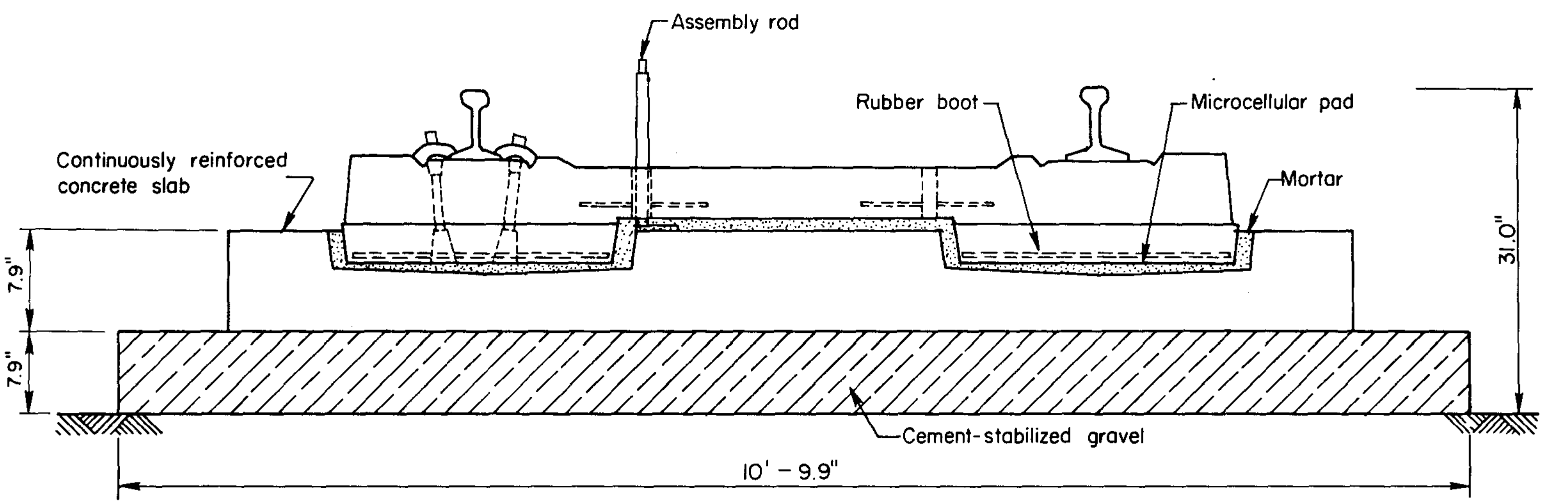

FIGURE 3-40. CROSS SECTION OF TRACK WITH RUBBER-BOOTED CONCRETE TIES SET INTO SLAB

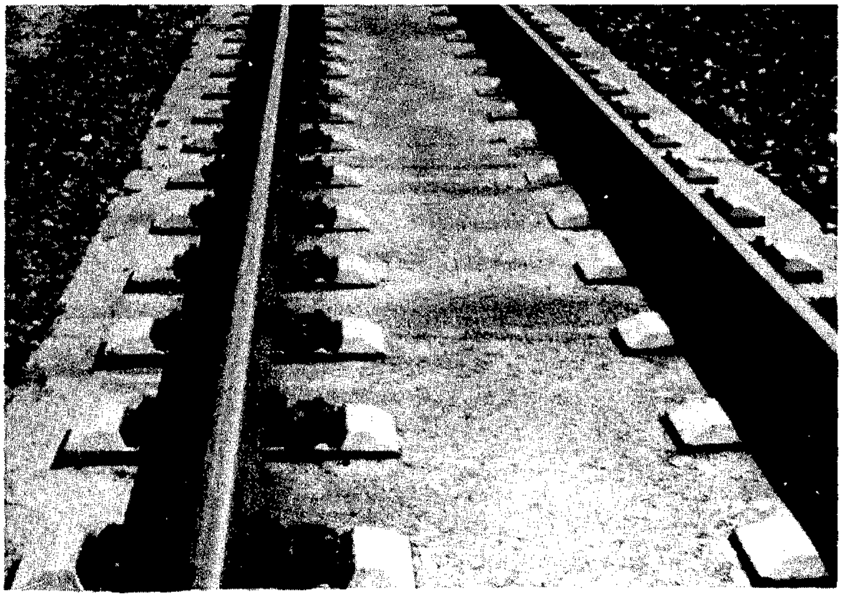

FIGURE 3-41. SLAB TRACK AT MUNICH-NORDRING

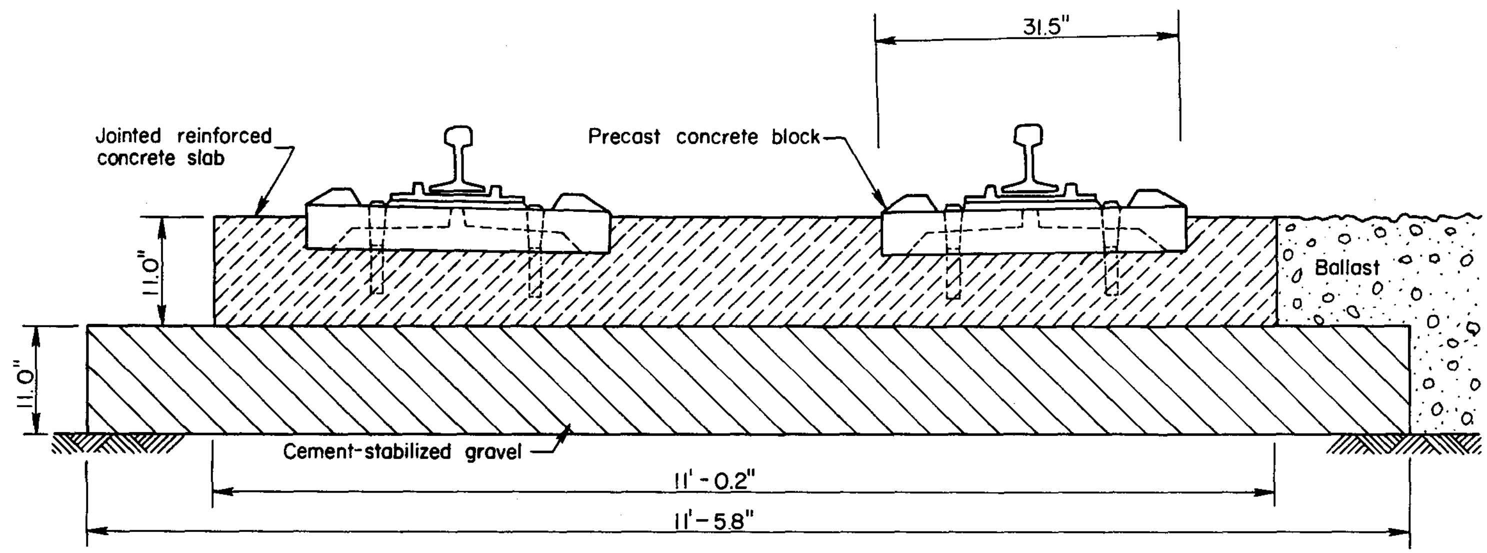

FIGURE 3-42. CROSS SECTION OF SLAB TRACK AT MUNICH-NORDRING

3.3.1 La Grillere

This project was built in 1970 at Grillere on the Paris-Toulouse mainline.[18] Track alignment included curves with a 262-ft radius and 0.9 to 1.0% gradients. Traffic was estimated at 26,000 tons per day at a maximum speed of 72 mph. Axle load was estimated at 20 tons.

The project consisted of a 410-ft long double track. Different designs were used for each track, as shown in Figure 3-43.

Both tracks consisted of 23.0-ft long, 11.8-ft wide, 5.9-in. thick reinforced concrete slabs. In one track, two-block ties fitted with rubber boots were set into the concrete slab at 27.6 in. spacing. Rails were attached to ties with elastic-type fasteners. In the other track, rails were secured directly to the concrete slab with adjustable-type fasteners installed at 27.6 in. spacing. Fasteners were capable of providng vertical and lateral rail adjustments.

Figures 3-44 and 3-45 illustrate the two slab track designs.

3.3.2 Neuilly-sur-Marne

This 984-ft long test project, shown in Figure 3-46, was built in 1970 at Neuilly-sur-Marne station on the outer ring of the Paris region.[19] Track alignment included tangent and curved sections with 2,000 and 4,200 ft radius. Traffic consisted of freight trains with 20-ton axle loads operating at a 56-mph speed at the rate of 100,000 tons per day.

The project consisted of three prestressed concrete slab sections each 328 ft long. Slabs were 9.2 ft wide and 7.1 in. thick. Each slab section was prestressed with twelve, 0.32-in. diameter strands placed at slab mid-depth and anchored at slab ends. Strands were encased in 1.65-in. diameter sheaths.

Slab sections were interconnected with two 4.9-ft long prestressed concrete joint slabs. Additional prestressing strands were placed in joint sections. In addition, two layers of transverse reinforcement were used.

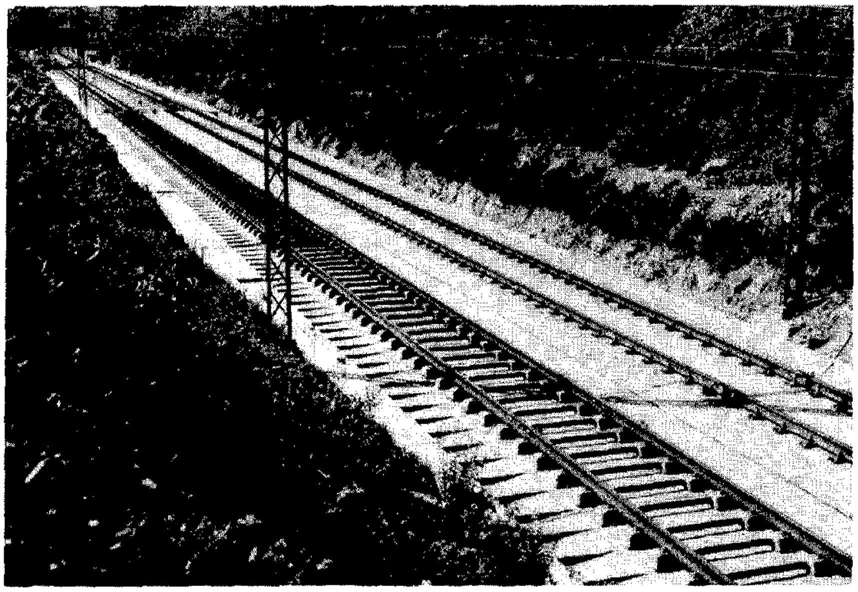

FIGURE 3-43. SLAB TRACKS AT LA GRILLERE

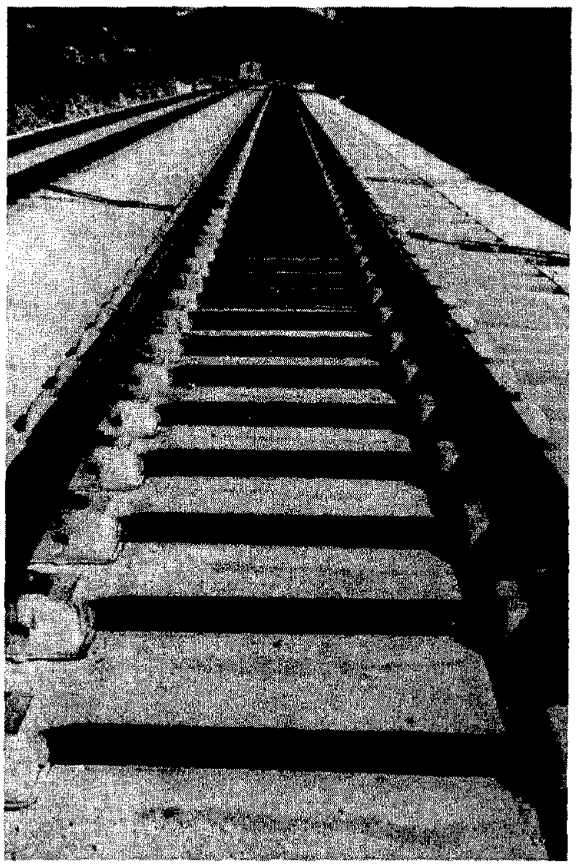

FIGURE 3-44. RUBBER-BOOTED CONCRETE TIES
SET INTO SLAB AT LA GRILLERE

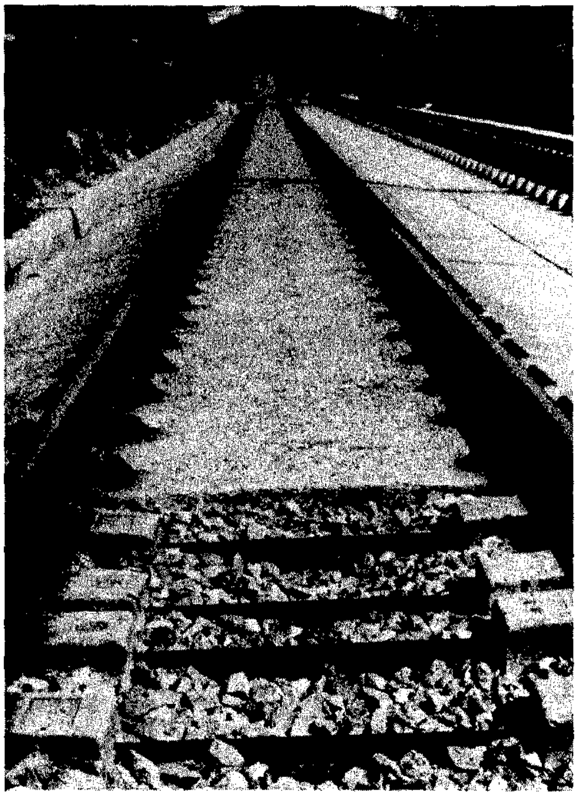

FIGURE 3-45. REINFORCED CONCRETE SLABS AT LA GRILLERE

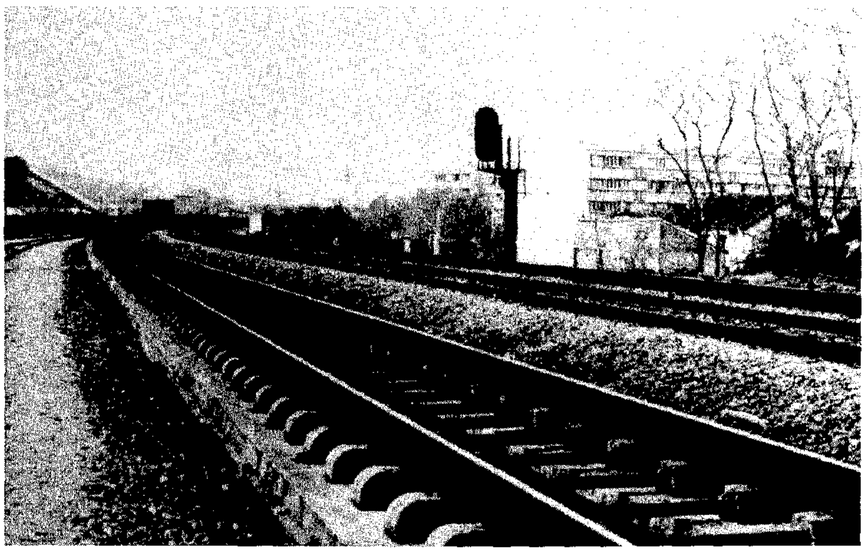

FIGURE 3-46. SLAB TRACK AT NEUILLY-SUR-MARNE

After placement of prestressed concrete slabs, four, 5.1-in. tall walls were built to restrain the two-block ties placed on top of slab. Track panels consisting of two-block ties fitted with rubber boots, rails, and fasteners were set at proper level and alignment between the side walls. Ties were spaced at 27.6 in. center to center. Space around ties was filled with cement-grout. Rails were attached to the ties with elastic type fasteners.

A drainage filter consisting of 3.9-in. thick layers of fine and coarse sand was placed over the subgrade. These layers were covered with a 3.9-in. thick lean concrete base. A 7.9-in. diameter drainage pipe was installed along the slab, as shown in Figure 3-47. A friction reducing layer was placed between the lean concrete base and slab.

3.4 SPAIN

A 2.6-mile long experimental slab track project was built in 1975 between Ricla and Calatorao on the electrified Madrid-Barcelona mainline.[20,21] This track was designed for a 5-ft 5.7-in. gage.

Track, shown in Figure 3-48, consisted of a 7.9-ft wide continuously reinforced concrete slab with a thickness varying from 11.4 in. under the rails to 9.4 in. at slab center. Reinforcement consisted of longitudinal and transverse steel placed approximately 5.7 in. from the slab bottom. Longitudinal reinforcement consisted of twenty 0.63-in. diameter bars representing 0.64% of concrete cross section. Transverse reinforcement was of 0.63-in. diameter bars placed at 27.6 in. spacing. The slab was placed on a 13.1-ft wide, 5.9-in. thick lean concrete base. Figure 3-49 shows slab cross section.

Continuously welded rails were supported on a 0.39-in. thick continuous rubber-bonded cork pad. The rails were fastened to the slab at a 27.6 in. spacing with elastic type fasteners. Fastener inserts were installed in preformed holes using epoxy grout.

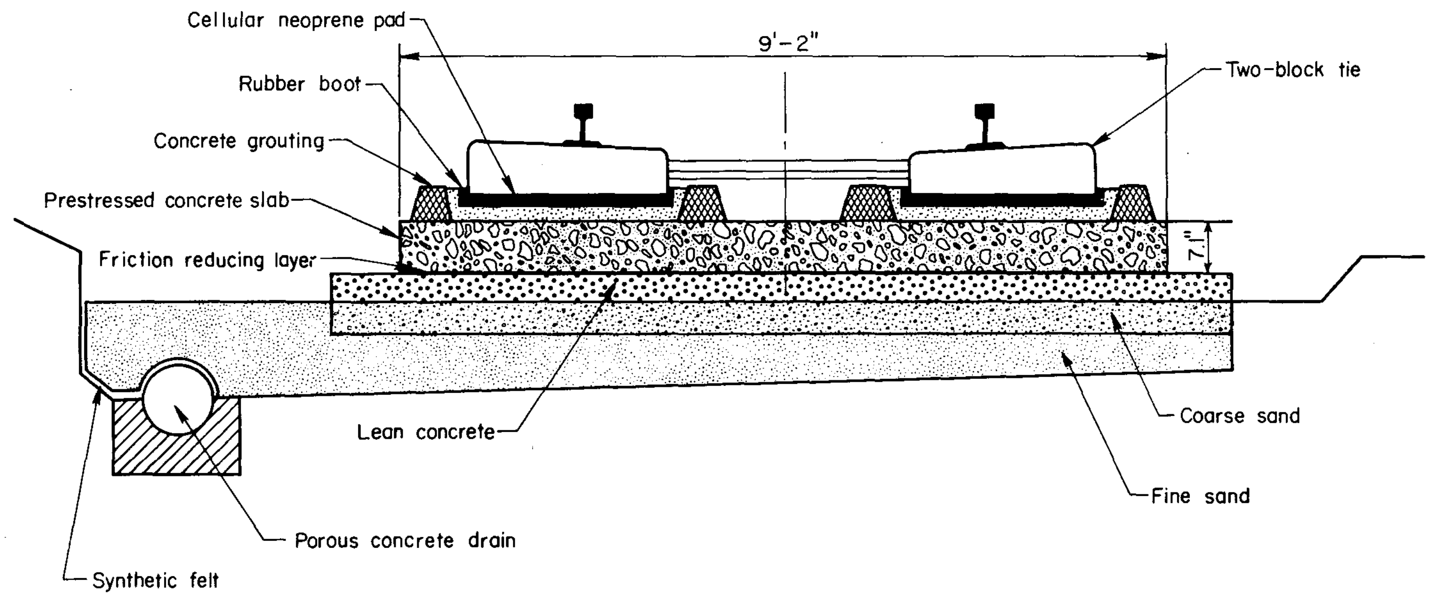

FIGURE 3-47. CROSS SECTION OF SLAB TRACK AT NEUILLY-SUR-MARNE

FIGURE 3-48. SLAB TRACK BETWEEN RICLA AND CLATORAO

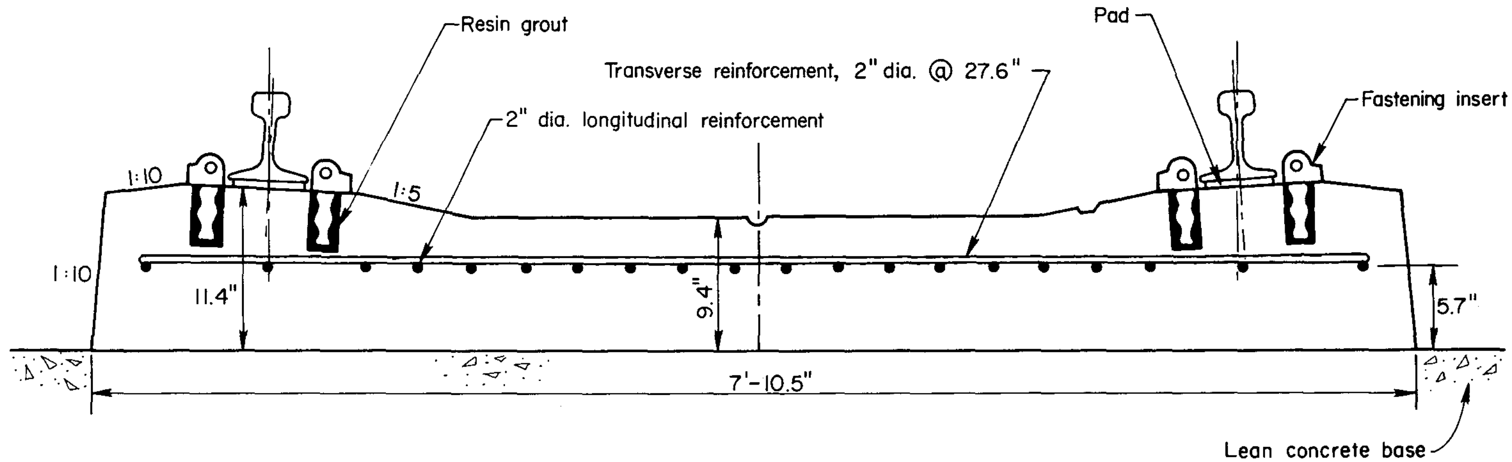

FIGURE 3-49. CROSS SECTION OF SLAB TRACK BETWEEN RICLA AND CALATORAO

The slab was slip-formed using a special paving machine. Transitions between slab and adjoining track consisted of two longitudinal and three transverse concrete beams as shown in Figure 3-50.

This project incorporated a crossover supported on a concrete slab.

3.5 THE NETHERLANDS

A 820-ft long test section was built in 1976-77 near Deurne on a tangent section of the Eindhoven-Venlo mainline.[22] Traffic density was estimated at 7.5 million gross tons per year. Operating speed averaged 100 mph.

Track consisted of 19.7-ft long precast reinforced concrete units. Units were 7.4 ft wide and 21.7 in. thick. Longitudinal reinforcement was 2% of the concrete cross section. No load transfer devices were used between units.

Slabs were supported on a 2.0-in. thick concrete layer placed over a sandy subgrade of an abandoned embankment. The embankment had been compacted by about 100 years of train traffic.

Specially-shaped channels were formed in the slab during fabrication to accommodate rails. Rails were secured in position using wedges of cork elastomer molded into the cavity between rail and slab. Rails were continuously supported on a rubber-bonded cork pad.

Figure 3-51 shows details of the system.

3.6 UNITED STATES

Construction of a slab track on The Long Island Rail Road was completed in 1980.[23,24] Traffic started in 1979 on several slab track sections located on the Metropolitan Atlanta Rapid Transit Authority lines. Another slab track built in 1974 as a part of the Kansas Test Track[25,26] was taken out of service in 1976.[27] These projects are described.

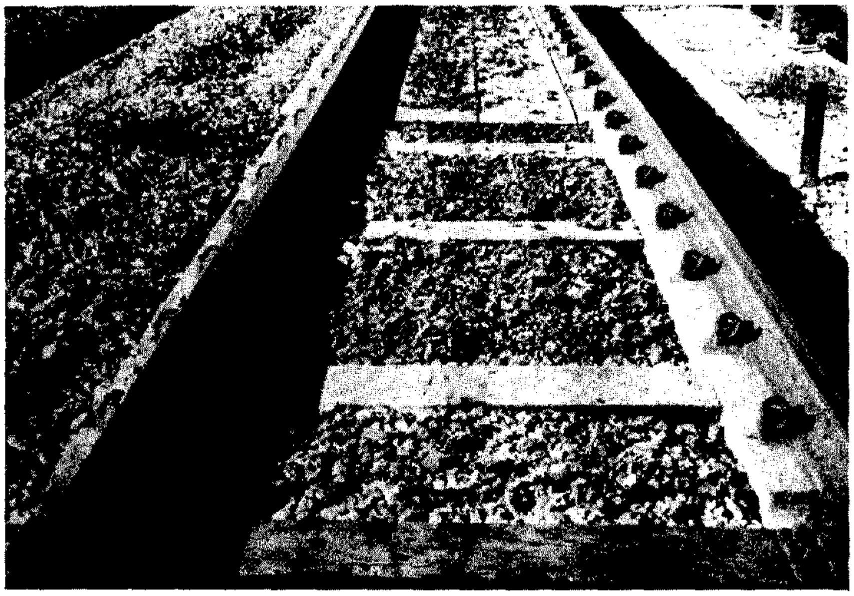

FIGURE 3-50. TRANSITION BETWEEN SLAB TRACK AND BALLASTED TRACK

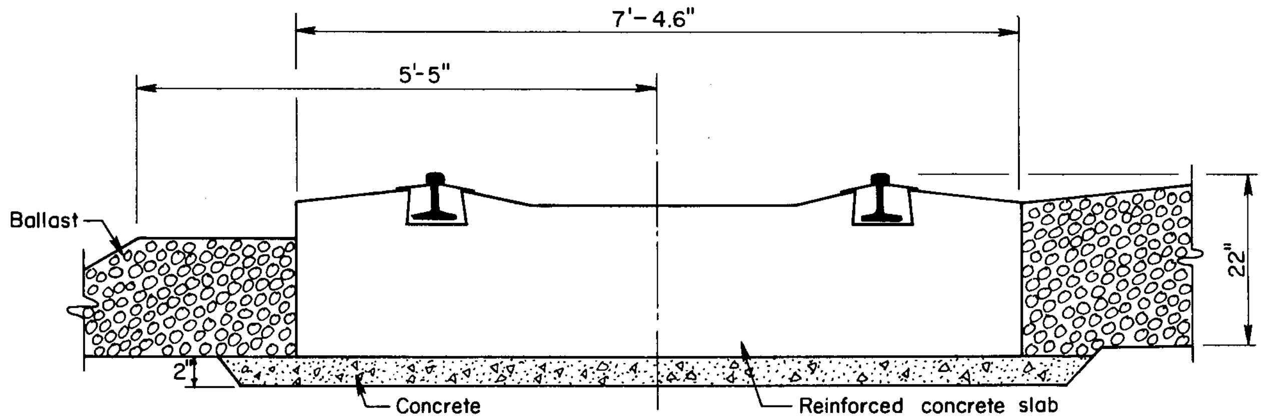

FIGURE 3-51. SLAB TRACK NEAR DEURNE

3.6.1 The Long Island Rail Road

An approximately 1.13-mile long slab track, shown in Figure 3-52, was built at Massapequa Park, Long Island between 1978 and 1980. Track was opened to traffic in December 1980. Track consisted of 10.5-ft wide, 12-in. thick continuously reinforced concrete slab placed on a 6-in. thick bituminous-treated subbase and compacted sandy subgrade. Two layers of steel were used. Longitudinal reinforcement consisted of 3/4-in. and 5/8-in. diameter bars located in the bottom and top, respectively. Bottom and top transverse reinforcement consisted of 1/2-in. diameter bars. Longitudinal reinforcement was 0.9% of the concrete cross section. A cross section is shown in Figure 3-53.

Adjustable elastic-type fasteners were used. Fastener bolt holes were drilled in the slab at 30 in. spacing. Epoxy-coated bolt inserts were bonded to the concrete using sand-epoxy grout.

3.6.2 Metropolitan Atlanta Rapid Transit

Nine slab track sections including a turnout were built on the Metropolitan Atlanta Rapid Transit Authority's East and West Lines. These double tracks were built in station areas and in transitions between elevated or subway sections and ballasted track. Track lengths ranged from 50 to 600 ft. Traffic consisted of MARTA trains with 30,500-lb axle loads operating at 70 mph maximum speed.

Slab track, shown in Figure 3-54, consisted of a 9.5-ft wide, 9-in. thick jointed reinforced concrete slabs placed on a 12-in. thick crushed stone subbase. Contraction joints were spaced 50 ft apart. Load transfer devices at joints consisted of 1.5-in. diameter, 2-ft long dowels spaced 1 ft apart. Slab reinforcement consisted of two layers of 0.75-in. diameter steel bars. Top and bottom longitudinal reinforcing bars were spaced at 9 in. Top and bottom transverse reinforcing bars were spaced at 12 and 6 in., respectively. Longitudinal reinforcement was 0.6% of the concrete cross section.

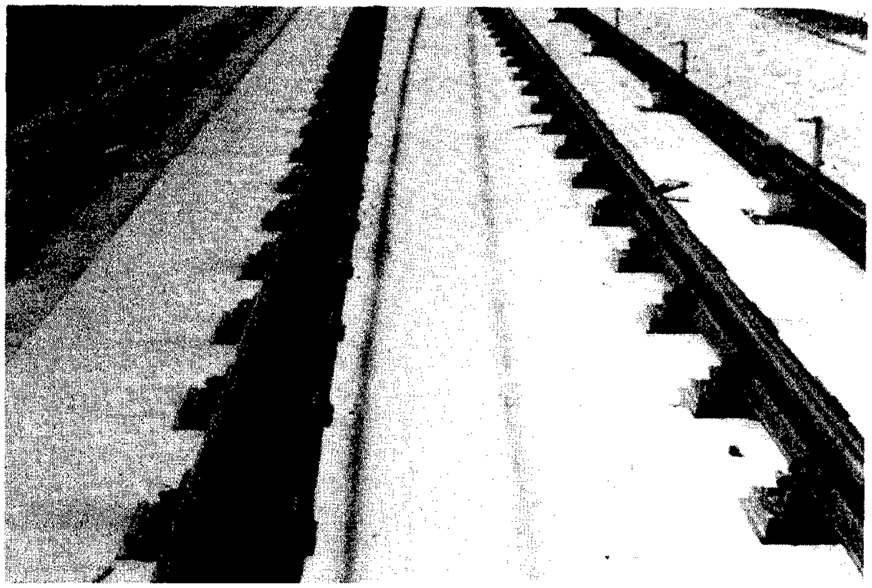

FIGURE 3-52. SLAB TRACK ON THE LONG ISLAND RAIL ROAD

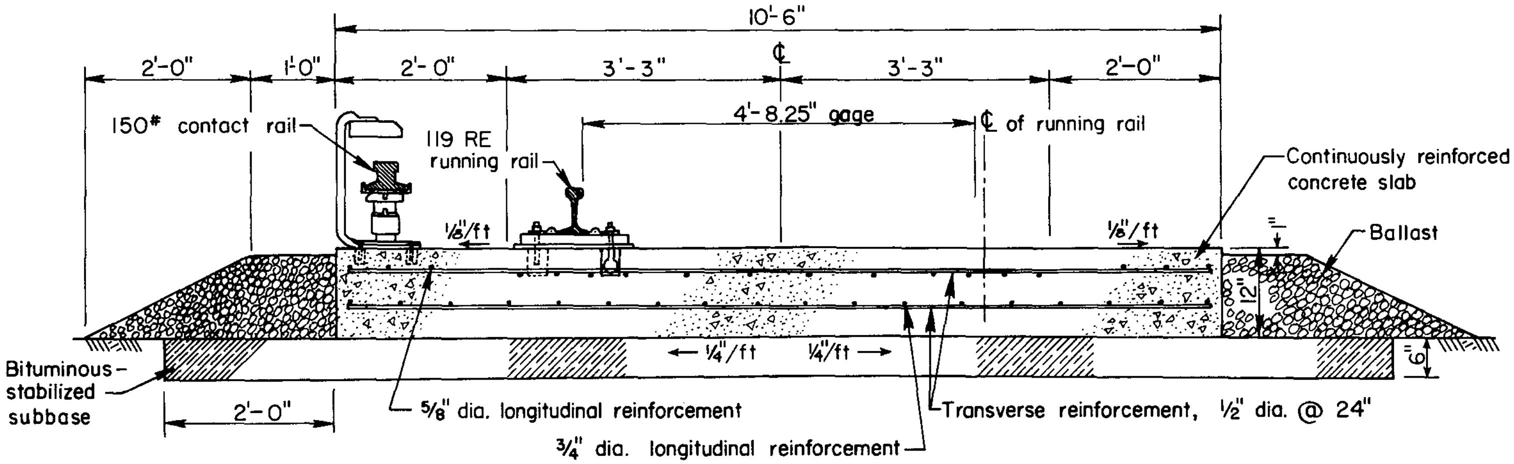

FIGURE 3-53. CROSS SECTION OF SLAB TRACK ON THE LONG ISLAND RAIL ROAD

FIGURE 3-54. SLAB TRACK ON METROPOLITAN
ATLANTA RAPID TRANSIT AUTHORITY

Slab panels at track ends were 25 ft long and 16 in. thick, supported on a 5-in. thick crushed stone subbase. Longitudinal and transverse reinforcement were 0.875 and 1.25-in. diameter bars, respectively. All reinforcing bars were spaced at 9 in.

Adjustable elastic-type fasteners were used. For this reason, second placement construction was used. Second placement consisted of two 6-in. thick by 3.83-ft wide concrete strips. To provide bond between the slab and second placement concrete, stirrups that projected approximately 3 in. above the surface were installed during slab construction. Concrete inserts for fasteners were also installed prior to second placement construction. Bolts were used to secure fastening base plate to these inserts. Rails were secured to the base plate with elastic-type clips and bolts. A cross section is shown in Figure 3-55.

A 383-ft long turnout, shown in Figure 3-56, was built on the West Line. Except for slab width, details were essentially similar to those of other slab track sections.

3.6.3 Kansas Test Track

This experimental slab track project was built as a part of U.S. Department of Transportation's effort to evaluate improved track structure designs. The 545-ft long test section was built in 1972 on a tangent track parallel to the Santa Fe's mainline between Aikman and Chelsea, Kansas. Traffic on the section consisted of heavy freight trains operating at speeds of up to 79 mph.

The slab track, shown in Figure 3-57, consisted of 9.0-ft wide continuously reinforced concrete slab built with control joints at 10 ft spacing. Slab thickness was 18 in. Two layers of longitudinal and transverse reinforcement were used. Longitudinal reinforcement consisted of thirteen 1/2-in. diameter top bars and twelve 3/4-in. diameter bottom bars. Transverse reinforcement consisted of 1/2-in. diameter bars at 10 in. spacing. A cross section is shown in Figure 3-58.

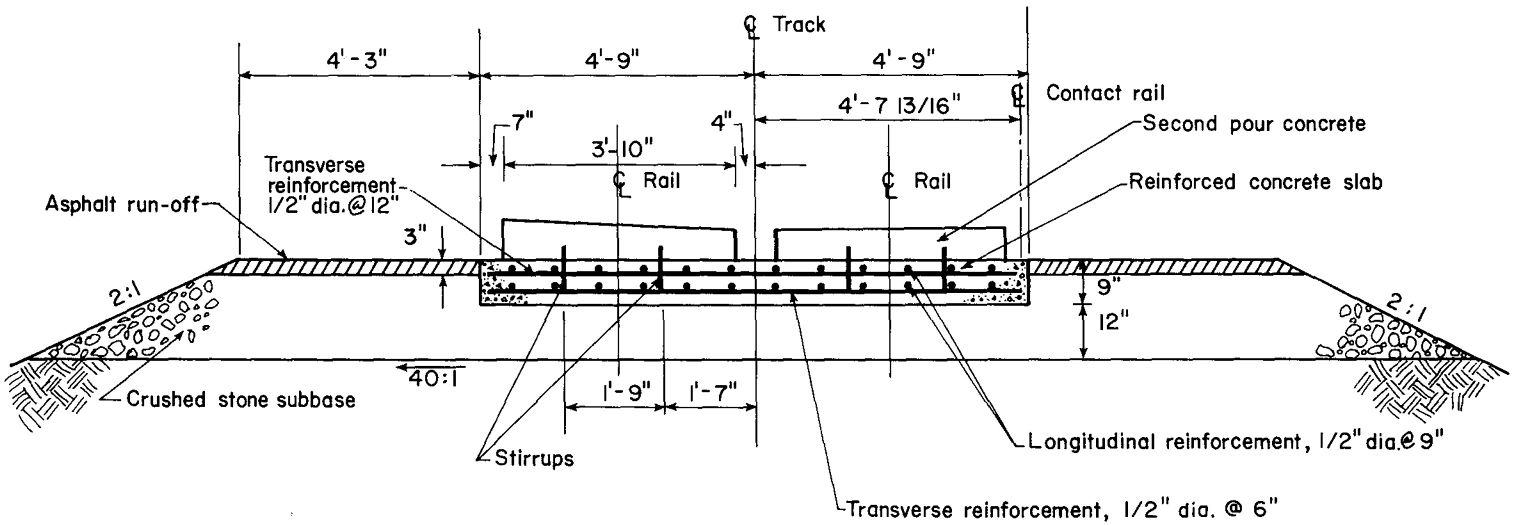

FIGURE 3-55. CROSS SECTION OF SLAB ON METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY

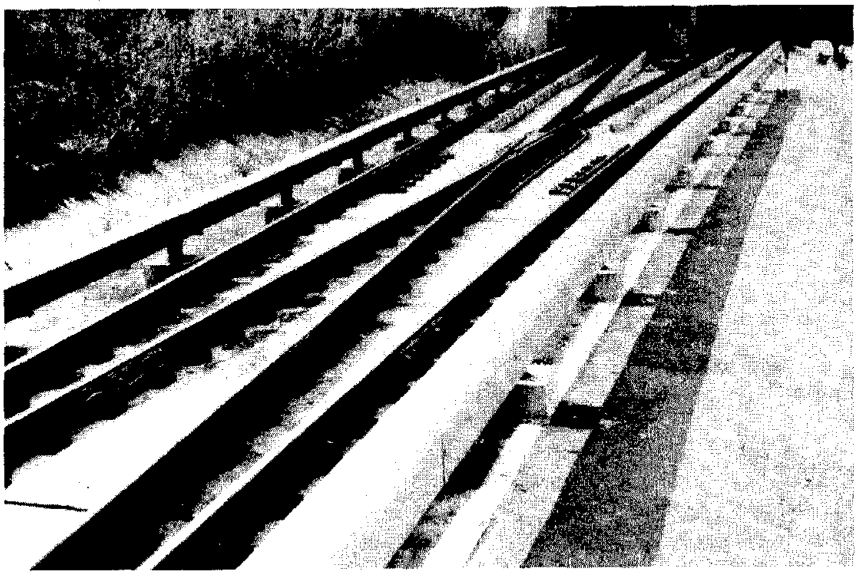

FIGURE 3-56. TURNOUT ON SLAB ON METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY

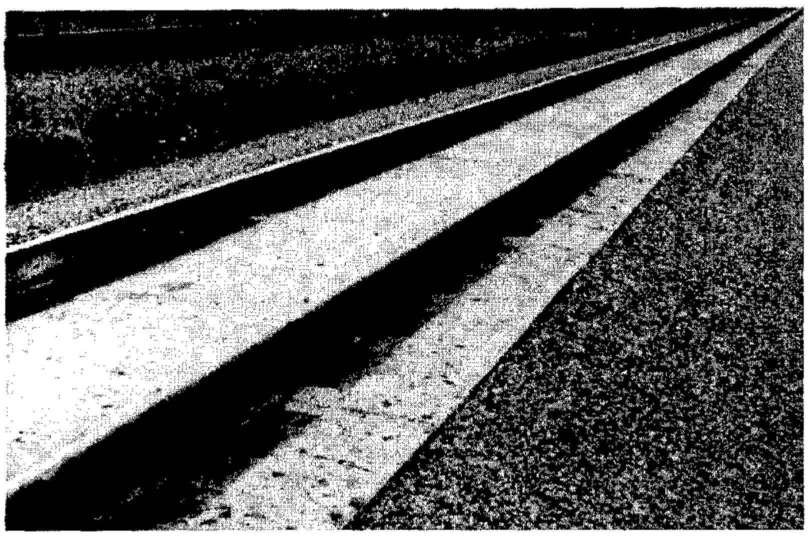

FIGURE 3-57. SLAB TRACK ON THE KANSAS TEST TRACK

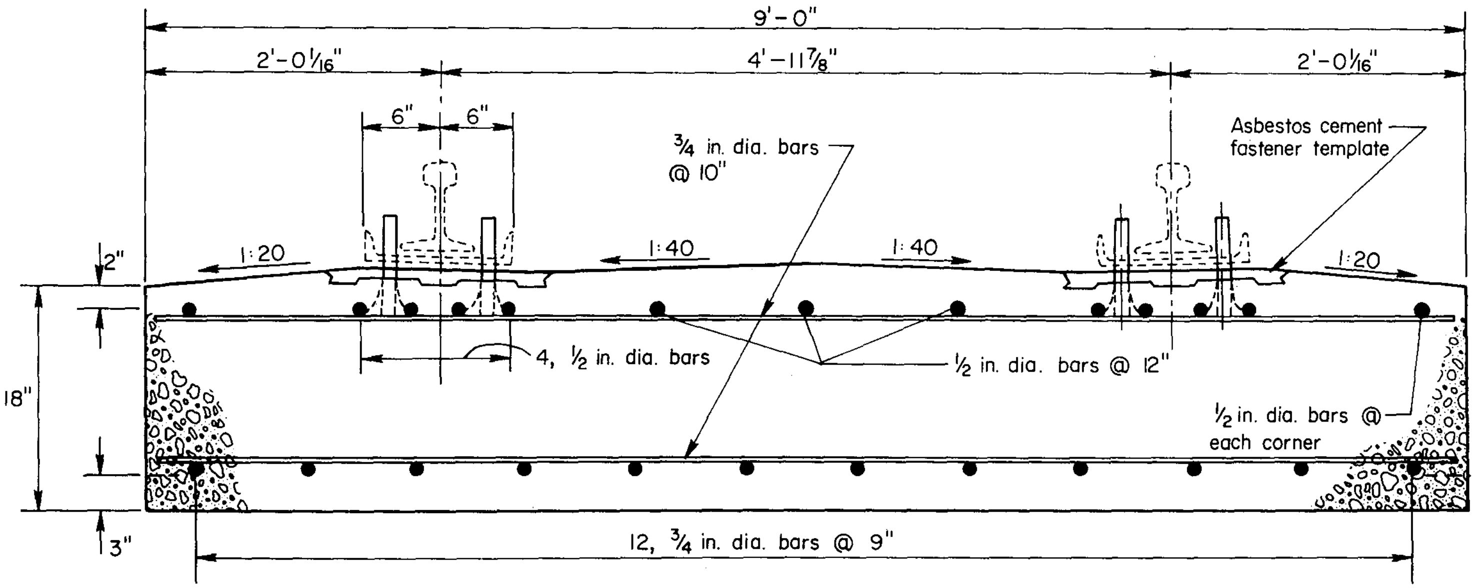

FIGURE 3-58. CROSS SECTION OF SLAB TRACK ON THE KANSAS TEST TRACK

Rails were fastened to the slab every 30 in. using a specially designed fastening system. For this purpose, fastening inserts were bonded to the concrete using an epoxy grout.

3.7 CANADA

A 1,200-ft long slab track, shown in Figure 3-59, was built in 1977 on a Toronto Transit Commission (TTC) line North of Yorkdale Station. Traffic consisted of TTC trains with 28,500-lb axle loads operating at 35 mph.

The slab track, designed for a 4-ft 10-7/8-in. gage, consisted of 11-in. thick, 10-ft wide plain concrete slabs placed on a 6-in. thick, 12-ft wide cement-treated subbase. A 3-in. thick, 14-ft wide layer of crushed granular material was placed between subbase and compacted subgrade. Contraction joints were formed by sawing at a 15 ft spacing. Standard TTC fasteners were used at 30 in. spacing. A cross section is shown in Figure 3-60.

3.8 SOVIET UNION

Several test sections of slab track were built in the Soviet Union after 1955.[28] These sections, built on main-line tracks with heavy freight traffic, utilized four designs of precast prestressed concrete slab and frame units.

Two designs of 8.5-ft wide slabs were used. Slab length and thickness were 20.5 ft and 11.8 in., respectively, for one design shown in Figure 3-61. For the other design, length and thickness were 13.6 ft and 9.8 in., respectively.

Also, two designs of 8.1-ft long frame units were used. Unit width and thickness were 8.1 ft and 9.4 in., respectively, for one design shown in Figure 3-62. For the other design, unit width and thickness were 7.4 ft and 8.3 in., respectively.

FIGURE 3-59. SLAB TRACK ON TORONTO TRANSIT COMMISSION LINE

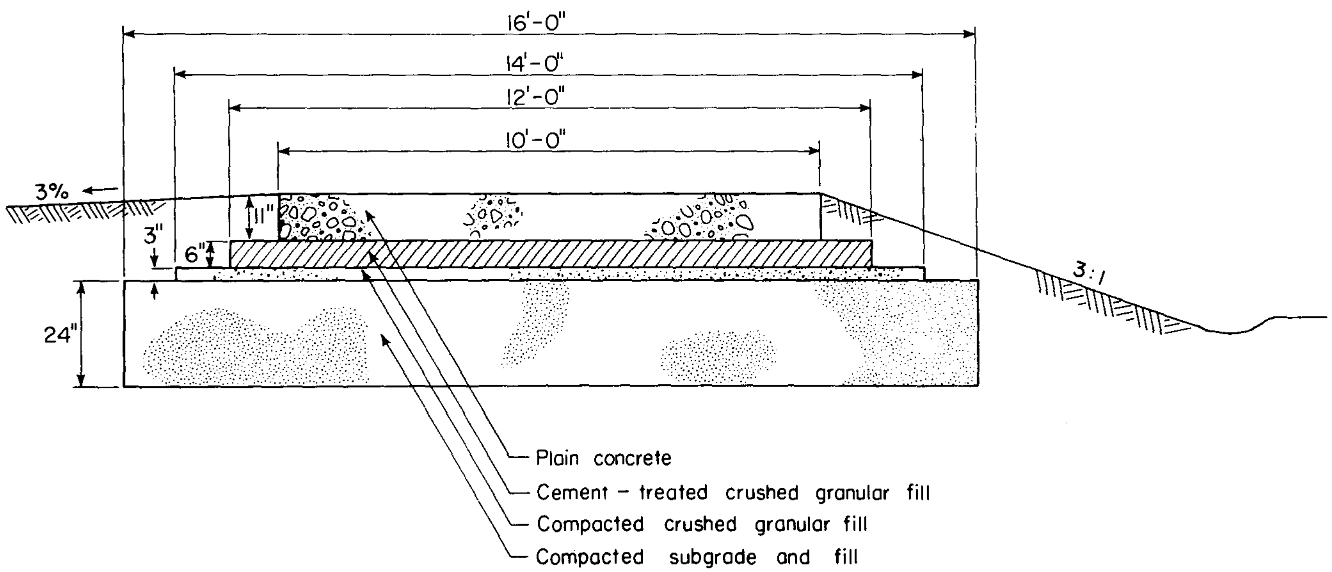

FIGURE 3-60. CROSS SECTION OF SLAB TRACK ON TORONTO TRANSIT COMMISSION

FIGURE 3-61. PRECAST CONCRETE SLABS IN THE SOVIET UNION

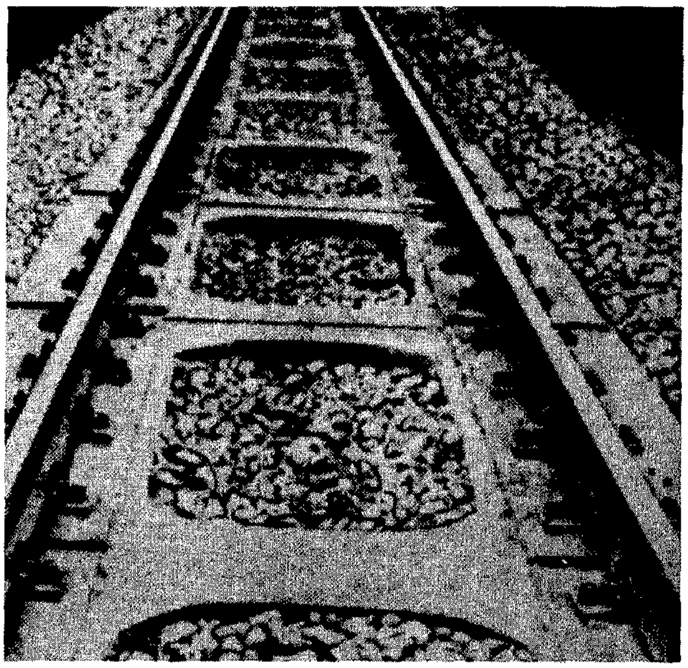

FIGURE 3-62. PRECAST FRAME UNITS IN THE SOVIET UNION

Embedded elements were installed in the concrete during slab and frame unit fabrication. These elements were used to fasten anchoring bolts that secured rail fasteners to the precast units.

4. RAIL FASTENERS

Several types of rail fasteners were used by railroads and transit properties on slab track projects described in Section 3. These fasteners secured rails to the concrete slabs, to precast concrete ties or blocks embedded in slabs, or to precast concrete ladder or frame units. Fastener spacing ranged from 23.6 to 30.0 in.

Rail fasteners used in these slab track projects are classified into three categories:

1. Fasteners having no provisions for adjusting rail level or track gage
2. Fasteners capable of adjusting either rail level or track gage
3. Fasteners capable of adjusting both rail level and track gage

Adjustment capabilities of fasteners used on the slab track projects are listed in Table 4-1. Features of these fasteners are described.

4.1 NON-ADJUSTABLE FASTENERS

Several types of non-adjustable fasteners were used on slab track projects at Radcliffe-on-Trent in England, at Hirschaid in Germany, and near Deurne in the Netherlands.

Four types of non-adjustable fasteners were used at Radcliffe-on-Trent. These fasteners were those used by London Transport (LTE), French Railways (SNCF), Swiss Railways (CFF), and British Railways (BR).

London Transport fastener, shown in Figure 4-1, was used to secure rails to the slab. Rails were supported on a rubber pad encased in a cast iron housing resting on a rubber base pad. Rails were secured to the slab with clamping plates, bolts, and nuts. Bolts were installed in predrilled holes and bonded to

TABLE 4-1. FEATURES OF SLAB TRACK FASTENERS

Country	Date	Location	Total Length, ft	Fastener Details				Remarks
				Designation	Spacing, in.	Adjustment, in. Vertical	Adjustment, in. Lateral	
England	1968-69	Radcliffe-on-Trent	236	LTE	25.6	0	0	
			236	NS	25.6	-0.08, + 0.39	+0.12	Lateral adjustments by means of eccentric bushes
			236	SNCF	25.6	0	0	
			236	CFF	23.6	0	0	Attached to rubber-booted two-block ties
			236	BR	25.6	0	0	Continuous rubber-bonded cork pad
			236	BR	25.6	0	0	Attached to precast longitudinal beams, continuous rubber-bonded cork pad
	1972	Radcliffe-on-Trent	197	BR	27.6	-0, + 0.39	-0.04, + 0.08	Continuous rubber-bonded cork pad
			230	BR	27.8 to 28.3	0	0	Turnout on slab, continuous rubber-bonded cork pad
	1972	Duffield	5,940	BR	27.6	-0, + 0.39	-0.04, + 0.08	Continuous rubber-bonded cork pad
	1975	Radcliffe-on-Trent	180	BR	27.6	-0.08, + 0.39	±0.16	Attached to precast concrete ladder units
			240	BR	27.6	-0.08, + 0.39	±0.16	Attached to precast concrete slabs

TABLE 4-1. FEATURES OF SLAB TRACK FASTENERS (Cont.)

Country	Date	Location	Total Length, ft	Fastener Details				Remarks
				Designation	Spacing, in.	Adjustment, in. Vertical	Lateral	
Germany	1967	Hirschaid	374	DB	23.6	0	0	Attached to precast concrete slabs
			187	DB	23.6	0	0	Attached to precast concrete slab
			191	DB	23.6	0	0	Attached to precast concrete ladder units
	1972	Rheda	2,297	DB	23.6	-0.12, + 0.39	±0.08	Attached to monoblock ties embedded in slab
	1972	Oelde	1,477	DB	23.6	-0.20, + 0.39	±0.39	
			656	NS	23.6	+0.32	±0.24	Lateral adjustment by means of eccentric bushes
	1977	Karlsfeld	1,312	DB	23.6	+0.39	±0.08	Attached to precast concrete slabs
			1,214	DB	23.6	+0.39	±0.08	Attached to precast concrete ladder units
			1,411	DB	23.6	+0.39	±0.08	Attached to monoblock ties embedded in slab
			820	NS	23.6	+0.32	±0.24	Attached to precast concrete blocks embedded in slab
			820	DB	23.6	0	±0.08	Attached to rubber-booted monoblock ties
	1978	Munich-Nordring	164	DB	23.6	+0.39	±0.08	Attached to precast concrete blocks

TABLE 4-1. FEATURES OF SLAB TRACK FASTENERS (Cont.)

Country	Date	Location	Total Length, ft	Fastener Details				Remarks
				Designation	Spacing, in.	Adjustment, in. Vertical	Lateral	
France	1970	La Grillere	410	SNCF	27.6	0	±0.10	Attached to rubber-booted two-block ties
			410	SNCF	27.6	+0.20	±0.10	
	1970	Neuilly-sur-Marne	948	SNCF	27.6	0	±0.10	Attached to rubber-booted two-block ties
Spain	1975	Ricla-Calatorao	13,451	BR	27.6	+0, + 0.39	±0.12	
The Nether-lands	1976-77	Deurne	820	NS	-	0	0	Rails are continuously attached to precast concrete slabs using molded cork elastomer
United States	1979-80	Massapequa Park, New York	11,878	LIRR	30.0	+0.50	±1.00	
	1975-79	Atlanta, Georgia	4,936	MARTA	30.0	+0.25	±0.375	Second placement construction
			383	MARTA	30.0	+0.25	±0.375	Turnout on slab, second pour construction
	1972	El Dorado, Kansas	545	Santa Fe	30.0	+0.50	±0.50	
Canada	1976-77	Toronto	2,400	TTC	24.0	0, + 0.50	0	

FIGURE 4-1. LONDON TRANSPORT'S FASTENER AT RADCLIFFE-ON-TRENT

the concrete slab with resin mortar. Packing plates were installed between clamping plates and rail.

French Railways fastener, shown in Figure 4-2, was used to secure rails to the slab. The fastener consisted of two base plates separated by a rubber pad. Another pad separated rail and upper base plate. The lower base plate rested on a grout pad. Both base plates were secured to the slab with bolts installed in predrilled holes and bonded to the concrete with resin mortar, clips, washers, and nuts. Rail was secured to the upper base plate with clips, Tee-head bolts, washers, and nuts.

Swiss Railways fastener, shown in Figure 4-3, was used to secure rails to rubber-booted two-block concrete ties embedded in the slab. Rails were supported on a rubber pad and secured to the tie with Tee-head bolts, clips, and nuts.

British Railways fastener, shown in Figure 4-4, was used to secure rails to the slab. Fastening shoulders were installed in predrilled holes and bonded to the slab with resin mortar. Rails were supported on a continuous rubber-bonded cork pad and secured to the shoulders with elastic type clips. Thermoplastic insulators were placed between rail and clips. A similar fastener was used to secure rails to precast concrete units on the Channel Tunnel and turnout slab track sections at Radcliffe-on-Trent.

A non-adjustable fastener was used to secure rails to precast concrete slabs and ladder units at Hirschaid. This fastening system represented an improved version of fasteners used by the German Federal Railway for securing rails to concrete and steel bridges.

The fastener consisted of a base plate with built-in shoulders resting on a synthetic pad. Base plate was secured to the concrete slab using four bolts that were screwed into plastic threaded inserts installed in predrilled holes and bonded to the concrete with epoxy resin. A tie plate welded to a steel plate was placed on a rubber pad and secured to the base plate with two elastic-type clips. Rails were supported

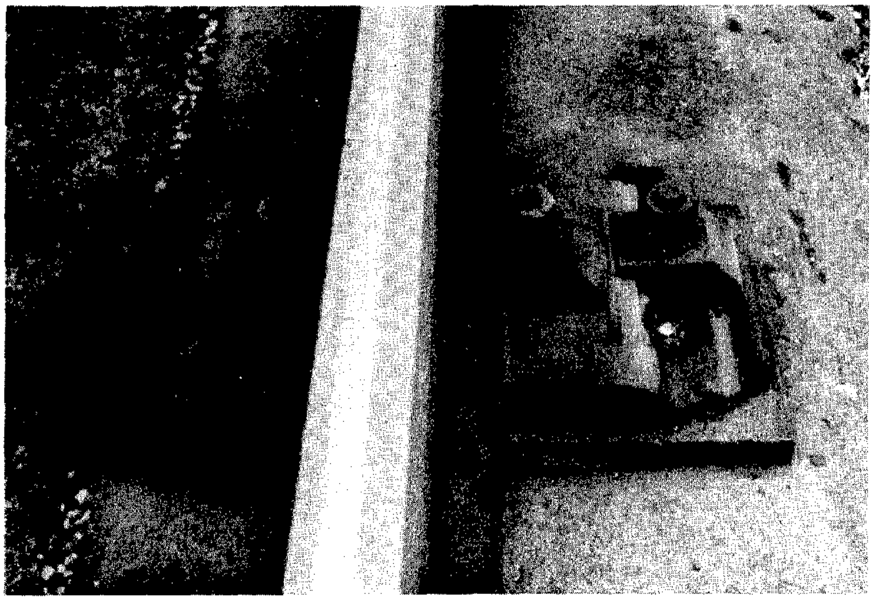

FIGURE 4-2. FRENCH RAILWAYS FASTENER AT RADCLIFFE-ON-TRENT

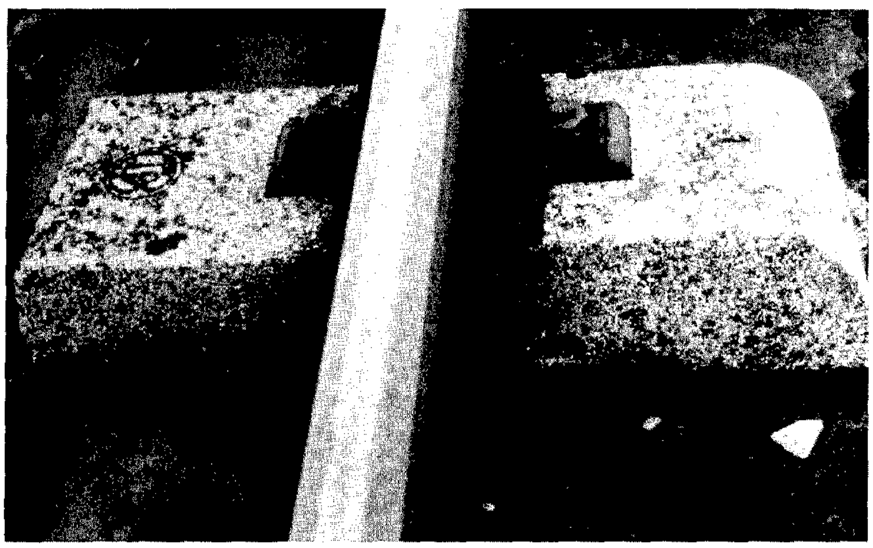

FIGURE 4-3. SWISS RAILWAYS FASTENER AT RADCLIFFE-ON-TRENT

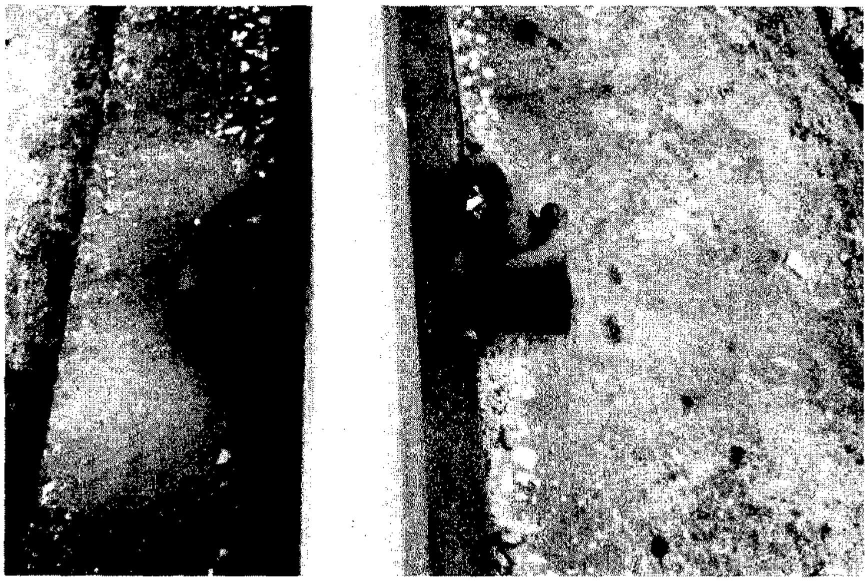

FIGURE 4-4. BRITISH RAILWAYS FASTENER AT RADCLIFFE-ON-TRENT

on a synthetic pad and secured to the tie plate with two additional clips.

In the slab track project near Deurne, rails were supported on a rubber-bonded cork pad and housed in grooves built in the precast concrete slab. Cork elastomer wedges were molded into the cavity between rail and slab. The groove was covered with a steel plate. Details of this fastening arrangement are shown in Figure 4-5.

4.2 VERTICALLY-ADJUSTABLE FASTENERS

A fastening system capable of level adjustment but having no provision for gage adjustment was used on a slab track north of Yorkdale station in Toronto.

The fastening, shown in Figure 4-6, consisted of a steel plate supported on rubber and grout pads and secured to the concrete slab with anchor bolts, washers, and nuts. Anchor bolts were installed in predrilled holes and bonded to the concrete with epoxy grout. Rails were secured to the steel plate with Tee bolts, compressive rail clips, and nuts. The fastening system permits a vertical rail adjustment of up to 0.5 in. Vertical adjustment is accomplished by inserting shims between base plate and grout pad.

4.3 LATERALLY-ADJUSTABLE FASTENERS

Two fasteners capable of adjusting track gage but not level were used on slab track projects at Karlsfeld in Germany, and La Grillere and Neuilly-sur-Marne in France. Both fasteners were used to secure rails to rubber-booted ties embedded in the concrete slab.

Fastener used to secure rails to rubber-booted monoblock ties at Karlsfeld is shown in Figure 4-7. The tie was fabricated with concrete shoulders and threaded plastic inserts for fastening bolts. In this system, rails were supported on a tie pad. Angled guide plates were placed between rail and tie

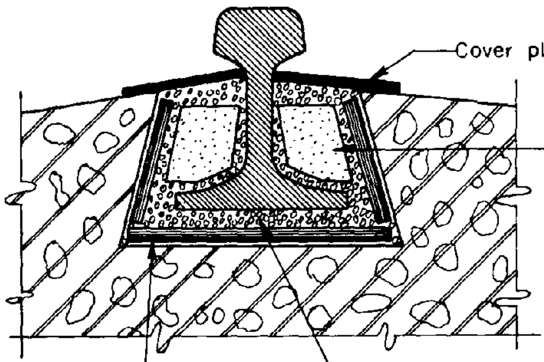

FIGURE 4-5. RAIL FASTENER FOR SLAB TRACK AT DEURNE

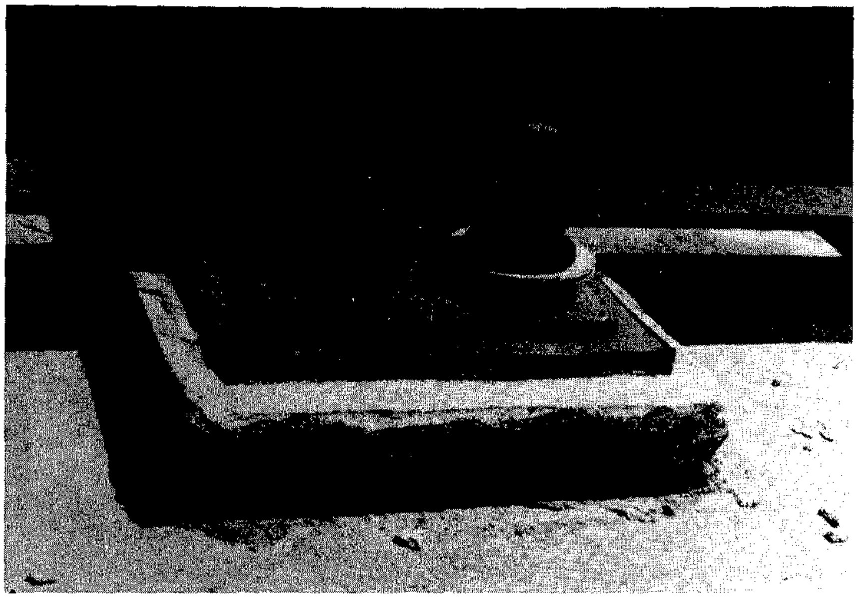

FIGURE 4-6. TORONTO TRANSIT COMMISSION FASTENER

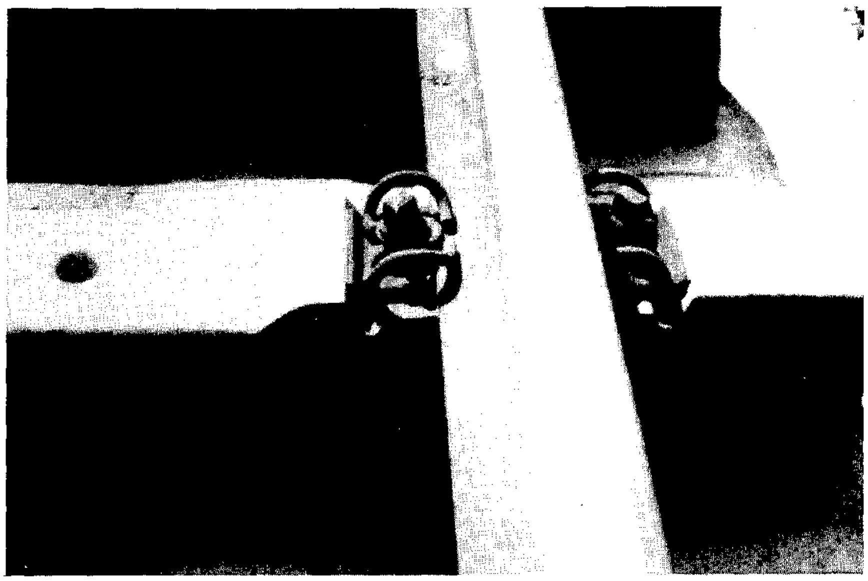

FIGURE 4-7. FASTENER FOR RUBBER-BOOTED TIES AT KARLSFELD

shoulders. Rails were secured to the tie with bolts that were screwed into plastic inserts, spring clips, and nuts. Lateral adjustment of up to 0.08 in. is made using different guide plates.

Fastener used to secure rails to rubber-booted two-block ties at La Grillere and Neuilly-sur-Marne in France was essentially similar to that used at Radcliffe-on-Trent and is shown in Figure 4-3. However, a lateral adjustment of up to 0.10 in. was obtainable using different clips.

4.4 VERTICALLY- AND LATERALLY-ADJUSTABLE FASTENERS

Fastening systems capable of providing both vertical and lateral rail adjustments were used in several slab track projects. These included projects at Radcliffe-on-Trent and Duffield in England, at Rheda, Oelde, Karlsfeld, and Munich-Nordring in Germany, at La Grillere in France, between Ricla and Calaterao in Spain, and at Massapequa Park, in Atlanta and in Kansas in the United States. These fasteners were used to secure rails to concrete slabs, to precast concrete ties or blocks embedded in slabs, or to precast concrete ladders or frame units.

Generally, vertical adjustment is accomplished by inserting shims between fastener base plate and concrete slab or tie, or between fastener base plate and rail. Lateral adjustment is accomplished by lateral shimming or by means of an eccentric cam or tie plate adapter.

Three types of vertically- and laterally-adjustable fasteners were used on slab track project at Radcliffe-on-Trent. Two types were those used by British Railways (BR). The third type was that of Netherlands Railway (NS).

A British Railways adjustable fastener was used to secure rails directly to cast-in-place concrete slabs. This fastening system is similar to the non-adjustable one used on the same project and shown in Figure 4-4. However, a vertical adjustment of up to 0.39 in. was possible by shimming under the rail.

Also, a lateral adjustment ranging from -0.04 to +0.08 in. was possible by using insulators with different thicknesses. This type of fastener was also used on the slab track project at Duffield.

A different fastening type was used to secure rails to precast concrete slabs and ladder units at Radcliffe-on-Trent. This fastening system, shown in Figure 4-8, consisted of a base plate with built-in shoulders for elastic clips. Base plate was secured to concrete ladder units with bolts, washers, and nuts. Rails were secured to the base plate with elastic clips. This fastening system permits a vertical rail adjustment of up to 0.39 in. In addition, it permits a lateral adjustment of ± 0.16 in.

A British Railways adjustable fastener was also used on slab track project between Ricla and Calatorao. The fastening system is essentially similar to that used at Radcliffe-on-Trent. However, it permits a lateral rail adjustment of ± 0.12 in. and a vertical rail adjustment of up to 0.39 in.

The Netherlands Railway type fastener used at Radcliffe-on-Trent is shown in Figure 4-9. Fastener consisted of a base plate supported on an insulating pad and a rubber-bonded cork pad. Plate was secured to the concrete slab with bolts, eccentric bushes, springs, and nuts. Rails rested on a rubber-bonded cork pad and were secured to the base plate with elastic clips. A vertical adjustment of up to 0.39 in. was possible by shimming under the base plate. A lateral adjustment of ± 0.12 in. was possible by use of eccentric bushes.

Several types of vertically- and laterally-adjustable fasteners were used on slab track projects in Germany.

A fastening system, shown in Figure 4-10, was used in projects at Rheda, Karlsfeld, and Munich-Nordring. This fastener was used to secure rails to precast concrete slabs or ladder units, or to embedded concrete ties or blocks. Fastener consisted of a ribbed base plate supported on a rubber pad. Angled guide plates and plastic shims were placed between base plate and concrete shoulders at rail seats. Base and guide plates

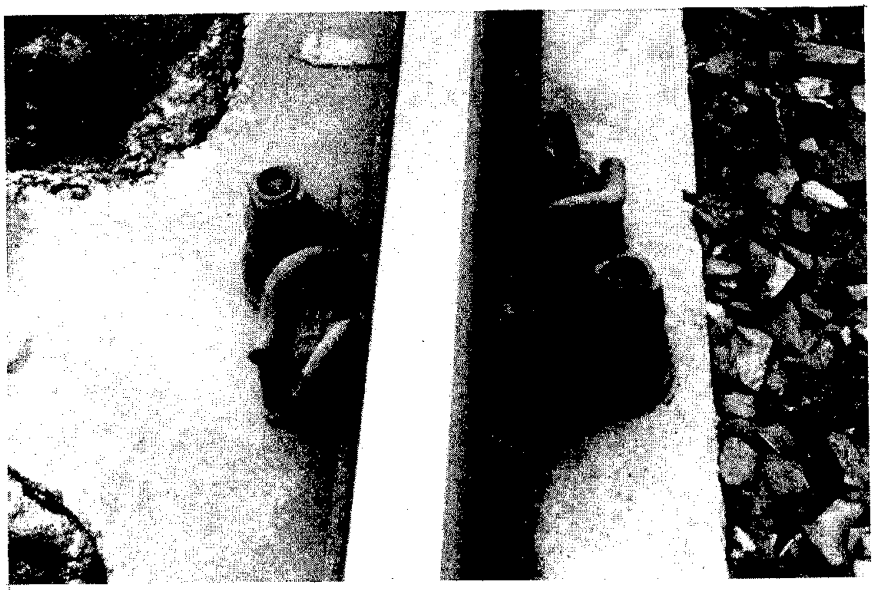

FIGURE 4-8. FASTENER FOR LADDER UNITS AT RADCLIFFE-ON-TRENT

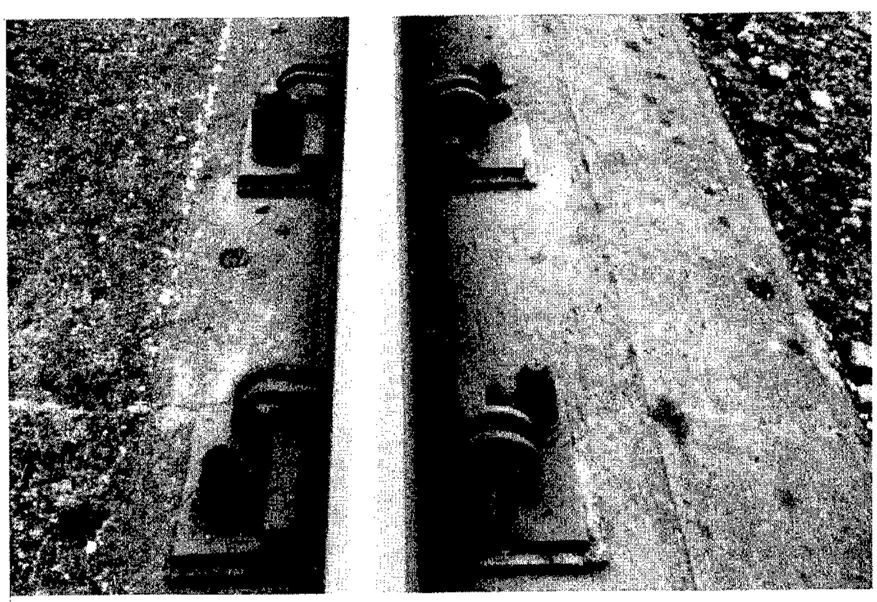

FIGURE 4-9. NETHERLANDS RAILWAY FASTENER AT RADCLIFFE-ON-TRENT

FIGURE 4-10. GERMAN RAILWAYS FASTENER AT KARLSFELD

were secured to the tie with elastic clips held down by bolts that screwed into threaded inserts. Rails were supported on a tie pad and secured to the base plate with elastic clips. A vertical adjustment of up to 0.39 in. was possible by shimming under the base plate. A lateral adjustment of $\pm$0.08 in. was obtained by shimming between tie shoulders and guide plates. However, a lateral adjustment of up to $\pm$0.59 in. was possible using different types of guide plates.

Another version of this fastening system was used at Munich-Nordring to secure rails to precast concrete blocks embedded in the slab. In this fastener, shown in Figure 4-11, clamping plates instead of elastic clips were used to secure rails to the base plate. Adjustment capabilities of both systems were identical.

Two Dutch type fasteners were used in the project at Karlsfeld to secure rails to precast concrete blocks embedded in the slab. This fastener, shown in Figure 4-12, is similar to the Netherlands Railway's fastener used at Radcliffe-on-Trent and shown in Figure 4-9. The other type, shown in Figure 4-13, utilizes clamping plates and not spring clips to secure rails to the base plate. Both fasteners could provide vertical and lateral rail adjustments of +0.32 and $\pm$0.24 in., respectively.

A vertically- and laterally-adjustable type fastener was used to secure rails directly to concrete slabs at La Grillere. In this fastening arrangement, shown in Figure 4-14, rail was supported on a tie pad and base plate. Rail was secured to the plate with clamping plates, bolts that were screwed into the base plate, spring washers, and nuts. Base plate was secured to the slab with angled plates, bolts, and nuts. Bolts were installed in predrilled holes and bonded to the slab with epoxy mortar. Fastener was capable of providing vertical and lateral adjustments of +0.20 and $\pm$0.10 in., respectively.

Vertically- and laterally-adjustable fasteners were used on slab track projects on The Long Island Rail Road at Massapequa Park, on Metropolitan Atlanta Rapid Transit Authority lines, and on the Kansas Test Track.

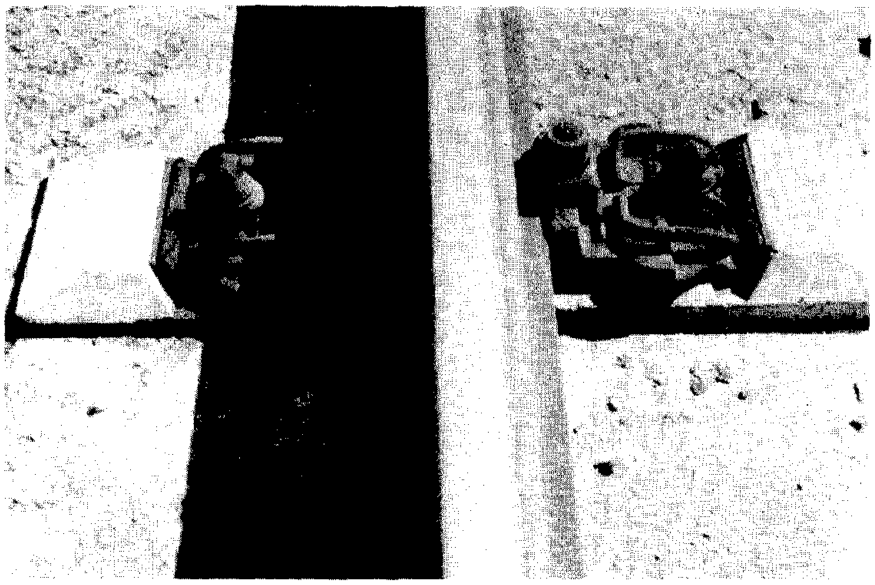

FIGURE 4-11. GERMAN RAILWAYS FASTENER AT MUNICH-NORDRING

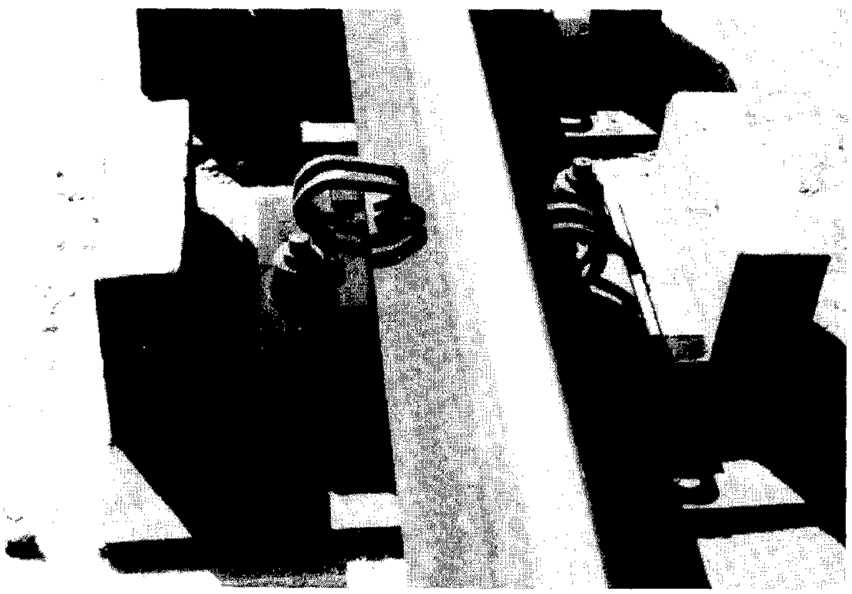

FIGURE 4-12. NETHERLANDS RAILWAY FASTENER AT KARLSFELD-TYPE 1

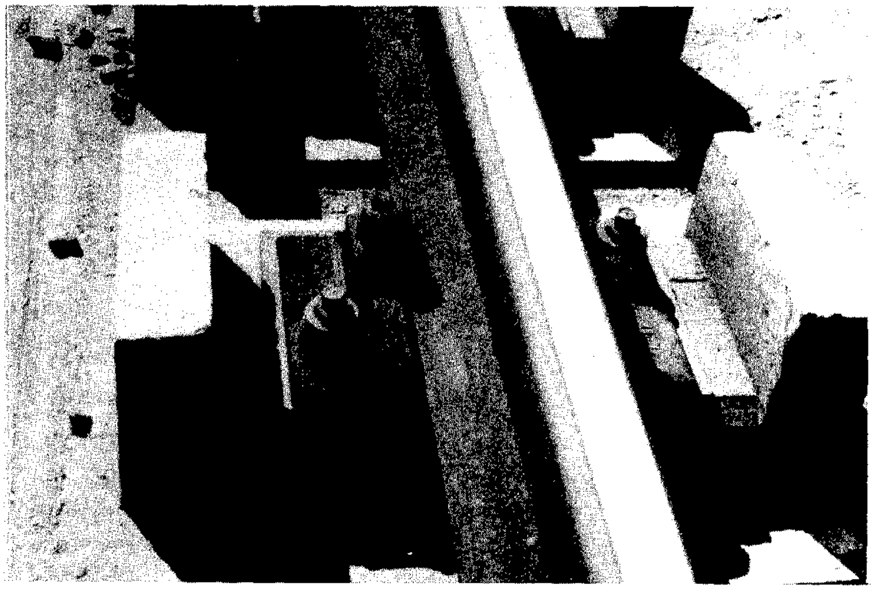

FIGURE 4-13. NETHERLANDS RAILWAY FASTENER AT KARLSFELD-
TYPE 2

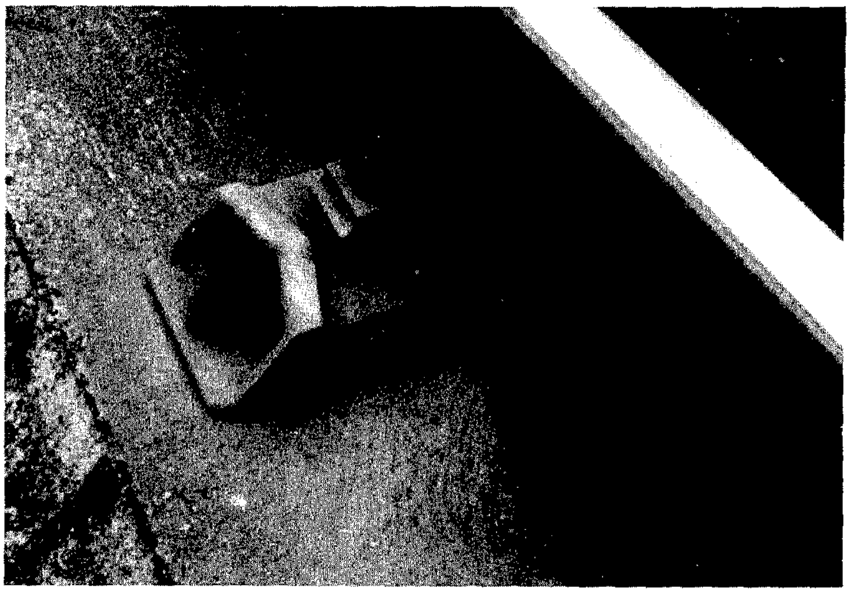

FIGURE 4-14. CONCRETE SLAB FASTENER AT LA GRILLERE

Fastener used on the Kansas Test Track, shown in Figure 4-15, consisted of a channel-shaped base plate supported on a sheet of extruded asbestos-cement. Rails were secured to the base plate slab with bolts, washers, and nuts. Bolts were installed in predrilled holes and bonded to the concrete with epoxy mortar. A vertical rail adjustment of up to 0.5 in. could be obtained by means of shims between base plate and concrete slab. A lateral rail adjustment of up to $\pm$0.5 in. could be accomplished with nylon inserts between rail base and vertical sides of the base plate.

Fastener used on slab track sections on MARTA's lines is shown in Figure 4-16. It consisted of a laminated base plate made of elastomer and steel. The base plate was secured to the slab with bolts, washers and nuts. Bolts were fastened to slotted concrete inserts installed during second placement construction. Rails were secured to the base plate with elastic clips fastened to the plate with bolts, washers, and nuts. A vertical rail adjustment of up to 0.25 in. could be obtained by inserting shims between base plate and concrete slab. A lateral rail adjustment of $\pm$0.375 in. could be obtained by displacing the base plate.

Fastener used on the slab track at Massapequa Park is shown in Figure 4-17. It consisted of a laminated base plate made of neoprene sheet sandwiched between two layers of steel. Plate was secured to the slab with bolts, washers, and nuts. Bolts were installed in predrilled holes and bonded to the concrete with epoxy mortar. Plate had provisions for attaching clip shoulders at different positions. Rails were secured to the base plate with elastic clips inserted in the shoulders. A vertical rail adjustment of up to 0.5 in. could be obtained by inserting shims between base plate and concrete slab. A lateral rail adjustment of $\pm$1.0 in. could be obtained by displacing clip shoulders.

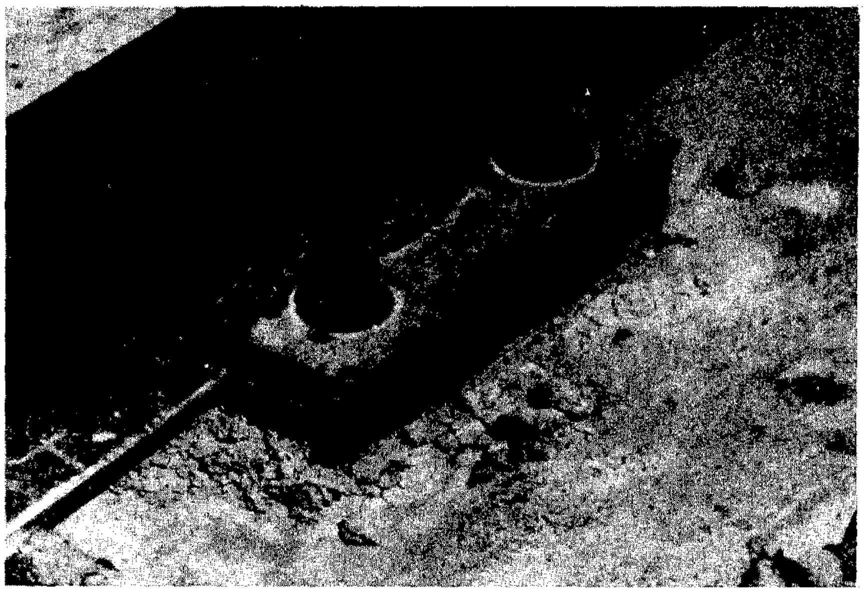

FIGURE 4-15. KANSAS TEST TRACK FASTENER

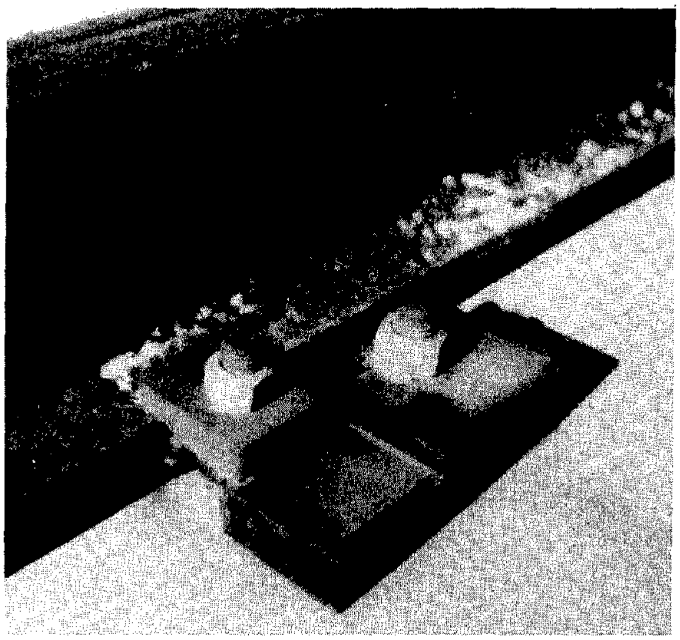

FIGURE 4-16. RAIL FASTENER ON METROPOLITAN ATLANTA RAPID TRANSIT AUTHORITY TRACK

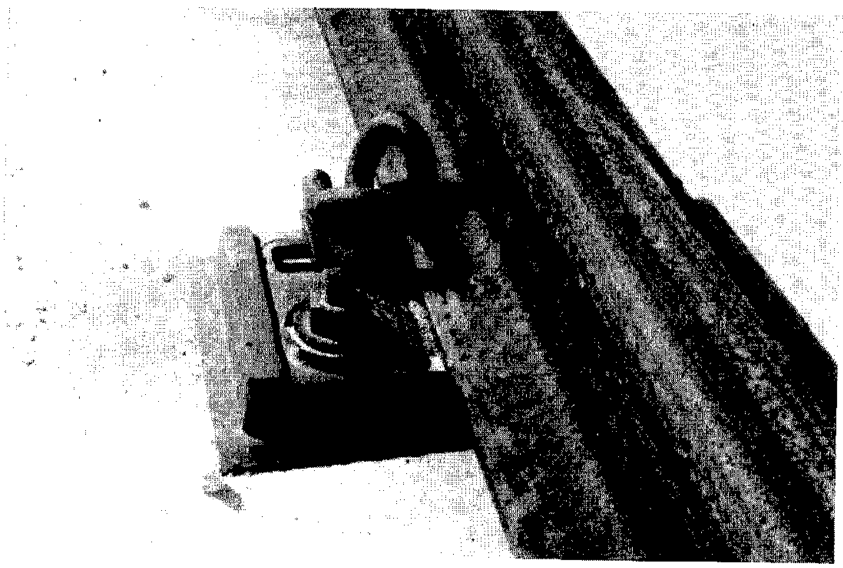

FIGURE 4-17. FASTENER ON THE LONG ISLAND RAIL ROAD SLAB TRACK

5. CONSTRUCTION METHODS AND TOLERANCES

Different methods were used to built slab track projects depending on slab type. These methods are described and construction tolerances are discussed.

5.1 CONSTRUCTION METHODS

Conventional paving equipment was used to deposit concrete for cast-in-place slabs. Cranes were used to install precast concrete slab and ladder units. Other methods were used to build slab tracks with rubber-booted ties and ties embedded in slab.

5.1.1 Slab Track with Cast-in-Place Slab

Conventional paving equipment was generally used to build cast-in-place slabs. Generally, side forms were used. However, a special machine similar to a slip-form paver was used for construction of slab track projects in England and Spain.

Construction of cast-in-place slab track involved the following operations:

1. Subgrade preparation, grading, and compaction
2. Subbase placement, as shown in Figure 5-1
3. Form setting, as shown in Figure 5-2
4. Placement of reinforcing steel, as shown in Figure 5-3
5. Concrete placement and consolidating, as shown in Figure 5-4
6. Concrete screeding, as shown in Figure 5-5, or hand-finishing, if required
7. Concrete curing

Figure 5-6 shows a completed slab prior to fastener installation.

When second placement construction was used, stirrups projecting from the slab were generally used to ensure bond between

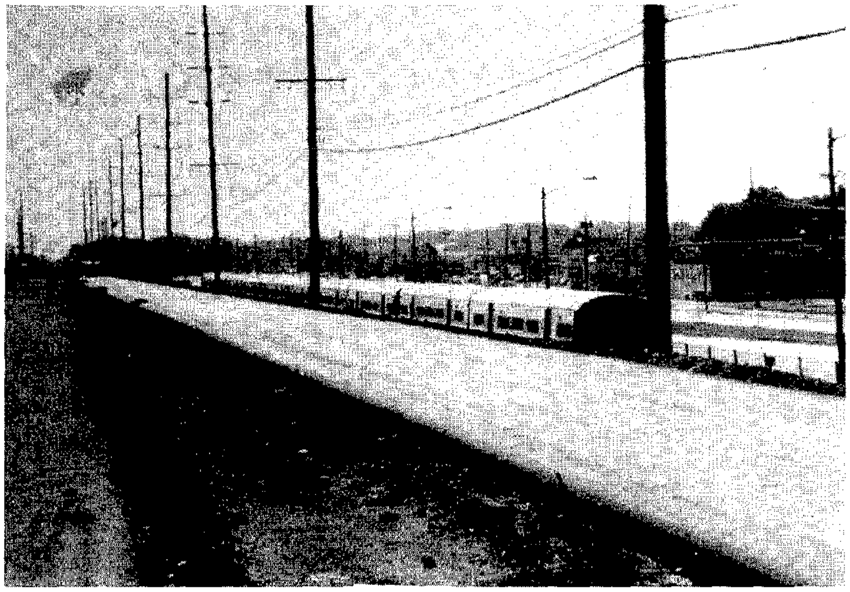

FIGURE 5-1. COMPLETED SUBBASE

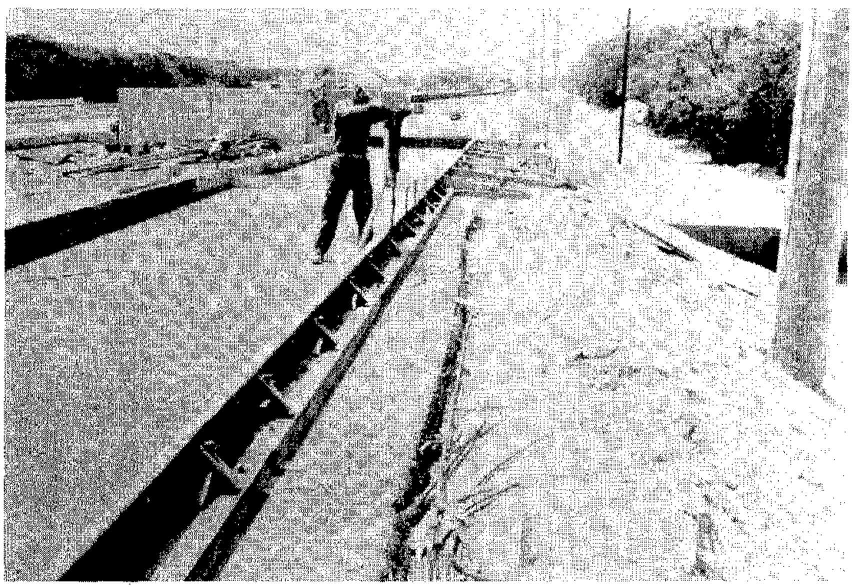

FIGURE 5-2. SETTING OF SIDE FORMS

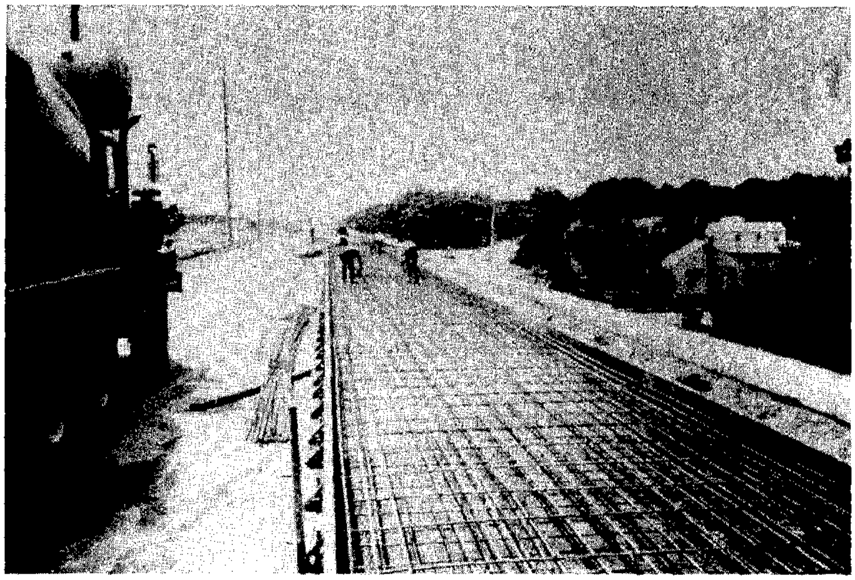

FIGURE 5-3. REINFORCING STEEL IN PLACE

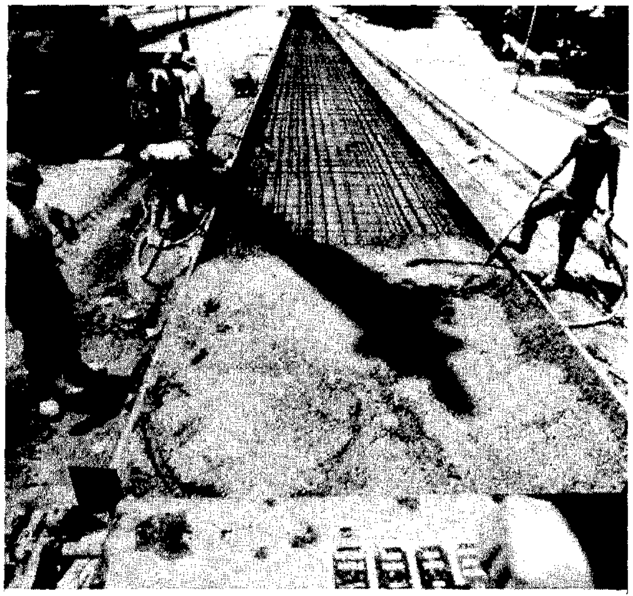

FIGURE 5-4. CONCRETE PLACEMENT AND CONSOLIDATION

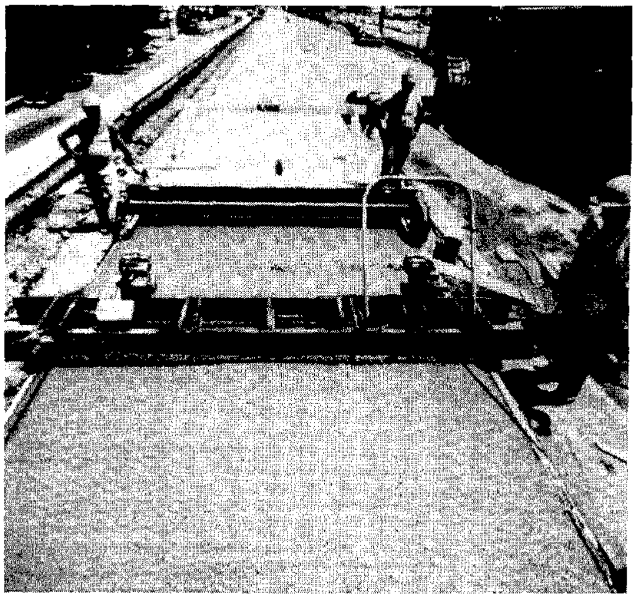

FIGURE 5-5. CONCRETE SCREEDING

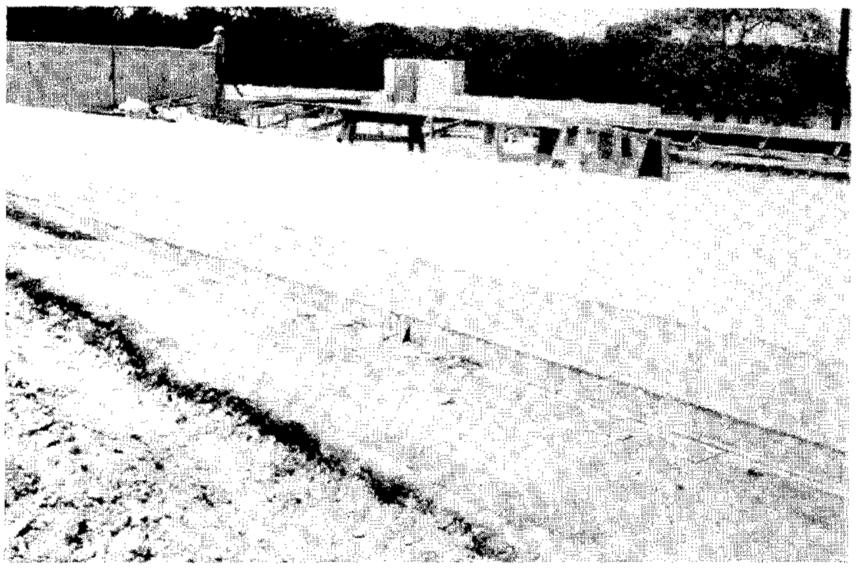

FIGURE 5-6. COMPLETED SLAB

slab and second placement concrete. Fastening inserts were installed during the second placement.

Installation of rail fasteners involved the following operations:

1. Use of a template to mark location of fastener inserts, as shown in Figure 5-7
2. Drilling of holes for fastener inserts, as shown in Figure 5-8
3. Use of jigs to hold fastener inserts in position, as shown in Figure 5-9, and bonding inserts to the concrete slab with epoxy grout as shown in Figure 5-10
4. Placing fastener base plates to slab, as shown in Figure 5-11, and securing them to slab with washers and nuts
5. Installing rails and securing them to fastener plates with clips as shown in Figure 5-12

However, for fastener inserts installed during second placement construction, operations of hole drilling and insert bonding were eliminated.

For installation of inserts for third rail chair assembies, holes were drilled in the slab at insert locations. Inserts were bonded in position with epoxy grout. The third rail chair assembly was then secured to the slab, as shown in Figure 5-13.

Concrete blocks cast with embedded inserts can be used to support third rail chair assembly. Assemblies are secured to the block with bolts as shown in Figure 5-14.

Cast-in-place slabs are readily placed at a good construction rate using conventional equipment. However, field installation of fastener inserts is labor intensive. Installation requires great accuracy particularly if adjustment cannot be provided by the fastener. In addition, slab cracking due to drying shrinkage may adversely affect fastener performance.

5.1.2 Slab Track with Ties Embedded in Slab

Construction of slab track with ties embedded in a slab requires the same preparation and construction of subgrade,

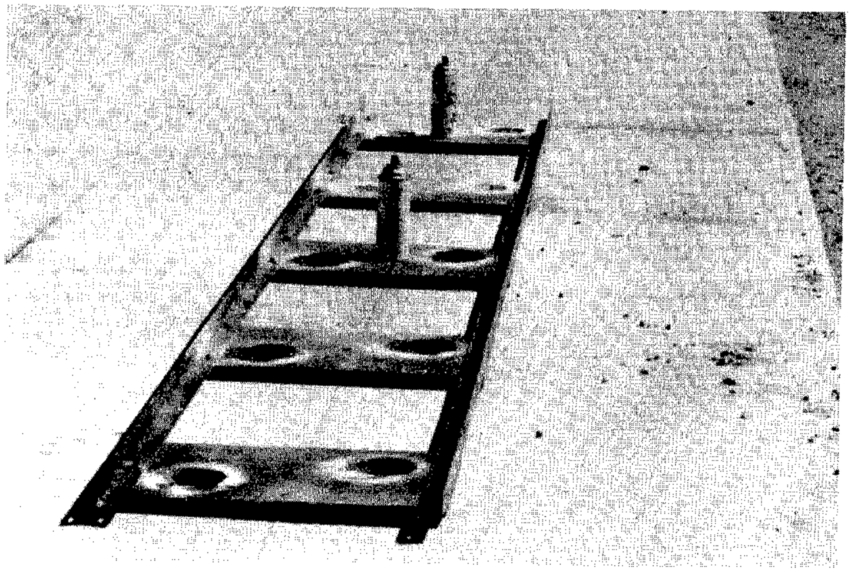

FIGURE 5-7. TEMPLATES FOR MARKING INSERT LOCATIONS

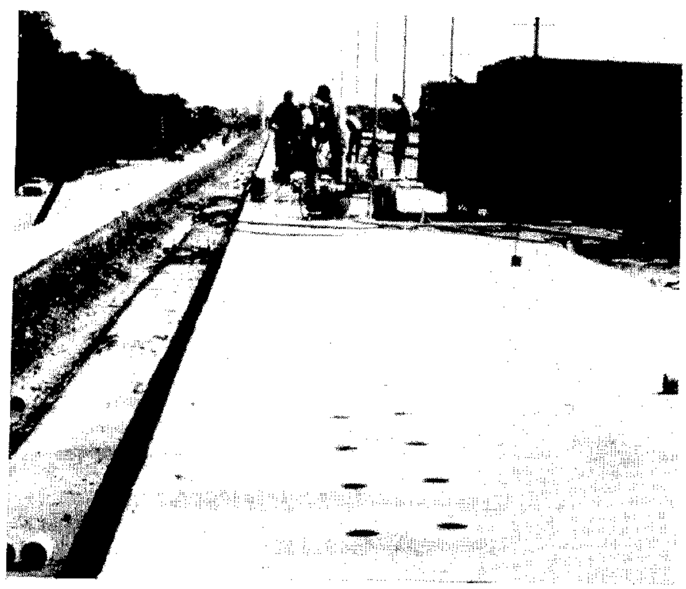

FIGURE 5-8. DRILLING HOLES FOR FASTENER INSERTS

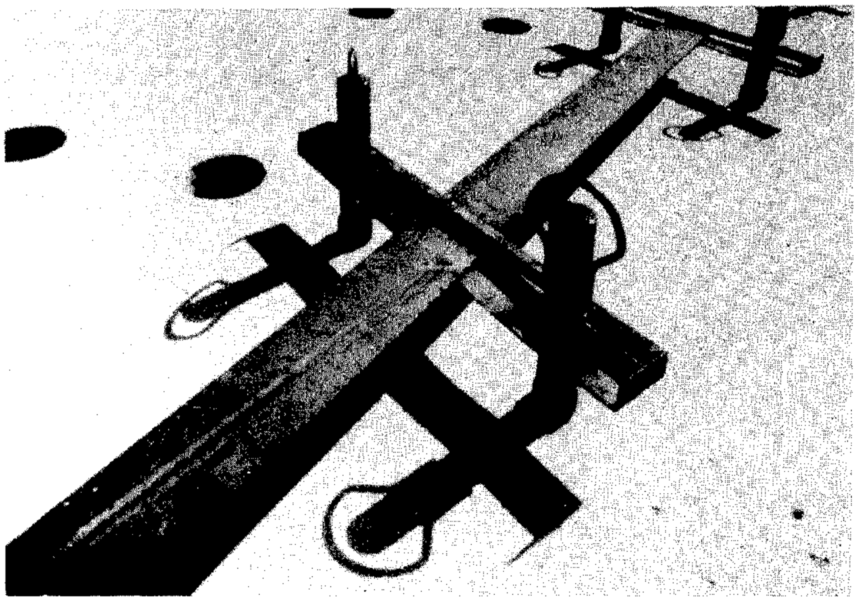

FIGURE 5-9. JIGS FOR HOLDING INSERTS IN POSITION

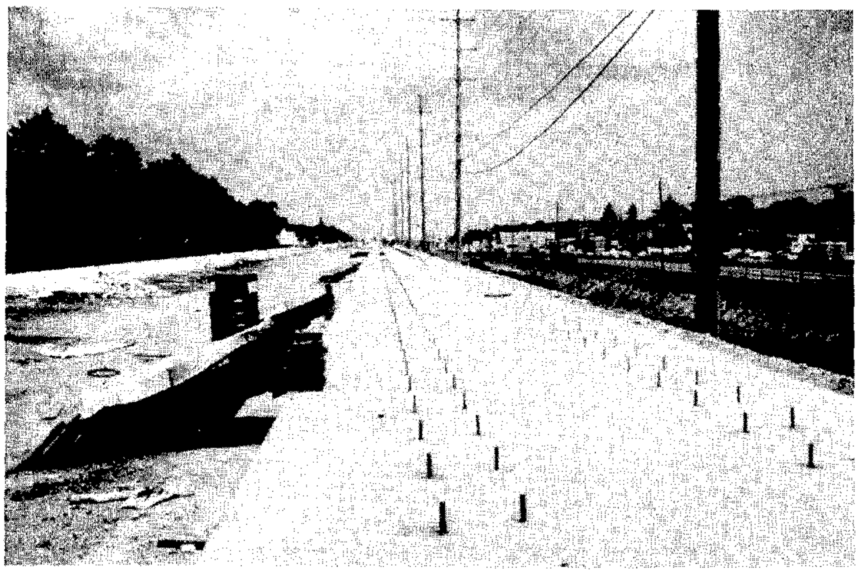

FIGURE 5-10. FASTENER INSERTS IN PLACE

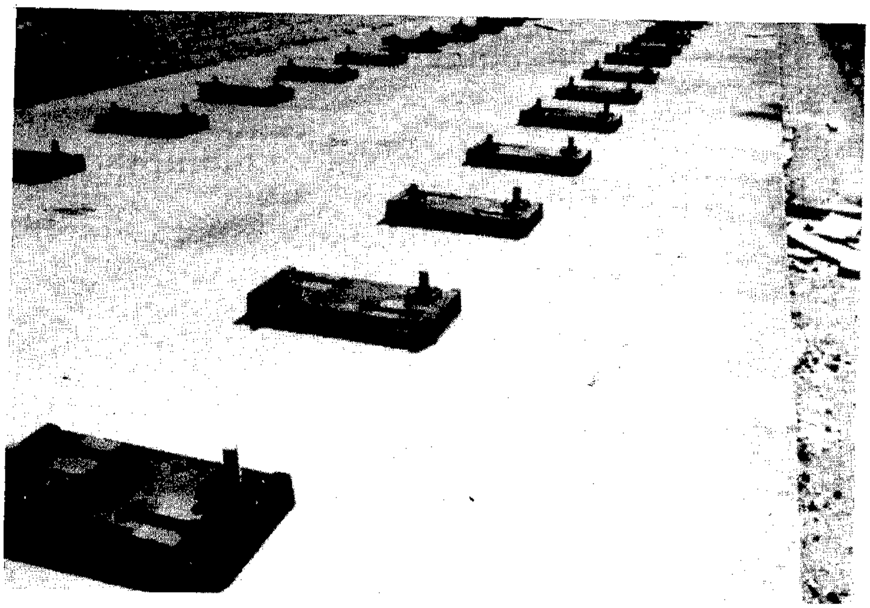

FIGURE 5-11 FASTENER BASE PLATES IN PLACE

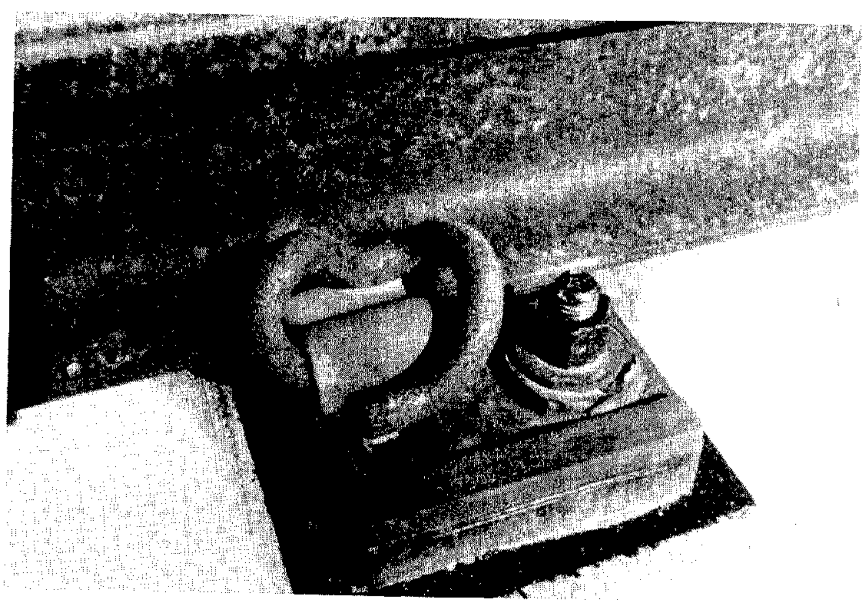

FIGURE 5-12. RAIL FASTENED TO BASE PLACE

FIGURE 5-13. THIRD RAIL CHAIR ASSEMBLY SECURED TO SLAB

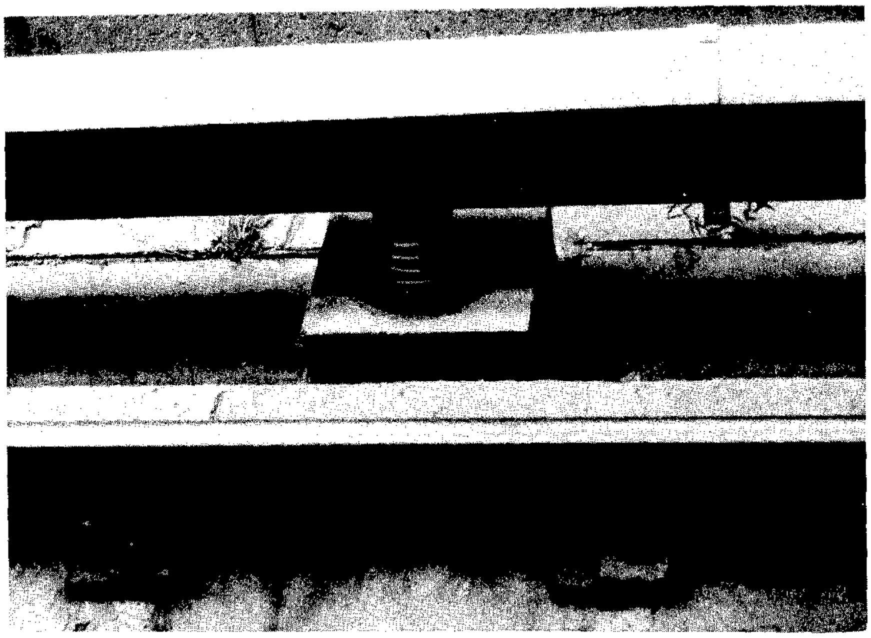

FIGURE 5-14. THIRD RAIL CHAIR ASSEMBLY SUPPORTED ON CONCRETE BLOCK

subbase, and slab as for cast-in-place slabs. However, slabs are generally provided with projecting stirrups for anchoring ties to the slab. Generally, the installation involves the following operations:

1. Placement of ties on slab surface at required spacing
2. Securing rails to ties with fasteners
3. Adjusting track level using wooden wedges and aligning track using conventional equipment
4. Placement of longitudinal reinforcing bars through holes in the ties and fastening to stirrups
5. Placement of transverse reinforcing bars when required
6. Placement and vibration of concrete between slab and tie bottom and between ties, and removal of wedges shortly after concreting

In this type of construction, fastener inserts are installed in ties during fabrication. This procedure provides accurate rail cant and gage and reduces contruction time. However, if the fastener cannot provide for level adjustment, care and accuracy are required in seating the ties. In this system, slab shrinkage cracking does not affect fastener inserts.

5.1.3 Slab Track with Rubber-Booted Ties

Construction of a slab track with rubber-booted ties is essentially similar to that of a slab track with ties embedded in slab. Generally, it requires preparation and construction of subgrade, subbase, and slab. In addition, it involves the following operations:

1. Placement of ties fitted with rubber boots on slab surface at required spacing
2. Securing rails to ties with fasteners
3. Lifting assembled track and adjusting alignment and level using wooden wedges or concrete blocks
4. Placement and vibration of cement grout between slab and tie bottom and between ties

This type of construction provides the same accuracy of cant and gage control as slab track with ties embedded in slab. In addition, rubber boots contribute to noise reduction. However, great care and accuracy are required during construction in seating the ties and compacting the grout between the slab and tie bottom.

5.1.4 Slab Track with Precast Concrete Units

Placement of precast concrete slabs or ladder units is generally accomplished using cranes. In addition to preparation and construction of subgrade and subbase, this procedure involves the following operations:

1. Placement of precast units on subbase
2. Securing rails to units with fasteners
3. Lifting assembled track panels and adjusting level and alignment
4. Injection of cement grout in spaces between subbase and precast units

This type of construction provides accurate rail cant and gage. Also, it reduces construction time since fastener inserts are accurately installed during fabrication. However, great accuracy is required in levelling during construction if fasteners cannot provide for level adjustment. In addition, this type of construction is difficult to mechanize.

5.2 CONSTRUCTION TOLERANCES

To assure proper track level, gage and alignment, tolerances were specified for installation of track layers. Accuracy of construction was considered essential, particularly if adjustments could not be provided by fasteners.

Ranges of finished track tolerances used for slab track projects are listed in Table 5-1. Also listed are construction tolerances of track layers. Generally, railroads and transit properties experienced no difficulty in obtaining the accuracy

TABLE 5-1. CONSTRUCTION TOLERANCES

Item	Tolerance
Finished Track	
Gage	±0.08 to ±0.10 in.
Cross Level	±0.12 in./32.8 ft ±0.20 in./65.6 ft
Alignment	±0.16 in./32.8 ft ±0.24 in./65.6 ft
Cant	±0.10 in./rail base
Twist	1:850 to 1:1000
Level of Track Layers	
Subgrade	±1.18 in.
Subbase	±0.39 in.
Slab	±0.20 in.
Drilled holes	±0.20 in in any direction

required for constructing tracks with fasteners capable of widely adjusting both rail level and track gage. However, difficulty has been experienced in achieving the surface accuracy required for constructing tracks with fasteners capable of limited adjustment. For example, on slab track project at Duffield in England it was necessary to grind off 13% of the rail seat area and to build up another 12% with an epoxy compound to obtain acceptable tolerances.

6. PERFORMANCE

As previously described, several slab track projects have been in service for a number of years. Information on performance of these projects was obtained through correspondence with railroad and transit officials, review of publications, and inspection of several slab track projects. Projects inspected included those at Radcliffe-on-Trent and Duffield in England, at Karlsfeld and Munich Nordring in Germany, at Neuilly-sur-Marne in France, between Ricla and Calatorao in Spain, and on The Long Island Rail Road and the Metropolitan Atlanta Rapid Transit Authority in the U.S.A.

Performance of slab track projects was discussed with officials of the British, German, French, and Spanish railways. Discussions were also held with officials of The Long Island Rail Road and The Metropolitan Atlanta Rapid Transit Authority.

A summary of observations on performance of slab track projects is presented.

6.1 ENGLAND

All slab track sections installed at Radcliffe-on-Trent have performed satisfactorily and provided the desired objective of eliminating day to day maintenance. Generally, there has been no significant change in level and alignment. Line and level were reported to be within tolerances established at construction time.

Except for the London Transport type, all fastening systems used in this slab track were reported to have performed satisfactorily despite large pad and clip movements. Bolts of some London Transport fasteners have worked loose in the concrete. Corrective measures were taken by drilling holes and installing inserts for a new fastening system shown in Figure 6-1.

It was reported that maintainence was performed only at transition beams and slab ends where excessive settlements

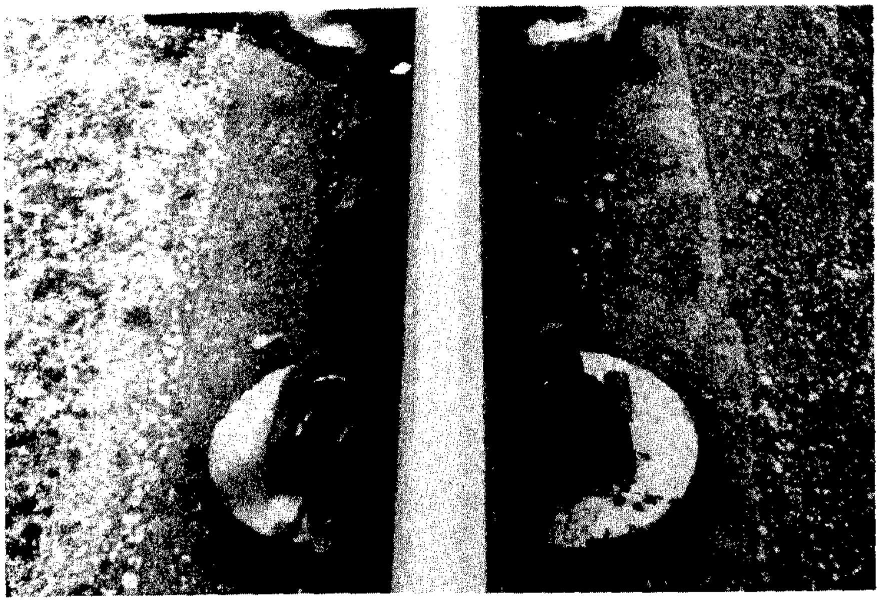

FIGURE 6-1. NEW FASTENERS INSTALLED NEAR LOOSE INSERTS

occurred. This was attributed to inadequate drainage that permitted water to penetrate into the subgrade and cause pumping.

Several problems were encountered on the slab track at Duffield. The most frequent problem was loosening of fastening inserts. Loosening was attributed to the passage of transverse cracks through fastening position and excessive slab deflection under load that caused spalling and working of cracks. Additional fasteners were installed by drilling new holes away from the crack and bonding new fastening inserts, as shown in Figure 6-2.

Differential slab settlement was attributed to the development of voids beneath the slab. This problem was corrected by slab jacking and filling voids with cement grout. Excessive settlement at transitions between slab track and adjoining ballasted track was corrected by periodic repacking. Large cracks resulting from thermal changes were maintained by sealing with epoxy compound.

Experience indicated that slab track was less affected by derailments than cross tie track. A derailment on the Duffield track was reported to have caused breakage of only seven fasteners over 2,600 ft of track with no damage occurring to the concrete slab. However, severe damage occurred to the adjacent concrete tie track. The better behavior of slab track in derailments was attributed to the ability of derailed wheels to roll freely on the slab without impact.

6.2 GERMANY

Generally, slab track projects built in Germany have performed satisfactorily. Only minor maintenance has been performed on some projects as described below.

It was reported that no maintenance has been performed on sections built at Hirschaid with precast slabs and ladder units supported on sandy-gravel subbase. These sections were provided with deep subgrade drains. However, large settlements occurred

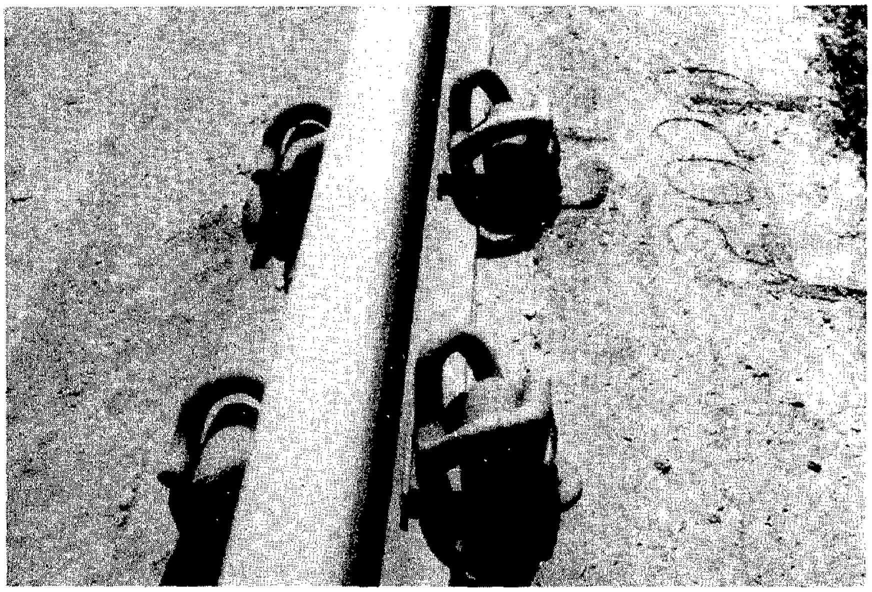

FIGURE 6-2. ADDITIONAL FASTENERS INSTALLED BETWEEN LOOSE ONES

in the section built with slabs supported on an expanded polystyrene concrete subbase. This was attributed to a reduction in subgrade strength due to moisture penetration and lack of deep subgrade drains. This problem was twice corrected by slab-jacking and grouting.

It was reported that the slab track at Rheda Station has performed very well. No maintenance work was performed except for occasional adjustment of some rail fasteners.

It was reported that the slab track at Oelde Station has performed satisfactorily. However, average slab settlement and apparent pumping between slab and subbase has occurred. This was corrected by pressure-grouting of epoxy grout between slab and subbase.

All test sections at Karlsfeld have performed satisfactorily. The only maintenance performed was on the precast concrete ladder unit system. At this section subbase deterioration occurred, apparently due to collection of water and snow in ladder unit openings. For this reason, openings of the ladder units were surfaced with a concrete layer. Inspection of this project revealed large tie movements on the section with rubber-booted ties set into the slab. These movements were attributed to the elastic deformations of the rubber boots due to traffic loads.

The slab track project at Munich-Nordring has performed well. No maintenance has been performed.

6.3 FRANCE

Slab track at Neuilly-sur-Marne has performed very satisfactorily. No appreciable maintenance was performed during eight years of operation. It was reported that slab track performance is generally superior to that of cross tie track.

It was reported that a derailment in July 1978 indicated that slab track condition can be restored to service with less traffic disruption than for conventional track.

Also, it was reported that no maintenance had been performed on slab track projects at Grillere since their construction in 1970. Performance was considered very satisfactory.

6.4 SPAIN

Spanish Railway's staff reported that performance of slab track project between Ricla and Calatorao has been satisfactory. The objective of eliminating day to day maintenance has been achieved. Further, it was stated that slab track performance was found to be superior to that of cross tie track.

It was pointed out that a construction deficiency caused excessive slab movement at one location. This was attributed to overexcavation and inadequate compaction of the backfill. This was corrected by slab jacking and pumping epoxy grout through holes drilled along the slab center line. No excessive movement was evident after repair. It was reported that no other maintenance had been performed since track was built in 1975.

Inspection of this project revealed that thermal cracks had always occurred at fastening insert locations and spalling of concrete at some inserts was evident, as shown in Figure 6-3. In addition, evidence of pumping between slab and subbase was visible at several locations.

6.5 THE NETHERLANDS

Performance of slab track near Deurne on Eindhoven-Venlo mainline was reported to be good. No markable change in track condition was reported after 3 years of service and no maintenance was performed during this period.

6.6 UNITED STATES

Performance of slab track on the Kansas Test Track was considered unsatisfactory. Several problems developed after

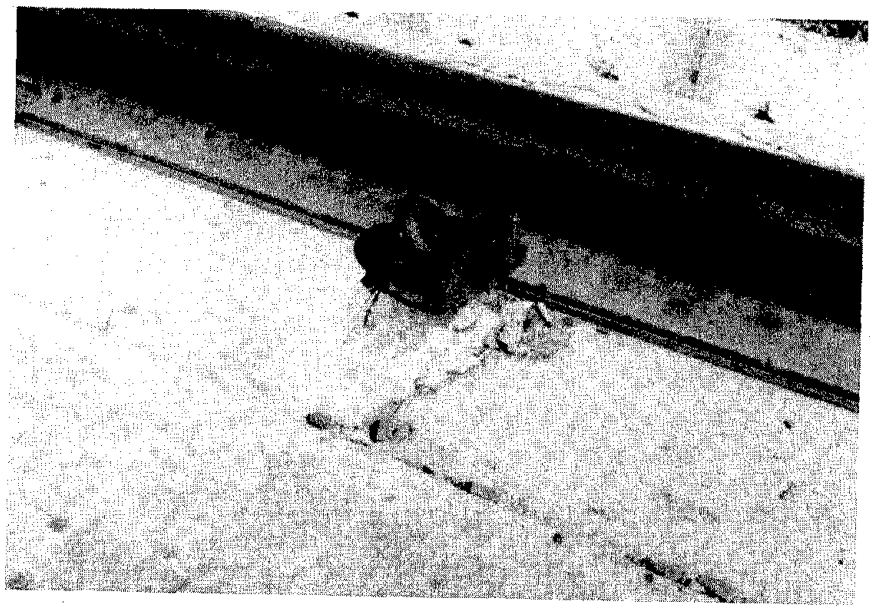

FIGURE 6-3. CONCRETE SPALLING AT LOOSENED INSERTS

opening track to traffic that resulted in removing the track from service.

Numerous fastening anchorages pulled out of the slab immediately after opening track to traffic in May 1973. This was attributed to an inadequate fastening insert length. Following installation of a new fastening anchorage system, track was placed in normal service in October 1974. However, the track was closed and scheduled testing terminated in June 1975 after approximately six months of service. This action was taken due to subgrade failure that resulted in excessive track deflections and mud-pumping.

It was reported that slab track sections on the metropolitan Atlanta Rapid Transit Authority lines have performed satisfactorily. However, loosening of some fastener bolts and cracking of fastener washers have occurred. This was attributed to inadequate dimensions of bolts and washers. Track inspection revealed thermal cracks in the second placement concrete. These cracks generally occurred at fastener location, but did not affect performance.

Also, it was reported that turnouts built on slab performed better than conventional turnouts and thus required less maintenance effort.

Slab track on The Long Island Rail Road was opened to revenue traffic in December 1980. Thus, there has not been sufficient traffic to develop performance data. However, it was reported that ride quality on slab track was superior to that on wood tie track.

6.7 CANADA

It was reported that slab track on the Toronto Transit Commission line near Yorkdale Station has performed satisfactorily. No detectable change in track alignment or gage was observed after 2 years of service. No maintenance was performed during this period.

7. ADVANTAGES AND DISADVANTAGES

Experience with slab track in several countries has indicated that use of slab track for at-grade construction provides certain advantages and disadvantages when compared with cross tie track. A comparison between technical, environmental, and economic features of slab track and those of conventional track is summarized in Table 7-1. A discussion of these features is presented.

7.1 TECHNICAL FEATURES

Experience with slab track projects has shown that a properly designed and built slab track system provides better overall performance than conventional cross tie track. Observations and measurements on these projects have indicated the following favorable features of slab track systems:

1. Track alignment and level are better maintained by slab track than by cross tie track.[29,30,31] Therefore, occurrences of derailment are reduced.
2. Slab track provides improved lateral stability and greater resistance to rail buckling than cross tie track.[29,30,31] Therefore, continuously welded rails can be used at higher ambient temperatures and on sharper radius curves than would be acceptable with ballasted track.
3. Derailments cause less damage to slab track than to cross tie track.[29,30,31] Therefore, shorter traffic disruption is required to repair damage caused by derailment.
4. Because of overall improved performance, interruption of traffic for maintenance purposes is reduced with slab track. Thus, safety is improved and service reliability is increased.
5. Third rail can be easily attached to slab track.

TABLE 7-1. COMPARISON OF TRACK FEATURES

Feature	Most Favorable Track			Comments
	Wood Tie	Concrete Tie	Concrete Slab	
Track alignment			X	Alignment is better maintained by slab track due to better distribution of load on subgrade.
Track gage		X	X	Concrete tie and slab track fasteners provide better gage control.
Lateral stability			X	Slab weight and slab track fasteners provide increased lateral stability and more uniform longitudinal rail restraint.
Electrical insulation			X	Insulating properties of wood tie track vary with weather and tie condition. Slab track fasteners and elimination of ballast provide better insulation that is unaffected by climatic conditions.
Derailments			X	Derailed wheels tend to roll freely on slab without impact, thus causing only superficial damage to the slab.
Environmental attack		X	X	Concrete is not affected by termites and fungus and does not burn.

TABLE 7-1. COMPARISON OF TRACK FEATURES (Cont.)

Feature	Most Favorable Track			Comments
	Wood Tie	Concrete Tie	Concrete Slab	
Train operations			X	Cross tie track requires more maintenance work affecting train operations to a greater extent.
Flexibility for alterations	X			Alterations in route layout can be made easier on wood tie track.
Special details	X			Special details such as guard rails, restraining rails, and gage widening are easier to accommodate on wood ties.
Third rail attachment			X	Third rail can be easily attached to concrete slab without need for special brackets or longer ties.
Impact on rolling stock			X	Deformations of concrete slab track are uniform and low, thus reducing rolling stock damage.
Energy requirement			X	Deformations of concrete slab track are uniform and low, thus reducing rolling resistance and energy requirement.

TABLE 7-1. COMPARISON OF TRACK FEATURES (Cont.)

Feature	Most Favorable Track			Comments
	Wood Tie	Concrete Tie	Concrete Slab	
Noise and vibrations	X			Wood ties and ballast provide more resilience that result in less noise and vibrations on wood tie track.
Environmental impact		X	X	Concrete ties and slab track reduce the demand for wood, creosote, and other treatment products.
Initial cost	X			Initial cost of a wood tie track is generally lower than that of a concrete tie or slab track.
Maintenance cost			X	Because of the improved properties of concrete slab track, maintenance cost is greatly less than that for cross tie track.
Service life			X	Because of elimination of ballast, overall service life of a concrete slab track is greater than that of conventional track.
Materials supply		X	X	Concrete and steel are generally available in sufficient supply with stable prices. However, availability and price of wood ties change frequently.

TABLE 7-1. COMPARISON OF TRACK FEATURES (Cont.)

Feature	Most Favorable Track			Comments
	Wood Tie	Concrete Tie	Concrete Slab	
Track labor			X	Concrete slab track requires less skilled labor for maintenance and thus will be least affected by labor shortage.
Track equipment			X	Concrete slab track requires considerably less maintenance equipment because of the elimination of ballast and associated maintenance operations.
Minimum quantity requirements	X			Wood ties are standard items that can be purchased in small quantities.

6. Slab track generally requires less construction depth than conventional track thus causing less interference with existing structures.

Also, observations and measurements on slab track projects have indicated the following unfavorable features of slab track systems:

1. Future alterations in route layout can be made easier on conventional track than on slab track.[29]
2. A longer possession time is required to install slab track with cast-in-place concrete on an existing line than that required to install conventional track.[29]

7.2 ENVIRONMENTAL FEATURES

Use of concrete slab track provides an environmental advantage by reducing the demand for wood, creosote, and other treatment products.

Higher noise levels are generated at certain frequencies with slab track than with conventional track.[29] This is due to the greater rigidity of slab track. However, the difference in noise level is relatively small,[32] and can be reduced using appropriate fastening systems.[33]

7.3 ECONOMIC FEATURES

Primary benefits sought from slab track are to reduce substantially maintenance costs and to avoid frequent interruption of traffic for maintenance. Saving direct cost of maintenance may not justify the higher capital investment in slab track. However, the cost of diverting or stopping traffic can be enormous. In addition, service life of slab track is expected to be longer than that of conventional track. These factors when taken into account may show that total annual cost of a slab track is less than that of a conventional track.

Another factor that may affect the economic feasibility of slab track systems is the possible energy savings caused by reduction in rolling resistance due to the improved track condition. Also, a reduction in rolling stock maintenance requirement may be achieved because of the improved uniformity and reduced deformation of track.

7.4 OTHER FEATURES

Concrete slab track provides favorable features with regard to use of materials and labor. Concrete and steel, the principal materials in a slab track system, are generally available in a sufficient supply with relatively stable prices. In contrast, wood tie prices and availability change frequently. Also, labor shortage would not represent a major problem for slab track, since it requires limited maintenance. In addition, less track maintenance equipment is needed for slab track because of elimination of ballast and need for periodical tamping and addition of ballast.

An unfavorable feature of concrete slab track, however, is effect of track length on cost. Cross ties are standard items that can be purchased in small quantities at a reasonable price. Construction of short sections of slab track is generally expensive.

8. COST ANALYSIS

Experience with slab track projects in foreign countries indicates that concrete slab track provides better performance than conventional ballasted track. This experience also indicates a generally higher initial cost for slab track. However, slab track provides advantages of reduced maintenance, lower traffic disruptions, expected longer service life, and improved ride quality. To compare construction plus maintenance costs for concrete slab track with those for wood and concrete tie tracks, an economic life analysis was made. Results of this comparison are presented.

8.1 METHOD OF ANALYSIS

The economic life comparison of the three track alternatives was made using the present worth method. In this method, present worth is defined as the amount of money that must be invested now at a given interest rate to generate sufficient funds to cover the expense when it occurs.

In this comparison, construction costs and future maintenance expenses are considered. Future expenses are estimated at current costs and then escalated by a factor to obtain their costs at time of occurrence. This escalation factor represents prevailing inflation rates. Escalated expenses are then discounted back to present worth using a discount rate representing prevailing interest rates. The present values of all future expenses for each track system are added to the construction cost and compared to determine the track system having lowest present cost.

In addition to discount and escalation rates, track design and installation cost, maintenance operations and equipment cost, service life, and labor wages affect the economic comparison. Assumptions made in the study regarding these factors are discussed.

The analysis develops cost differences between the three track alternatives. Items of equal cost are generally not included. Maintenance cost items are distributed over a 50-year period, escalated by inflation factors and then discounted to present worth.

Two track construction possibilities are considered. These are construction of a new transit system and the partial renewal or extension of an existing transit system. For construction of a new system, one track type is assumed for the entire system. Extensions or renewals are assumed to be made either with concrete slab track or with the existing type of ballasted track. Existing systems are assumed to consist of ballasted wood or concrete ties.

8.1.1 Installation of Track

The analysis utilizes track designs similar to those used by U.S. transit properties. For the three track alternatives, a 4 ft 8-1/2-in. gage and 115 RE continuously welded rails are assumed. Also, a 150 lb/yd contact rail supported at a 10-ft nominal spacing is assumed. Features of the three track alternative are listed in Table 8-1.

Wood ties are assumed to be 7 in. x 9 in. x 8-1/2 ft standard. However, every fifth tie is assumed 7 in. x 9 in. x 9 ft to provide space to support contact rail. Ties are machined, selectively dowelled, and treated in accordance with AREA specifications. Contact rail insulators are lagged directly to the long ties. Tie plates are AREA plan No. 4. Six cut spikes are used with each tie. Ties are spaced at 24 in. center to center and supported on 12- and 8-in. thick ballast and subballast layers, respectively. Every other tie is box-anchored.

Concrete ties are assumed to conform to the Preliminary Specifications for Standard Concrete Ties and Fastenings for Transit Track.[34] Contact rail insulators are mounted on brackets attached to each fourth tie. A fastening system conforming to these specifications is used. Ties are spaced at

TABLE 8-1. FEATURES OF TRACK ALTERNATIVES

Item	Wood Tie Track	Concrete Tie Track	Concrete Slab Track
Rail	115 RE, CWR	115 RE, CWR	115 RE, CWR
Gage	4 ft - 8-1/2 in.	4 ft - 8-1/2 in.	4 ft - 8-1/2 in.
Tie Dimensions	7 in. x 9 in. x 8-1/2 ft standard 7 in. x 9 in. x 9 ft every fifth tie	8-1/2 ft long, 9-3/4 in. wide	--
Tie Spacing	24 in.	30 in.	--
Fastener Spacing	24 in.	30 in.	30 in.
Ballast Depth	12 in.	12 in.	--
Subballast Depth	8 in.	8 in.	--
Slab Dimensions	--	--	10 in. x 10 ft
Subbase Dimensions	--	--	6 in. x 12 ft
Contact Rail	150 lb/yd	150 lb/yd	150 lb/yd
Spacing of third rail supports	10 ft	10 ft	10 ft

30 in. center to center, and supported on a 12-in. thick ballast layer.

Based on previous experience, a slab track consisting of a 10-in. thick and 10-ft wide continuously reinforced concrete slab with 0.7% longitudinal reinforcement is assumed. The slab is supported on a 6-in. thick, 12-ft wide stabilized subbase. Adjustable-type fasteners are installed for securing running rails at 30 in. spacing. Contact rail supports are installed at 10 ft spacing.

8.1.2 Maintenance Operations

Maintenance operations that affect cost comparison are listed in Table 8-2. The frequency of these operations is also listed. These operations include the following:

1. Wood and concrete tie replacement
2. Spot surfacing and lining
3. Lining and surfacing
4. Regaging on wood ties
5. Rail replacement
6. Fastening components replacement on concrete tie and slab tracks
7. Vegetation control on concrete and wood tie tracks
8. Track inspection

Material, equipment, and labor costs of the following maintenance operations are assumed equal for the three alternatives and, therefore, were not included in the calculations:

1. Contact rail assembly maintenance
2. Track car geometry operation
3. Rail inspection car operation
4. Rail grinding and welding
5. Track patrol
6. Roadway drainage
7. Fence maintenance
8. Turnout maintenance
9. Access points maintenance

TABLE 8-2. TYPE AND FREQUENCY OF MAINTENANCE OPERATIONS

Maintenance Item	Wood Tie Track	Concrete Tie Track	Concrete Slab Track
Tie or Slab Replacement	Average life 30 years (Forest Products Laboratory failure curve)	In excess of at 50 years, 0.5% failure within first 5 years	In excess of 50 years
Spot Surfacing and Lining	2 years	2 years	--
Lining and Surfacing	4 years	4 years	12-15 years
Rail Replacement:			
Tangent*	30 years	30 years	30 years
Curve	6 years	6 years	6 years
Station	12 years	12 years	12 years
Regaging**	15 years	--	--
Fastening Components Replacement	--	25 years	25 years
Track Inspection	2 times/week	2 times/week	2 times/week
Vegetation Control	Annual	Annual	--

*Used in the evaluation
**For tangent track

8.1.3 Service Life

Based on available information on cross tie and slab tracks and discussions with railroad representatives, the following assumptions are made:

1. Wood ties are assumed to have an average life of 30 years. Forest Products Laboratory studies[35] indicated that failure rate varies according to a damped harmonic curve with 50% of the ties failing at 94% of the average life. However, tie replacement is assumed to be performed when 25% of the ties required replacement. This is assumed to occur after 24, 28, 33, and 41 years of service.
2. Concrete ties are assumed to have a life in excess of 50 years, as indicated from European experience. It is also assumed that 0.5% of installed ties will fail within 5 years after installation due to rough handling during construction.
3. Concrete slab is assumed to have a life in excess of 50 years.

8.1.4 Economic Factors

A discount rate is used to convert future expenses to present value. It is generally based on present cost, or interest rate, of money required to construct a proposed system. Since interest rates fluctuate, discount rates ranging from 6 to 14% are used in the analysis.

An escalation factor is used to increase the current cost of a maintenance item for estimating its future cost when performed. It is generally based on prevailing inflation rates. Annual escalation factors ranging from 6 to 14% are used for materials, wages, and equipment.

Generally, inflation rates exceed interest rates by about 2%. However, transit projects are commonly financed by municipal bonds at a rate about 2% below the prevailing interest rate, resulting in an escalation rate that exceeds discount rate by about 4%.

8.2 COST EVALUATION

Costs of materials, equipment, and labor involved in track installation and maintenance operations are estimated utilizing data obtained from transit properties and railroad suppliers. However, these costs are site-specific and may vary considerably depending on project location, length, and details. Costs are generally presented for each track-mile.

Labor rates used in the analysis are comparable to those used by transit properties in mid 1980. These rates, listed in Table 8-3, include a 46% allowance for fringe benefits.

Equipment used for track construction and maintenance operations is listed in Tables 8-4 and 8-5, respectively. Also listed are capital recovery and use costs per shift. These costs are used to estimate equipment costs involved in construction and maintenance operations for the different track types. Capital recovery costs are not included for maintenance equipment because of underutilization or early obsolesence of equipment. However, purchase cost is included in the analysis as a capital investment.

8.2.1 Construction Costs

Construction cost of slab track depends greatly on track length. Therefore, estimates are made for installation of 2-, 5-, and 20-mile long slab tracks. However, construction cost of cross tie track is assumed unaffected by track length. A summary of material, labor, and equipment costs per track-mile is listed in Table 8-6. Details of these costs are presented in Appendix A.

8.2.1.1 Wood Tie Track - Material costs for each track-mile are listed in Table A-1. Daily labor costs for each construction operation are listed in Table A-2. Daily costs of equipment used on each construction operation are listed in Table A-3. Using estimated reasonable production rates for each construction operation, labor and equipment costs per track-mile are calculated. These costs are listed in Table A-4.

TABLE 8-3. LABOR WAGES

Title	Basic Rate $/day	Rate* $/day
Trackman	73.60	107.46
Flagman	88.00	128.48
Third Rail Man	102.56	149.74
Foreman	96.00	140.16
Machine Operator	75.44	110.14
Welder	78.00	113.88

*Mid 1980 rates including 46% fringe benefits

TABLE 8-4. CONSTRUCTION EQUIPMENT COSTS

Machine	Purchase Price, $	Depreciation Life, Years	Cost per Shift,* $			
			Maintenance	Fuel	Capital Recovery	Total
Ballast Regulator	72,000	10	72	33	59	164
Flat Car	8,000	10	4	-	4	8
Lift Truck	35,000	8	35	10	31	76
Preplate Machine	48,000	10	48	13	39	100
Production Tamper	140,000	6	241	37	108	386
Rail Anchor Applicator	42,000	8	42	8	38	88
Rail Clip Applicator/Remover	42,000	8	42	8	38	88
Speed Swing	90,000	10	45	23	70	138
Spike Driver	62,700	6	94	16	69	180
Switch Engine	500,000	15	110	50	313	473
Track Wrench	3,400	8	4	1	3	8
Truck	14,500	6	17	20	16	53

*Based on 200 shifts per year

TABLE 8-5. MAINTENANCE EQUIPMENT

Machine	Purchase Price, $	Cost per Shift,* $			Number Needed		
		Mainte-nance	Fuel	Total	Wood Tie Track	Concrete Tie Track	Concrete Slab Track
Air Compressor	15,000	15	17	32	1		
Ballast Regulator	72,000	72	33	105	1	1	
Crane	190,000	48	28	76	1	1	1
Gaging Machine	32,800	33	3	36	1		
Gondola	10,000	5		5	4	2	2
Push Cart	800	1		1	2	3	3
Rail Anchor Applicator	42,000	42	8	50	1		
Rail Clip Applicator/ Remover	42,000	42	8	50		1	1
Rail Lifter	5,200	3	2	5		1	1
Rail Threader	24,800	13	2	15	1	1	1
Spike Driver	58,700	88	17	105	1		
Spike Driver-Pneumatic	1,000	2		2	2		
Spike Puller	5,300	8	2	10	2		
Tamper	63,000	42	15	57		1	
Tamper-Switch	152,000	100	30	130	1	1	
Tie Crane	27,300	27	24	51		1	
Tie Renewer	60,600	61	8	69	1	1	
Track Wrench	3,400	4	1	5			2

*Capital recovery cost is not included, purchase price is introduced as capital investment.

TABLE 8-6. CONSTRUCTION COSTS

Item	Cost/Track-Mile,* $				
	Wood Tie Track	Concrete Tie Track	Concrete Slab Track		
			2 miles	5 miles	20 miles
Materials	296,422**	331,622**	763,511***	747,048***	695,777***
Labor and Equipment	13,536	9,778	7,465	7,465	7,465
Total	309,958	341,400	770,976	754,513	703,242

*Excludes costs for unloading and stressing rails and installing third rail
**Includes labor and equipment costs for subballast placement
***Includes labor and equipment costs for slab and subbase placement and installation of fastening inserts

8.2.1.2 Concrete Tie Track - Material costs for each track-mile are listed in Table A-5. Daily labor costs for each construction operation are listed in Table A-6. Daily costs of equipment used in each construction operation are listed in Table A-7. Using estimated reasonable production rates for each construction operation, labor and equipment costs per track-mile are calculated. These costs are listed in Table A-8.

8.2.1.3 Concrete Slab Track - Materials costs for each track-mile are listed in Table A-9. These costs include labor and equipment costs involved in subbase and slab placement, and installation of fastener inserts. Daily labor costs for other construction operations are listed in Table A-10. Daily costs for equipment used in these operations are listed in Table A-11. Using estimated reasonable production rates for each construction operation, labor and equipment costs per track-mile are calculated. These costs are listed in Table A-12.

8.2.2 Maintenance Costs

Costs for performing each maintenance operation were estimated for the three track alternatives. These costs, listed in Table 8-7, were based on 6 hours of track possession for maintenance. Details of costs are shown in Appendix A.

8.2.2.1 Tie Replacements - This maintenance operation is required for wood and concrete tie tracks only. Daily labor and equipment costs involved in wood and concrete tie replacements are listed in Tables A-13 and A-14, respectively. Total replacement costs per tie including labor, equipment, and materials are listed in Table A-15 for wood and concrete ties.

8.2.2.2 Spot Surfacing and Lining - This maintenance operation is required for wood and concrete tie tracks only and generally involves no ballast addition. Daily labor and equipment costs involved in spot surfacing and lining are listed in Table A-16. Total costs per mile are listed in Table A-17.

TABLE 8-7. COST OF MAINTENANCE OPERATIONS

Maintenance Item	Cost per Mile,* $		
	Wood Tie Track	Concrete Tie Track	Concrete Slab Track
Tie Replacement	38.92/tie	207.80/tie	
Spot Surfacing and Lining	1,430	1,144	0
Lining and Surfacing	7,975	7,732	4,421
Rail Replacement	14,639**	11,218**	11,126**
Regaging	6,350	0	0
Fastening Components Replacements	0	13,618	13,618
Track Inspection	35.83/ inspection	35.83/ inspection	28.67/ inspection
Vegetation Control	300/year	300/year	0

*Unless otherwise stated
**Excluding costs for rails, rail stressing, welding, loading, and unloading

8.2.2.3 Track Lining and Surfacing - This maintenance operation is required for all three track alternatives and generally involves ballast addition on cross tie track. However, it is most easily performed on slab track, involving only adjusting and shimming of rail fasteners. Daily labor and equipment costs involved in lining and surfacing are listed in Table A-18. Material costs involved in this operation are listed in Table A-19. Total lining and surfacing costs per track-mile including labor, equipment, and materials are listed in Table A-20.

8.2.2.4 Rail Replacement - This maintenance operation is required for all three track alternatives. However, it is more easily performed on concrete tie and slab tracks. Daily labor and equipment costs involved in rail replacement are listed in Table A-21. Material costs involved in this operation are listed in Table A-22. Total rail replacement costs per track-mile including labor, equipment, and materials are listed in Table A-23.

8.2.2.5 Regaging - This maintenance operation is required for wood tie track only. Total regaging costs per track-mile including labor, equipment, and materials are listed in Table A-24.

8.2.2.6 Fastening Components Replacement - This maintenance operation is required for concrete tie and slab tracks only. Fastening components replacement costs per track-mile including labor, equipment, and materials are listed in Table A-25.

8.2.2.7 Track Inspection - This maintenance operation is required for all three track alternatives. However, it is most easily performed on slab track. Track inspection costs per track-mile are listed in Table A-26.

8.2.2.8 Vegetation Control - This maintenance operation is required for wood and concrete tie tracks only. Depending on climate, 1 to 3 sprayings may be required annually. However, for this evaluation, cost for vegetation control per track-mile is estimated at $300 based on a single spraying per year.

8.2.3 Maintenance Equipment

As indicated in Table 8-5, type and number of machines required for track maintenance depend on track type. Costs associated with the purchase of track maintenance equipment depend on whether a new transit system will be built, or an existing cross tie track system will be renewed or extended.

For new construction, a complete fleet of maintenance equipment is required. However, for renewal or extension with track of a similar type to that existing, available maintenance equipment is assumed adequate and, therefore, purchase of new equipment is not be required. For renewal or extension of an existing system with concrete slab track, limited additional equipment will be required to handle certain maintenance operations.

Costs associated with the purchase of equipment for maintenance of a newly constructed transit system are listed in Table A-27. Also listed are costs associated with purchase of additional equipment for maintenance of a concrete slab track section on an existing transit system built with ballasted wood or concrete tie track.

8.3 COMPARISON OF PRESENT WORTH COSTS

Maintenance costs per track-mile distributed in time and escalated have been worked back to present worth using different escalation and discount rates. Present worth of maintenance costs for the three track alternatives are listed in Table A-28.

Present worth of maintenance equipment required for construction of new transit systems is listed in Table A-29. Present worth of additional equipment required for extending an existing transit system with concrete slab track is listed in Table A-30.

Differences in present value per track-mile between slab track and wood or concrete tie track are calculated for two construction possibilities. These are the construction of a new transit system and the renewal or extension of an existing cross tie track system. Differences in present value for these track types and construction possibilities are listed in Tables A-31, A-32, A-33, and A-34. For construction of a new transit system, differences in present worth costs per track-mile are listed for track lengths up to 100 miles. For renewals or extensions on an existing system, differences in present worth costs per track-mile are listed for extension lengths up to 20 miles. For all cases, values are listed for escalation and discount rates of 6, 8, 10, 12, and 14%.

Differences in present worth costs between concrete slab and ballasted wood tie tracks are listed in Tables A-31 and A-33 for the construction of a complete new transit system and extensions on an existing system, respectively. Differences in present worth costs between concrete slab and ballasted concrete tie tracks are listed in Tables A-32 and A-34 for the construction of a complete new transit system and extensions on an existing system, respectively.

8.4 FINDINGS

Differences in present worth between concrete slab and ballasted tracks are listed in Tables A-31, A-32, A-33, and A-34 for a 50-year period. Review of these data indicate that difference in present worth depends on the difference between escalation and discount rates and track length. Differences in present worth for a 50-year period are listed in Table 8-8 as function of track length and difference between escalation and discount rates for selected track types and construction possibilities. These present worth differences are also shown in Figures 8-1 and 8-2 for the construction of a complete new transit system and in Figures 8-3 and 8-4 for renewals or extensions on an existing system. Track lengths for which

TABLE 8-8. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB TRACK AND BALLASTED TRACK

Construction Type	Track Type	Track Length, mile	Range of Difference in Present Worth,* $1,000/mile						
			Escalation Rate - Discount Rate, %						
			+6	+4	+2	0	-2	-4	-6
New System	Wood Tie	2.0	-4,254/-4,109	-2,282/-2,181	-1,210/-1,168	-617	-287/-300	-99/-110	+12/+7
		5.0	-2,323/-2,235	-1,130/-1,069	-490/-465	-140	+52/+43	+159/+153	+223/+220
		20.0	-1,401/-1,342	-597/-557	-173/-157	+55	+178/+173	+246/+242	+285/+284
		50.0	-1,206/-1,153	-481/-444	-99/-85	+104	+213/+209	+273/+270	+308/+307
		100.0	-1,142/-1,090	-442/-406	-75/-61	+121	+225/+221	+282/+279	+316/+314
	Concrete Tie	2.0	-3,243/-3,133	-1,735/-1,657	-911/-880	-454	-197/-207	-49/-57	+40/+36
		5.0	-1,516/-1,456	-705/-663	-268/-252	-28	+105/+100	+181/+177	+227/+225
		20.0	-696/-660	-233/-210	+10/+19	+141	+213/+210	+254/+251	+278/+277
		50.0	-520/-491	-128/-109	+76/+84	+185	+245/+242	+274/+276	+298/+297
		100.0	-462/-435	-93/-75	+98/+105	+200	+255/+253	+287/+285	+305/+304
Extension on Existing System	Wood Tie	2.0	-576/-539	-75/-50	+181/+191	+314	+384/+381	+421/+419	+442/+441
		5.0	-852/-807	-247/-207	+65/+78	+232	+320/+317	+368/+365	+395/+394
		10.0	-939/-891	-299/-267	+34/+46	+210	+304/+300	+355/+353	+385/+383
		20.0	-1,033/-984	-377/-344	-34/-21	+148	+245/+241	+298/+295	+328/+327
	Concrete Tie	2.0	-283/-258	+42/+58	+208/+214	+296	+344/+341	+370/+369	+386/+387
		5.0	-331/-306	+6/+23	+180/+186	+272	+321/+319	+349/+348	+366/+366
		10.0	-342/-317	-1/+16	+176/+182	+269	+319/+317	+348/+346	+364/+364
		20.0	-399/-373	-55/-38	+122/+129	+216	+267/+265	+296/+294	+313/+312

*For a 50-year period and 6 to 14% escalation and discount rates.

(-) and (+) indicate lower and higher costs for concrete slab track, respectively.

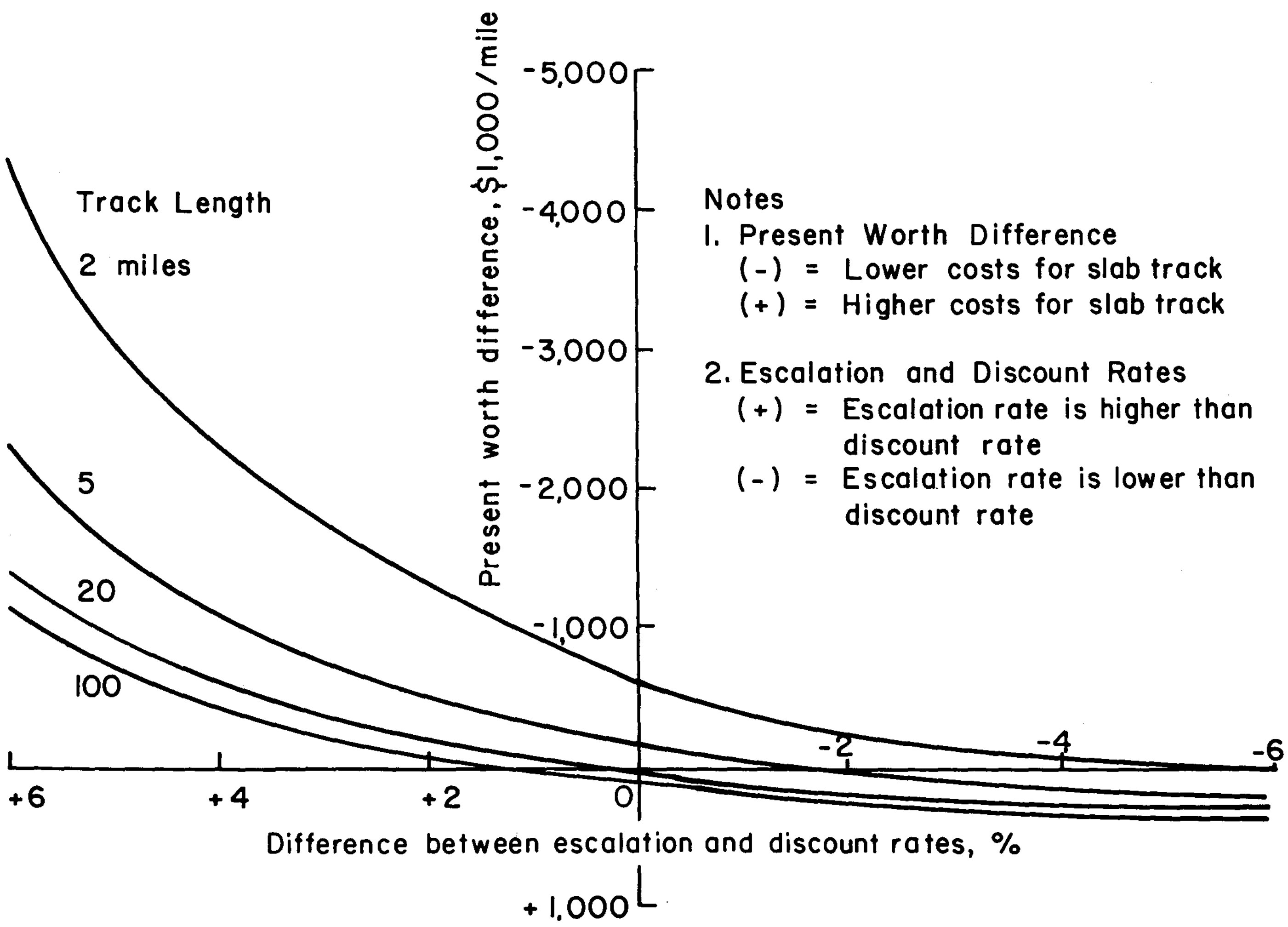

FIGURE 8-1. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND WOOD TIE TRACKS FOR NEW CONSTRUCTION

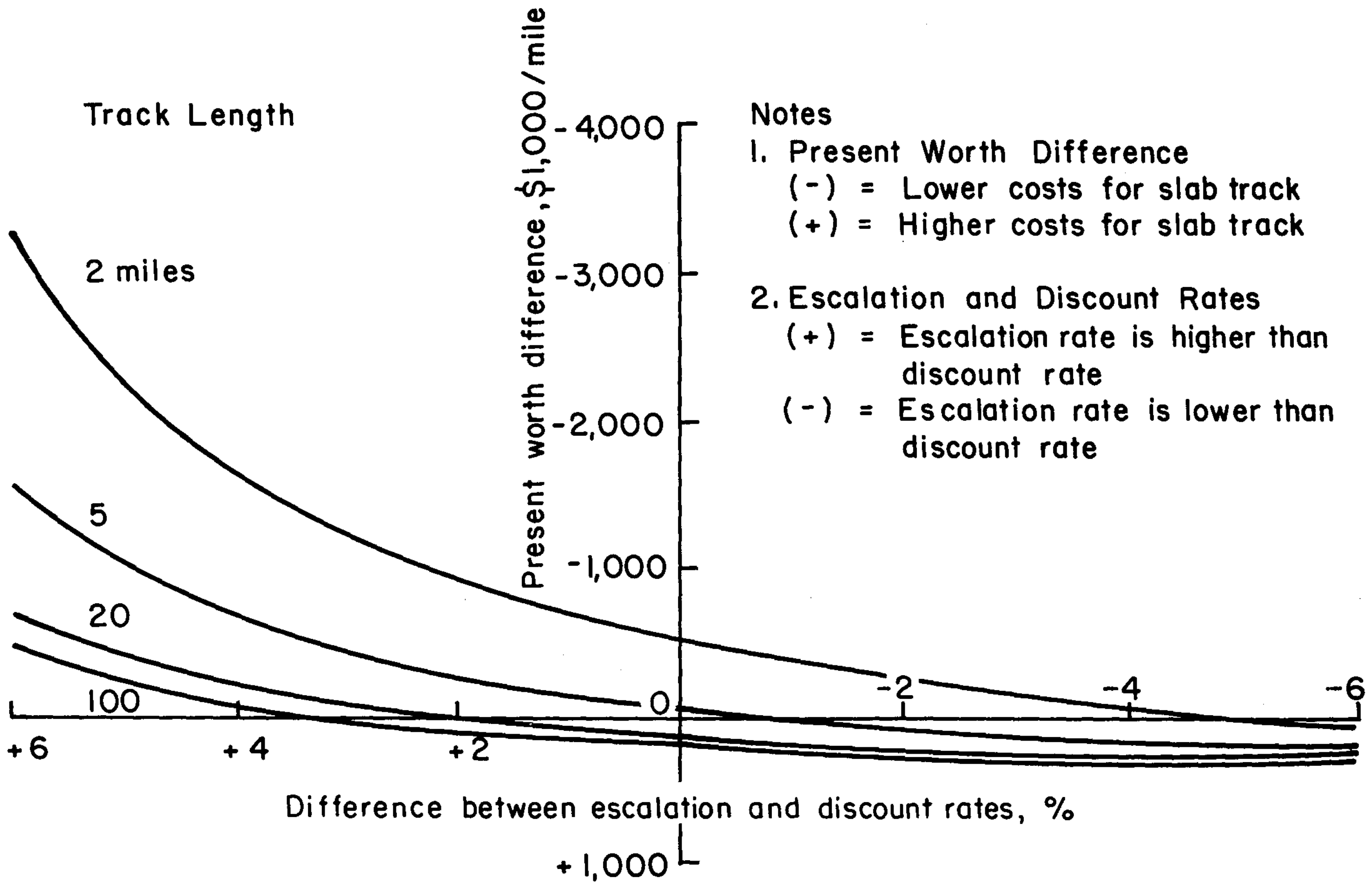

FIGURE 8-2. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND CONCRETE TIE TRACKS FOR NEW CONSTRUCTION

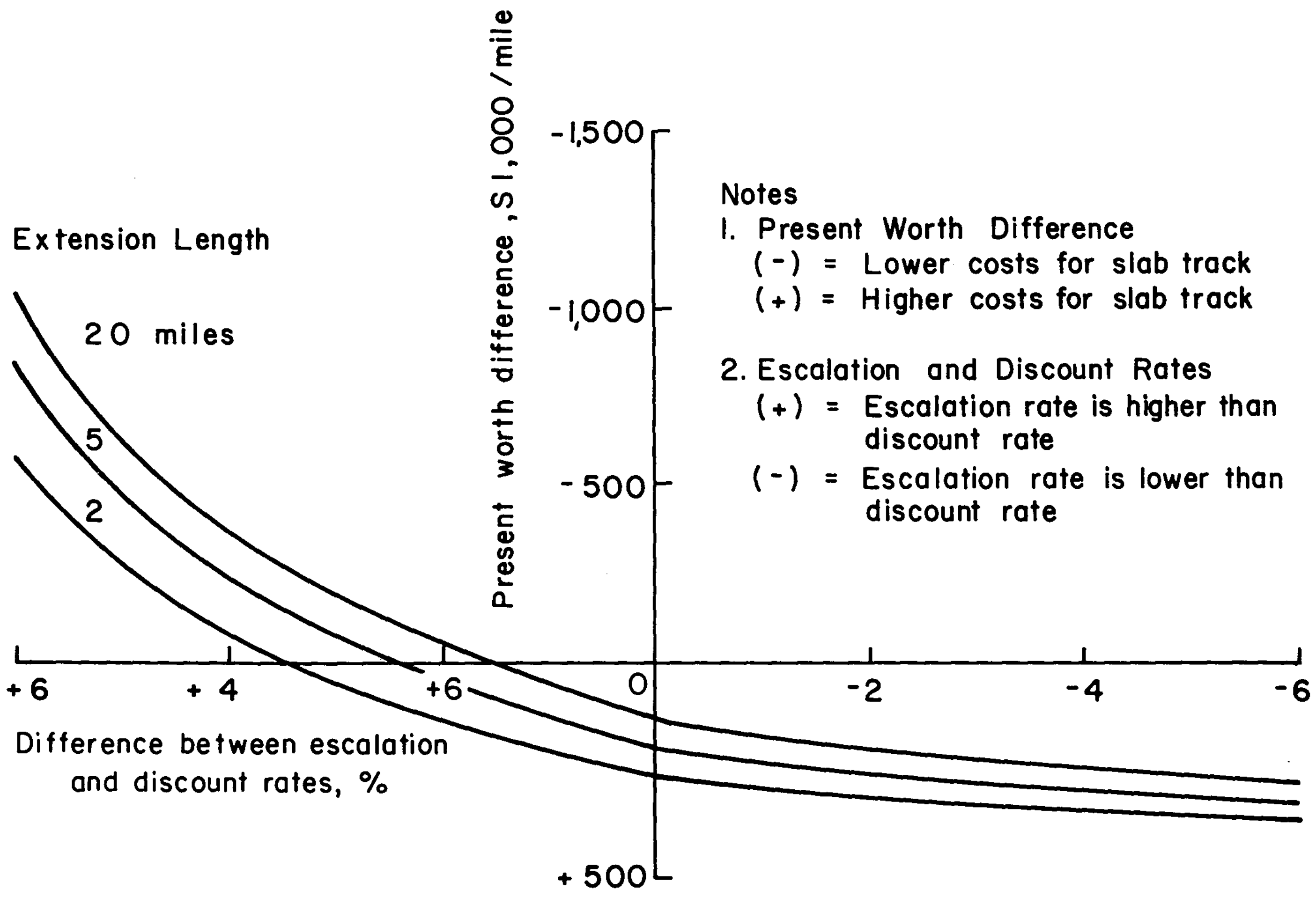

FIGURE 8-3. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND WOOD TIE TRACKS FOR EXTENDING A WOOD TIE TRACK

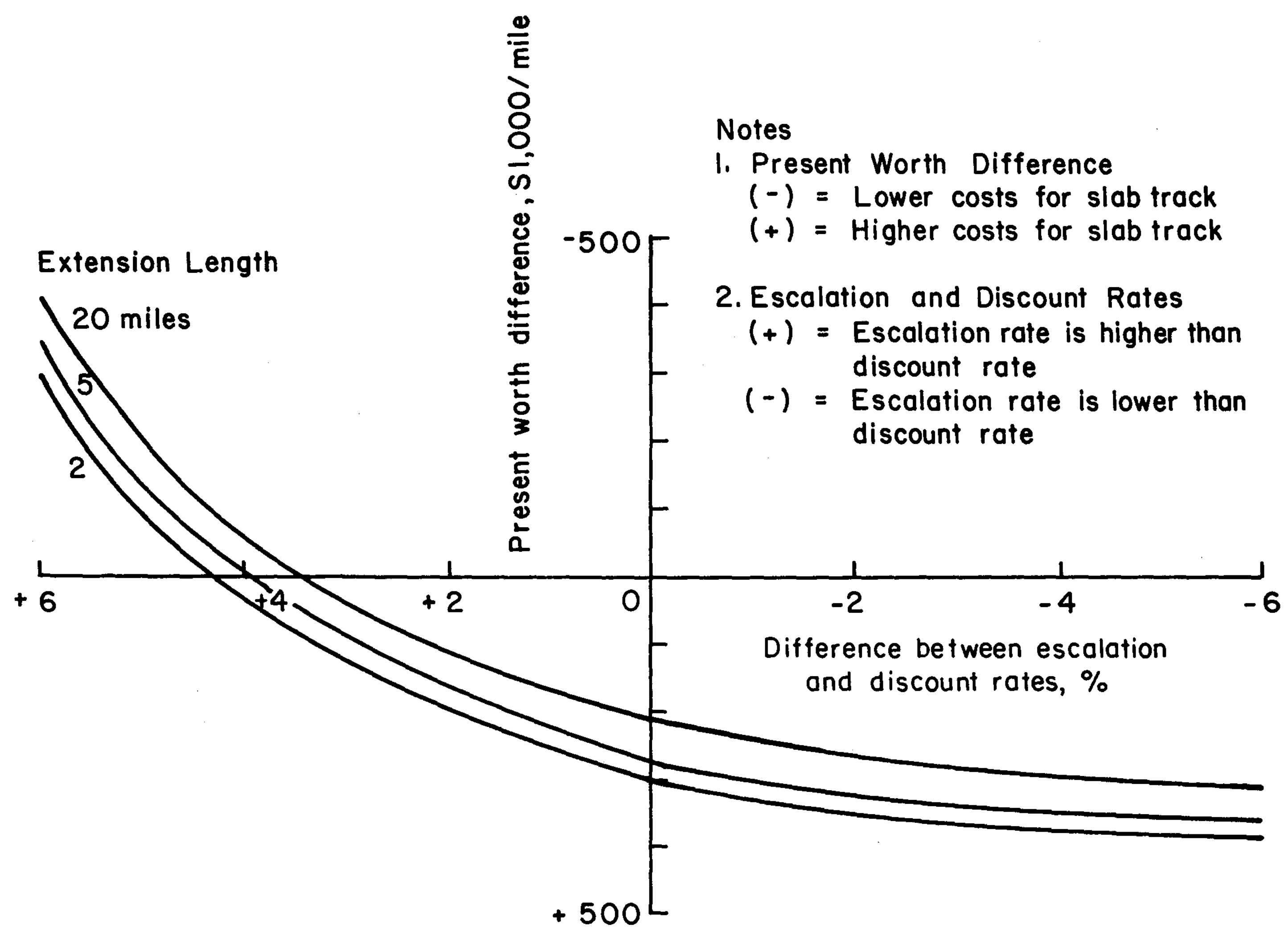

FIGURE 8-4. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND CONCRETE TIE TRACKS FOR EXTENDING A CONCRETE TIE TRACK

concrete slab track present worth costs are lower than those for ballasted tracks are listed in Table 8-9.

Discussion of present worth differences between concrete slab and ballasted tracks is presented for the construction of a new transit system and for the partial renewal or extension of an existing system.

8.4.1 Construction of a New Transit System

Present worth difference data listed in Table 8-8 indicate that in terms of present worth cost, concrete slab track is generally less expensive than wood tie track if the escalation rate exceeds the discount rate by at least 2%. For other rates, concrete slab track is less expensive than wood tie track if a given track length is not exceeded, as indicated in Table 8-9.

Data listed in Table 8-8 also indicate that in terms of present worth cost, concrete slab track is generally less expensive than concrete tie track if the escalation rate exceeds the discount rate by at least 4%. For other rates, concrete slab track is less expensive than concrete tie track if a specified track length is not exceeded, as indicated in Table 8-9.

Present worth difference data also indicate that for an escalation rate exceeding discount rate by 4%, as generally encountered in transit projects, concrete slab track provides a cost advantage over wood or concrete tie track. Depending on track length and prevailing interest and inflation rates, the 50-year cost advantage of concrete slab track over wood tie track ranges from $406,000 to 2,282,000/mile. Cost advantage over concrete tie track ranges from $75,000 to 1,735,000/mile.

8.4.2 Partial Renewal or Extension of an Existing Transit System

Present worth difference data listed in Table 8-8 indicate that in terms of present worth cost, concrete slab track is generally less expensive than wood tie track if the escalation rate

TABLE 8-9. TRACK LENGTH FOR LOWER PRESENT WORTH OF CONCRETE SLAB TRACK

Construction Type	Track Type	Track Length, mile						
		Escalation Rate - Discount Rate, %						
		+6	+4	+2	0	-2	-4	-6
New System	Wood Tie	All	All	All	≤9.5	≤4.1	≤2.6	≤1.9
	Concrete Tie	All	All	≤14.8	≤5.6	≤3.2	≤2.3	≤1.8
Extension on Existing System	Wood Tie	All	All	≥13.2	None	None	None	None
	Concrete Tie	All	≥10.3	None	None	None	None	None

exceeds the discount rate by at least 4%. For an escalation rate exceeding the discount rate by 2 to 4%, concrete slab track is less expensive than wood tie track if a given extension length is exceeded, as indicated in Table 8-9. For other rates, concrete slab track is generally more expensive than wood tie track.

Data listed in Table 8-8 also indicate that in terms of present worth cost, concrete slab track is generally less expensive than concrete tie track if the escalation rate exceeds the discount rate by at least 6%. For an escalation rate exceeding the discount rate by 4 to 6%, concrete slab track is less expensive than concrete tie track if a given extension length is exceeded, as indicated in Table 8-9. For other rates, concrete slab track is generally more expensive than concrete tie track.

Present worth difference data also indicate that for an escalation rate exceeding the discount rate by 4%, as generally encountered in transit projects, concrete slab track provides a cost advantage over wood tie track. Depending on extension length and prevailing interest and inflation rates, the 50-year cost advantage of concrete slab track over wood tie track ranges from $50,000 to 377,000/mile. However, concrete slab track provides a cost advantage over concrete tie track only if the extension length exceeds 10.3 miles. For other extension lengths, concrete slab track provides a 50-year cost disadvantage over concrete tie track of up to 58,000/mile.

8.5 OTHER FACTORS AND REMARKS

Costs associated with construction and maintenance of track have been considered in the analysis. It should be pointed out that the process of predicting the costs and savings may involve certain errors. These errors may occur as a result of incorrect assumption of discount and escalation rate, service life, time and extent of maintenance operations, and study period. Therefore, assumptions used should be evaluated on an individual basis for the project under consideration. In this manner, a reliable comparison of track alternatives can be made.

Several factors have not been considered because of the difficulty of expressing them in terms of dollars. However, these factors should be considered together with the economic factors in evaluating the potential benefits of concrete slab track. An important factor is cost of diverting or stopping traffic for maintenance. It is estimated that 60 hours of track possession are required for slab track maintenance operations in a 50-year period. This compares to about 560 and 340 hours wood and concrete tie tracks, respectively. Other factors, discussed in Section 7, include safety, noise generation, energy savings, and others.

9. CONCLUDING REMARKS

In the past 25 years, 18 at-grade concrete slab track projects were built in eight countries. These projects incorporated different slab track and fastener designs. Cast-in-place slabs, precast concrete slabs and ladder units, and systems incorporating concrete ties embedded in cast-in-place slabs have been built. Also, non-adjustable, vertically-adjustable, laterally-adjustable, and vertically- and laterally-adjustable fasteners have been used.

Experience has shown that cast-in-place slabs are readily placed at a good production rate using conventional equipment. However, field installation of fastener inserts is labor intensive. In addition, slab cracking due to drying shrinkage may adversely affect fastener performance.

Construction with ties embedded in slab or precast concrete units eliminates the effect of slab cracking on fastener performance. Also, it provides accurate rail cant and gage and reduces construction time.

Construction with rubber-booted ties embedded in slab reduces noise level. However, it requires great care during construction to assure proper compaction of the grout between the slab and tie bottom.

Construction with precast concrete units requires special equipment that makes it difficult to mechanize.

Performance evaluation of several projects indicated that a slab track should incorporate the following features:

1. Slabs or ladder units capable of withstanding traffic loads and distributing load to the subbase
2. A good quality subbase to distribute loads to the subgrade
3. A well compacted or stabilized subgrade to reduce deformations
4. Frost protective layers in areas with frost-susceptible soil

5. Proper drainage to prevent subgrade weakening by moisture
6. Proper transition between slab track and adjacent ballasted track to reduce differential settlements

Experience has shown difficulty in achieving desired accuracy of slab surface during construction. Surface grinding was required at projects where vertical adjustment could not be provided by the fastening system. Also, preparation of subgrade and subbase under precast concrete slabs and ladder units cannot be expected to match that of a cast-in-place slab. Therefore, vertical fastener adjustment is desired to compensate for such tolerances.

Transverse adjustment is needed to allow for the various tolerances and clearances occurring during construction and service. Therefore, a slab track fastening system should be capable of providing both vertical and lateral adjustments to maintain the design accuracy of line and level. In addition, fasteners should provide the following properties:

1. Adequate service life
2. Adequate restraint to longitudinal rail movement
3. Sufficient electrical insulation
4. Means for reducing noise and vibrations
5. Proper means for anchoring to the concrete

Experience has shown that concrete slab track systems performed satisfactorily under various traffic conditions that differed from those encountered on U.S. transit systems. Generally, axle loads were higher, traffic frequencies were lower, and third rails were not used.

Generally, performance of slab track systems was superior to that of ballasted track. Better gage and alignment were maintained during service life and maintenance was considerably reduced. Also, life-cycle analysis of maintenance and construction costs of concrete slab and ballasted tracks indicated that, depending on prevailing economic conditions and specifics of the project under consideration, slab track may provide a cost advantage over ballasted track. Operating advantages resulting from slab track use such as reduction in traffic disruption and energy savings could also affect this comparison. For example, track possession time required for slab track maintenance operations is substantially less than that required for wood and concrete tie tracks.

Experiments with concrete slab track in the past 25 years have demonstrated its superiority to ballasted track. However, more studies and field experience are needed to identify optimum designs suitable for the traffic and enivornmental conditions encountered on U.S. transit systems.

APPENDIX A - COST ANALYSIS DATA

Section 8 presents a life-cycle analysis of construction and maintenance costs of wood tie, concrete tie, and concrete slab tracks. Details of these costs are presented in this Appendix.

Tables A-1 through A-4 list costs associated with construction of wood tie track. Tables A-5 through A-8, lists costs associated with construction of concrete tie track. Tables A-9 through A-12 list costs associated with construction of concrete slab track.

Tables A-13 through A-27 list costs associated with the different maintenance operations for the three track alternatives.

Table A-28 lists present worth of maintenance costs for the three track alternatives.

Tables A-29 and A-30 list present worth of maintenance equipment costs for constructing a new transit system and for extending an existing ballast track system, respectively.

Tables A-31 through A-33 list the difference in present worth between concrete slab track and wood or concrete tie track for constructing a new transit system and for extending an existing ballasted track system.

TABLE A-1. WOOD TIE TRACK MATERIAL COSTS

Item	Quantity per Track-Mile	Unit Price $	Cost/Track-Mile $
Standard Ties	2,112	20.50	43,296
Third Rail Ties	528	23.50	12,408
Tie Plates	5,280	3.60	19,008
Spikes	15,840	0.25	3,960
Anchors	5,808	0.90	5,227
Ballast	3,662 cu yd	10.70	39,183
Subballast	2,194 cu yd	9.50*	20,843*
Running Rail	202.4 tons	417.00	84,401
Contract Rail	132.0 tons	417.00	55,044
Insulator Chair Assembly	528	24.72	13,052
Total			296,422

*Includes placement

TABLE A-2. LABOR COSTS FOR WOOD TIE TRACK INSTALLATION

Operation	Number of each Labor Category			Cost per Day, $
	Foreman	Trackman	Operator	
Distribute Ties	1	4	2	790
Distribute Rollers	1	3	1	573
Set Rail and Spike Ties	1	3	3	793
Unload Ballast	1	4	1	680
Raise Track	1	3	2	683
Unload Ballast	1	4	1	680
Surface Track	1	3	2	683
Apply Anchors	1	2	2	575
Surface Track and Broom	1	2	2	575
Preplate Ties	1	9	3	1,438

TABLE A-3. EQUIPMENT COSTS FOR WOOD TIE TRACK INSTALLATION

Operation	Equipment		Cost per Shift, $
	Type	Number	
Distribute Ties	Flat Cars Speed Swing Switch Engine	6 1 1	659
Distribute Rollers	Truck	1	53
Set Rails and spike Ties	Speed Swing Spike Driver	1 2	498
Unload Ballast	Switch Engine	1	473
Raise Track	Production Tamper Ballast Regulator	1 1	550
Unload Ballast	Switch Engine	1	473
Surface Track	Production Tamper Ballast Regulator	1 1	550
Apply Anchors	Anchor Applicator	2	176
Surface Track and Broom	Production Tamper Ballast Regulator	1 1	550
Preplate Ties	Replate Machine Lift Truck	1 2	252

TABLE A-4. LABOR AND EQUIPMENT COSTS FOR WOOD TIE TRACK INSTALLATION

Operation	Cost per Shift, $			Miles per Shift	Cost per Mile, $
	Labor	Equipment	Total		
Distribute Ties	790	659	1,449	0.50	2,898
Distribute Rollers	573	53	626	1.75	358
Unload Rails*	-	-	-	-	-
Set Rails and spike Ties	793	498	1,291	1.75	738
Unload Ballast	680	473	1,153	1.25	922
Raise Track	683	550	1,233	1.25	986
Unload Ballast	680	473	1,153	1.25	922
Surface Track	683	550	1,233	1.25	986
Stress Rails*	-	-	-	-	-
Apply Anchors	575	176	751	1.25	601
Surface Track and Broom	575	550	1,125	1.25	900
Install Third Rail*	-	-	-	-	-
Preplate Ties	1,438	252	1,690	0.40	4,225
Total					13,536

*These operations are not included in cost evaluation. They are assumed equal for all track alternatives.

TABLE A-5. CONCRETE TIE TRACK MATERIAL COSTS

Item	Quantity per Track-Mile	Unit Price, $	Cost/Track-Mile, $
Ties	2,112	46.00*	97,152
Fastenings	4,224	4.33**	18,290
Third Rail Bracket	528	8.00	4,224
Ballast	3,609 cu yd	10.70	38,616
Subballast	2,194 cu yd	9.50***	20,843***
Running Rail	202.4 tons	417.00	84,401
Contract Rail	132.0 tons	417.00	55,044
Insulator Chair Assembly	528	24.72	13,052
Total			331,622

*Includes fastening inserts
**Includes pad, insulators, and clips for one rail seat
***Includes placement

TABLE A-6. LABOR COSTS FOR CONCRETE TIE TRACK INSTALLATION

Operation	Number of each Labor Category			Cost per Day, $
	Foreman	Trackman	Operator	
Distribute Ties	1	4	1	680
Distribute Rollers, Clips, and Pads	1	7	1	1,003
Set Rail and Temporary Install Fasteners	1	3	2	683
Unload Ballast	1	4	1	680
Raise Track	1	3	2	683
Unload Ballast	1	4	1	680
Surface Track	1	3	2	683
Remove Fasteners and Permanently Install Them (after rail stressing)	1	3	2	683
Surface Track	1	2	2	575

TABLE A-7. EQUIPMENT COSTS FOR CONCRETE TIE TRACK INSTALLATION

Operation	Equipment		Cost per Shift, $
	Type	Number	
Distribute Ties	Flat Car Speed Swing Switch Engine	6 1 1	659
Distribute Rollers, Clips and Pads	Truck	1	53
Set Rail and Temporarily Install Fasteners	Speed Swing Clip Driver	1 2	226
Unload Ballast	Switch Engine	1	473
Raise Track	Production Tamper Ballast Regulator	1 1	550
Unload Ballast	Switch Engine	1	473
Surface Track	Production Tamper Ballast Regulator	1 1	550
Remove Fasteners and Permanently Install Them (after rail stressing)	Clip Driver	2	176
Surface Track	Production Tamper Ballast Regulator	1 1	550

TABLE A-8. LABOR AND EQUIPMENT COSTS FOR CONCRETE TIE TRACK INSTALLATION

Operation	Cost per Shift, $			Miles per Shift	Cost per Mile, $
	Labor	Equipment	Total		
Distribute Ties	680	659	1,339	0.40	3,348
Distribute Rollers and Tie Pads	1,003	53	1,056	1.50	704
Unload Rails*	-	-	-	-	-
Set Rail and Temporarily Install Fasteners	683	226	909	1.75	519
Unload Ballast	680	473	1,153	1.25	922
Raise Track	683	550	1,233	1.25	986
Unload Ballast	680	473	1,153	1.25	922
Surface Track	683	550	1,233	1.25	986
Stress Rails*	-	-	-	-	-
Install Fasteners	683	176	859	1.75	491
Surface Track	575	550	1,125	1.25	900
Install Third Rail*	-	-	-	-	-
Total					9,778

*These operations are not included in cost evaluation. They are assumed equal for all track alternatives.

TABLE A-9. CONCRETE SLAB TRACK MATERIAL COSTS

Item	Quantity per Track-Mile	Unit Price, $			Cost/Track-Mile, $		
		Track Length, Mile			Track Length, Mile		
		2	5	20	2	5	20
Concrete Slab*	5,867 sq yd	34.65	33.20	29.00	203,292	194,784	170,143
Subbase*	7,040 sq yd	10.35	9.97	8.97	72,864	70,189	63,149
Fastening Insert Holes**	5,280 ft	40.00	39.17	35.83	211,200	206,818	189,182
Third Rail Insert Holes**	5,280 ft	3.42	3.25	2.88	18,058	17,160	15,206
Rail Fasteners***	4,224	25.00	25.00	25.00	105,600	105,600	105,600
Running Rail	202.4 tons	417.00	417.00	417.00	84,401	84,401	84,401
Contact Rail	132.0 tons	417.00	417.00	417.00	55,044	55,044	55,044
Insulator Chair Assembly	528	24.72	24.72	24.72	13,052	13,052	13,052
Total					763,511	747,048	695,777

*Includes placement
**Includes installation of inserts
***Includes components for one rail seat

TABLE A-10. LABOR COSTS FOR CONCRETE SLAB TRACK INSTALLATION

Operation	Number of each Labor Category			Cost per Day, $
	Foreman	Trackman	Operator	
Distribute and Set Fastening Plates	1	4	1	680
Distribute Rollers	1	3	1	573
Set Rails	1	2	1	465
Distribute Fasteners and Collect Rollers	1	4	1	680
Install Fasteners	1	4	2	790
Adjust Fasteners	1	2	2	575

TABLE A-11. EQUIPMENT COSTS FOR CONCRETE SLAB TRACK INSTALLATION

Operation	Equipment		Cost per Shift, $
	Type	Number	
Distribute and Set Fastening Plates	Truck	1	53
Distribute Rollers	Truck	1	53
Set Rails	Speed Swing	1	138
Distribute Fasteners and Collect Rollers	Speed Swing Gondola	1 1	148
Install Fasteners	Track Wrench	2	16
Adjust Fasteners	Track Wrench	2	16

TABLE A-12. LABOR AND EQUIPMENT COSTS FOR CONCRETE SLAB TRACK INSTALLATION

Operation	Cost per Shift, $			Miles per Shift	Cost per Mile, $
	Labor	Equipment	Total		
Place Subbase*	-	-	-	-	-
Place Slab*	-	-	-	-	-
Drill Holes and Install Fastening Inserts*	-	-	-	-	-
Distribute and Set Fastening Plates	680	53	733	0.5	1,466
Distribute Rollers	573	53	626	2.0	313
Unload Rails**	-	-	-	-	-
Set Rails	465	138	603	2.0	302
Distribute Fasteners	680	148	828	2.0	414
Stress Rails**	-	-	-	-	-
Install Fasteners	790	16	806	0.4	2,015
Adjust Fasteners	575	16	591	0.2	2,955
Install Third Rail**	-	-	-	-	-
Total					7,465

*Included in material cost
**These operations are not included in cost evaluation. They are assumed equal for all track alternatives.

TABLE A-13. LABOR AND EQUIPMENT COSTS FOR WOOD TIE REPLACEMENT

Operation	Type	Quantity	Cost per Shift, $
Removal and Installation			
Labor			2,102
	Foreman	1	
	Machine Operator	3	
	Trackman	10	
	Flagman	2	
	Third Rail Man	2	
Equipment			184
	Spike Puller	1	
	Tie Renewer	1	
	Spike Driver	1	
Distribution			
Labor			1,045
	Foreman	1	
	Machine Operator	5	
	Trackman	1	
	Flagman	2	
Equipment			86
	Crane	1	
	Freight Car	2	
Warehouse Operation			
Labor			325
	Trackman	2	
	Machine Operator	1	
Equipment			86
	Crane	1	
	Gondola	2	

TABLE A-14. LABOR AND EQUIPMENT COSTS FOR CONCRETE TIE REPLACEMENT

Operation	Type	Quantity	Cost per Shift, $
Removal and Installation			
Labor			1,672
	Foreman	1	
	Machine Operator	3	
	Trackman	6	
	Flagman	2	
	Third Rail Man	2	
Equipment			177
	Tie Renewer	1	
	Tie Crane	1	
	Tamper	1	
Distribution			
Labor			1,045
	Foreman	1	
	Machine Operator	5	
	Trackman	1	
	Flagman	2	
Equipment			86
	Crane	1	
	Freight Car	2	
Warehouse Operation			
Labor			325
	Trackman	2	
	Machine Operator	1	
Equipment			86
	Crane	1	
	Gondola	2	

TABLE A-15. TIE REPLACEMENT COST

Track Type	Cost per Shift, $			Production per Shift, Ties	Cost per Tie, $
	Labor	Equipment	Total		
Wood Tie					
Removal and Installation	2,102	184	2,286	150	15.24
Distribution	1,045	86	1,131	600	1.89
Warehouse Operation	325	86	411	600	0.69
Materials					21.10*
Total					38.92
Concrete Tie					
Removal and Installation	1,672	177	1,849	12	154.08
Distribution	1,045	86	1,131	200	5.66
Warehouse Operation	325	86	411	200	2.06
Materials					46,00
Total					207.80

*Average price of standard and third rail ties

TABLE A-16. LABOR AND EQUIPMENT COSTS FOR SPOT SURFACING AND LINING

Item	Type	Quantity	Cost per Shift, $
Labor			615
	Foreman	1	
	Machine Operator	1	
	Trackman	1	
	Flagman	2	
Equipment			130
	Tamper - Switch	1	

TABLE A-17. SPOT SURFACING AND LINING COST

Track Type	Cost per Shift, $			Production per Shift, ft	Cost per Mile, $
	Labor	Equip-ment	Total		
Wood Tie	615	130	745	2,750	1,430
Concrete Tie	615	130	745	3,438	1,144

TABLE A-18. LABOR AND EQUIPMENT COSTS FOR LINING AND SURFACING

Track Type and Item	Type	Quantity	Cost per Shift, $
Wood and Concrete Tie			
Labor			940
	Foreman	1	
	Machine Operator	2	
	Trackman	3	
	Flagman	2	
Equipment			235
	Tamper - Switch	1	
	Ballast Regulator	1	
Concrete Slab			
Labor			832
	Foreman	1	
	Machine Operator	2	
	Trackman	2	
	Flagman	2	
Equipment			10
	Track Wrench	2	

TABLE A-19. MATERIAL COSTS FOR LINING AND SURFACING

Track Type	Materials	Quantity per Track-Mile	Unit Price, $	Cost/Track-Mile, $
Wood Tie	Ballast	465 cu yd	11.76*	5,468
Concrete Tie	Ballast	487 cu yd	11.76*	5,727
Concrete Slab	Shims	1,056	0.20	211

*Price includes $1.06 per cu yd for distribution.

TABLE A-20. LINING AND SURFACING COST

Track Type	Cost per Shift, $			Production per Shift, ft	Cost per Mile, $
	Labor	Equipment	Total		
Wood Tie					
Labor and Equipment	940	235	1,175	2,475	2,507
Materials					5,468
Total					7,975
Concrete Tie					
Labor and Equipment	940	235	1,175	3,094	2,005
Materials					5,727
Total					7,732
Concrete Slab					
Labor and Equipment	832	10	842	1,056	4,210
Materials					211
Total					4,421

TABLE A-21. LABOR AND EQUIPMENT COSTS FOR RAIL REPLACEMENT

Operation and Track Type	Type	Quantity	Cost per Shift, $
Rail Replacement - Wood Tie			
Labor			2,252
	Foreman	1	
	Machine Operator	8	
	Trackman	8	
	Flagman	2	
	Welder	1	
Equipment			235
	Spike Puller	2	
	Push Car	2	
	Rail Threader	1	
	Crane	1	
	Gaging Machine	1	
	Spike Driver	2	
	Anchor Applicator	1	
	Air Compressor	1	
Rail Replacement - Concrete Tie and Slab			
Labor			1,596
	Foremen	1	
	Machine Operator	4	
	Trackman	6	
	Flagman	2	
	Welder	1	
Equipment			144
	Clip Remover/ Inserter	1	
	Push Cart	3	
	Crane	1	
	Rail Threader	1	
Distribution and Collection of Mate-rials - All Track Type			
Labor			830
	Foreman	1	
	Machine Operator	1	
	Trackman	3	
	Flagman	2	
Equipment			86
	Crane	1	
	Gondola	2	

*Costs for rail stressing, welding, loading, and unloading are not included.

TABLE A-22. MATERIAL COSTS FOR RAIL REPLACEMENT

Track Type	Materials	Quantity per Track-Mile	Unit Price, $	Cost/Track-Mile*, $
Wood Tie				4,615
	Spikes	15,840	0.25	
	Tie Plugs	2,640	0.05	
	Anchors	581	0.90	
Concrete Tie				5,821
	Pads	4,224	0.55	
	Insulators	8,448	0.25	
	Clips	845	1.64	
Concrete Slab				5,821
	Pads	4,224	0.55	
	Insulators	8,448	0.25	
	Clips	845	1.64	

*Cost of new rails is not included.

TABLE A-23. RAIL REPLACEMENT COST

Track Type	Cost per Shift, $			Production per Shift, ft	Cost per Mile, $
	Labor	Equip-ment	Total		
Wood Tie					
Rail Replacement	2,252	235	2,487	1,395	9,413
Distribution and Collection of Materials	830	86	916	7,920	611
Materials					4,615
Total					14,639
Concrete Tie					
Rail Replacement	1,596	144	1,740	1,860	4,939
Distribution and Collection of Materials	830	86	916	10,560	458
Materials					5,821
Total					11,218
Concrete Slab					
Rail Replacement	1,596	144	1,740	1,860	4,939
Distribution and Collection of Materials	830	86	916	13,200	366
Materials					5,821
Total					11,126

*Costs for rails, rail stressing, welding, loading, and unloading are not included. They are assumed equal for all track alternatives.

TABLE A-24. REGAGING COST

Item	Type	Quantity	Cost per Shift, $	Production per Shift	Cost per Mile, $
Labor and Equipment			1,129	0.5 mile	2,258
Labor			1,047		
	Foreman	1			
	Machine Operator	2			
	Trackman	4			
	Flagman	2			
Equiment			82		
	Spike Puller	1			
	Gaging Machine	1			
	Spike Driver	2			
	Air Compressor	1			
Materials					4,092
	Spikes	15,840			
	Tie Plugs	2,640			
Total					6,350

TABLE A-25. FASTENING COMPONENTS REPLACEMENT COST

Item	Type	Quantity	Cost per Shift, $	Production per Shift	Cost per Mile, $
Labor and Equipment			1,103	675 ft	8,628
Labor			1,047		
	Foreman	1			
	Machine Operator	2			
	Trackman	4			
	Flagman	2			
Equipment			56		
	Clip applicator/ Remover	1			
	Rail Lifter	1			
	Pust Cart	1			
Materials					4,990
	Clips	338			
	Insulators	8,448			
	Pads	4,224			
Total					13,618

TABLE A-26. TRACK INSPECTION COST

Item	Track Type		
	Wood Tie	Concrete Tie	Slab Track
Labor Cost per Shift,* $	215	215	215
Production per Shift, mile	6.0	6.0	7.5
Inspection Cost per Mile, $	35.83	35,83	28.67
Weekly Cost per Mile,** $	71.66	71.66	57.34
Annual Cost per Mile,** $	3,726	3,726	2,982

*Based on 2 trackmen per shift
**Based on 2 inspections per week

TABLE A-27. MAINTENANCE EQUIPMENT COST

Year Needed	Cost,* $				
	New System Construction			Extension on an Existing System	
	Wood Tie Track	Concrete Tie Track	Concrete Slab Track	Wood Tie Track**	Concrete Tie Track**
0	702,100	659,300	291,200	54,800	6,800
13	512,100	469,300	101,200	54,800	6,800
26	702,100	659,300	291,200	54,800	6,800
39	512,100	469,300	101,200	54,800	6,800

*Based on a 26-year life for crane and 13-year service life or obsolescence for other equipment
**Type of existing track

TABLE A-28. PRESENT WORTH OF MAINTENANCE COSTS

Escalation Rate, %	Track Type	Present Worth, $1,000/mile				
		Discount Rate, %				
		6	8	10	12	14
6	Wood Tie	440	273	181	128	95
	Concrete Tie	331	213	147	108	83
	Concrete Slab	184	117	80	58	44
8	Wood Tie	750	440	275	184	130
	Concrete Tie	548	331	215	149	109
	Concrete Slab	306	184	118	81	59
10	Wood Tie	1,330	742	440	278	186
	Concrete Tie	954	543	331	216	151
	Concrete Slab	534	303	184	119	82
12	Wood Tie	2,438	1,301	735	440	280
	Concrete Tie	1,734	934	537	331	218
	Concrete Slab	969	523	301	184	120
14	Wood Tie	4,585	2,356	1,274	728	440
	Concrete Tie	3,258	1,676	915	533	331
	Concrete Slab	1,811	936	512	298	184

TABLE A-29. PRESENT WORTH OF MAINTENANCE EQUIPMENT FOR A NEW TRANSIT SYSTEM

Escalation Rate, %	Track Type	Present Worth, $1,000				
		Discount Rate, %				
		6	8	10	12	14
6	Wood Tie	2,428	1,783	1,407	1,180	1,037
	Concrete Tie	2,257	1,659	1,312	1,101	968
	Concrete Slab	785	598	489	422	380
8	Wood Tie	3,558	2,428	1,792	1,418	1,190
	Concrete Tie	3,302	2,257	1,668	1,322	1,110
	Concrete Slab	1,103	785	601	492	425
10	Wood Tie	5,542	3,531	2,428	1,800	1,429
	Concrete Tie	5,136	3,277	2,257	1,676	1,331
	Concrete Slab	1,647	1,096	785	604	495
12	Wood Tie	9,073	5,446	3,505	2,428	1,809
	Concrete Tie	8,397	5,048	3,253	2,257	1,684
	Concrete Slab	2,583	1,621	1,089	785	606
14	Wood Tie	15,420	8,818	5,356	3,480	2,428
	Concrete Tie	14,253	8,161	4,965	3,230	2,257
	Concrete Slab	4,211	2,517	1,597	1,082	785

TABLE A-30. PRESENT WORTH OF ADDITIONAL MAINTENANCE EQUIPMENT FOR EXTENDING BALLASTED TRACK WITH CONCRETE SLAB TRACK

Escalation Rate, %	Existing Track Type	Present Worth, $1,000				
		Discount Rate, %				
		6	8	10	12	14
6	Wood Tie	219	158	122	101	88
	Concrete Tie	27	20	15	13	11
8	Wood Tie	327	219	159	124	102
	Concrete Tie	41	27	20	15	13
10	Wood Tie	519	325	219	160	125
	Concrete Tie	64	40	27	20	15
12	Wood Tie	865	510	322	219	160
	Concrete Tie	107	63	40	27	20
14	Wood Tie	1,495	840	501	320	219
	Concrete Tie	186	104	62	40	27

TABLE A-31. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND WOOD TIE TRACKS FOR NEW CONSTRUCTION

Escalation Rate, %	Track Length, mile	Difference in Present Worth,* $1,000/mile				
		Discount Rate, %				
		6	8	10	12	14
6	2.0	-617	-287	-99	+12	+81
	5.0	-140	+52	+159	+223	+262
	20.0	+55	+178	+246	+285	+309
	50.0	+104	+213	+273	+308	+329
	100.0	+121	+225	+282	+316	+336
8	2.0	-1,210	-617	-292	-105	+7
	5.0	-490	-140	+49	+156	+220
	20.0	-173	+55	+176	+244	+284
	50.0	-99	+104	+212	+272	+307
	100.0	-75	+121	+224	+281	+314
10	2.0	-2,282	-1,195	-617	-296	-110
	5.0	-1,130	-481	-140	+46	+153
	20.0	-597	-167	+55	+175	+242
	50.0	-481	-94	+104	+210	+270
	100.0	-442	-70	+121	+222	+279
12	2.0	-4,254	-2,230	-1,182	-617	-300
	5.0	-2,323	-1,099	-473	-140	+43
	20.0	-1,401	-576	-162	+55	+173
	50.0	-1,206	-462	-89	+104	+209
	100.0	-1,142	-423	-65	+121	+221
14	2.0	-7,917	-4,109	-2,181	-1,168	-617
	5.0	-4,571	-2,235	-1,069	-465	-140
	20.0	-2,941	-1,342	-557	-157	+55
	50.0	-2,604	-1,153	-444	-85	+104
	100.0	-2,492	-1,090	-406	-61	+121

*(-) and (+) indicate lower and higher costs for concrete slab track, respectively.

TABLE A-32. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND CONCRETE TIE TRACKS FOR NEW CONSTRUCTION

Escalation Rate, %	Track Length, Length, mile	Difference in Present Worth,* $1,000/mile				
		Discount Rate, %				
		6	8	10	12	14
6	2.0	-454	-197	-49	+40	+96
	5.0	-28	+105	+181	+227	+256
	20.0	+141	+213	+254	+278	+293
	50.0	+185	+245	+274	+298	+311
	100.0	+200	+255	+287	+305	+317
8	2.0	-911	-454	-262	-53	+36
	5.0	-268	-28	+79	+179	+225
	20.0	+10	+141	+206	+252	+277
	50.0	+76	+185	+242	+277	+297
	100.0	+98	+200	+253	+286	+304
10	2.0	-1,735	-900	-454	-204	-57
	5.0	-705	-262	-28	+102	+177
	20.0	-233	+23	+141	+211	+251
	50.0	-128	+79	+185	+243	+276
	100.0	-93	+101	+200	+254	+285
12	2.0	-3,243	-1,695	-890	-454	-207
	5.0	-1,516	-684	-257	-28	+100
	20.0	-696	-221	+17	+141	+210
	50.0	-520	-118	+81	+185	+242
	100.0	-462	-84	+103	+200	+253
14	2.0	-6,038	-3,133	-1,657	-880	-454
	5.0	-3,042	-1,456	-663	-252	-28
	20.0	-1,587	-660	-210	+19	+141
	50.0	-1,286	-491	-109	+84	+185
	100.0	-1,185	-435	-75	+105	+200

*(-) and (+) indicate lower and higher costs for concrete slab track, respectively.

TABLE A-33. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND WOOD TIE TRACKS FOR EXTENDING A WOOD TIE TRACK

Escalation Rate, %	Extension Length, mile	Difference in Present Worth,* $1,000/mile				
		Discount Rate, %				
		6	8	10	12	14
6	2.0	+314	+384	+421	+442	+454
	5.0	+232	+320	+368	+395	+411
	10.0	+210	+304	+355	+385	+402
	20.0	+148	+245	+298	+328	+347
8	2.0	+181	+314	+383	+420	+441
	5.0	+65	+232	+319	+366	+394
	10.0	+34	+210	+303	+354	+383
	20.0	-34	+148	+244	+298	+327
10	2.0	-75	+185	+314	+382	+419
	5.0	-247	+71	+232	+319	+365
	10.0	-299	+38	+210	+302	+353
	20.0	-377	-29	+148	+242	+295
12	2.0	-576	-62	+188	+314	+381
	5.0	-852	-232	+75	+232	+317
	10.0	-939	-285	+42	+210	+300
	20.0	-1,033	-360	-25	+148	+241
14	2.0	-1,565	-539	-50	+191	+314
	5.0	-2,030	-807	-217	+78	+232
	10.0	-2,179	-891	-267	+46	+210
	20.0	-2,305	-984	-344	-21	+148

*(-) and (+) indicate lower and higher costs for concrete slab track, respectively.

TABLE A-34. DIFFERENCE IN PRESENT WORTH BETWEEN CONCRETE SLAB AND CONCRETE TIE TRACKS FOR EXTENDING A CONCRETE TIE TRACK

Escalation Rate, %	Extension Length, mile	Difference in Present Worth,* $1,000/mile				
		Discount Rate, %				
		6	8	10	12	14
6	2.0	+296	+344	+370	+386	+396
	5.0	+272	+321	+249	+366	+376
	10.0	+269	+319	+348	+364	+375
	20.0	+216	+267	+296	+313	+323
8	2.0	+208	+296	+343	+368	+387
	5.0	+180	+272	+321	+347	+366
	10.0	+176	+269	+319	+346	+364
	20.0	+122	+216	+266	+293	+312
10	2.0	+42	+210	+296	+342	+369
	5.0	+6	+182	+272	+320	+348
	10.0	-1	+178	+269	+318	+346
	20.0	-55	+125	+216	+266	+294
12	2.0	-283	+50	+212	+296	+341
	5.0	-331	+24	+184	+272	+319
	10.0	-342	+8	+180	+269	+317
	20.0	-399	-46	+126	+216	+265
14	2.0	-924	-258	+58	+214	+296
	5.0	-996	-306	+23	+186	+272
	10.0	-1,015	-317	+16	+182	+269
	20.0	-1,076	-373	-38	+129	+216

*(-) and (+) indicate lower and higher costs for concrete slab track, respectively.

APPENDIX B - REPORT OF NEW TECHNOLOGY

This report presents a review of concrete slab track technology for at-grade construction. Also, it compares the technical and economic features of concrete slab track to those of ballasted track. A careful review of the work performed under this contract indicates that no discoveries or inventions have been made. However, the work provides useful information on concrete slab track designs, performance, and economics. This information will be used in further evaluation and development of concrete slab track systems for at-grade rapid transit track.

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