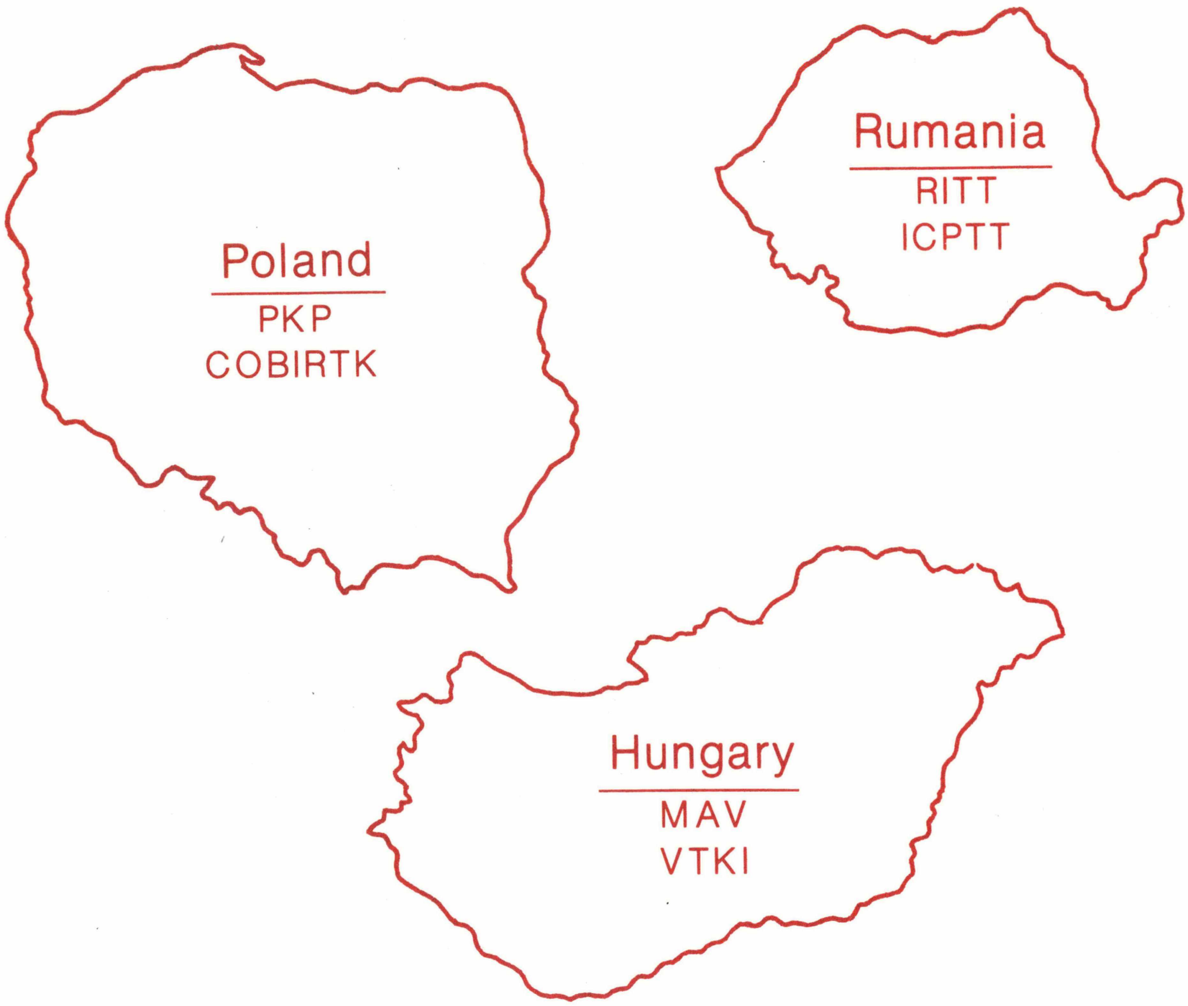
U.S. Department
of Transportation
Federal Railroad Administration

Eastern European Track Structure Technology & Research



Office of Research
and Development
Washington, D.C. 20590

FRA/ORD-81/58

Final Report

JULY 1981

A.T. Kearney, Inc.

NOTICE

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/ORD-81-58		
4. Title and Subtitle Eastern European Track Structure Technology and Research		5. Report Date July 81
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address A. T. Kearney, Inc. 699 Prince Street Alexandria, Virginia 22313		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-FR-9051
12. Sponsoring Agency Name and Address Office of Rail Safety Research Federal Railroad Administration 400 Seventh Street, S.W. Washington, D.C. 20590		13. Type of Report and Period Covered
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

Cooperative agreements between the United States and the Eastern European countries of Poland, Hungary and Rumania provide for the exchange of technical research and operational railroad information. To obtain on site, as well as published information on topics of specific interest to the Federal Railroad administration (FRA), a United States delegation visited the railroad research laboratories, spoke with railroad experts, and explored the railroad operational systems of these three countries. The agenda was scheduled to include railroad practices on which the countries were conducting extensive research or possessed researchers renowned in the field. Initial evaluation of the numerous reports and observations resulting from this trip revealed that the information obtained was of interest not only to the FRA, but the U.S. railroad industry. Therefore a review was made of all reports and the material segregated into major technical topics so that the resulting report would be useful to the railroad industry. Five major topics are discussed: Descriptions of Railroad Systems and Research Programs, Ballast Research, Lateral Resistance, Buckling of Track, and Tie practices are presented, followed by the current U.S. practices. In addition, descriptions of Rumanian railroad research outside the scope of the prior chapters and the Polish and United States cooperative agreement are described briefly.

17. Key Words		18. Distribution Statement
Track Structure Ballast Lateral Resistance Eastern European	Ties Rail Fasteners Track Buckling	This document is available to the U.S. Public through National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

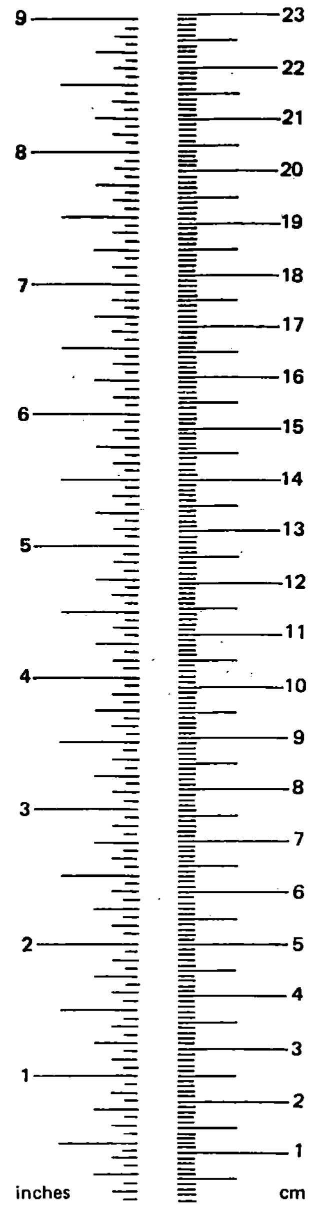
Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

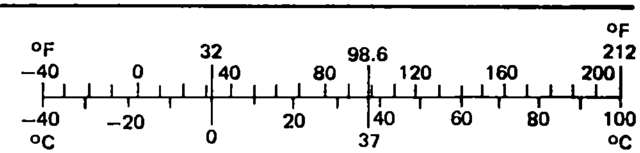
Symbol	When You Know	Multiply by	To Find	Symbol
LENGTH				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



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	36	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



EXECUTIVE SUMMARY

INTRODUCTION

Cooperative agreements between the United States and the Eastern European countries of Poland, Hungary and Rumania provide for the exchange of technical research and operational railroad information. To obtain on site as well as published information on topics of specific interest to the Federal Railroad Administration (FRA), a U.S. delegation consisting of Mr. Philip Olekszyk of the FRA, Mr. Andrew Sluz and Dr. Andrew Kish of the Transportation System Center (TSC), visited the railroad research laboratories, held discussions with railroad experts, and explored the railroad operational systems of these three countries in April, 1979. The numerous reports and observations resulting from this trip were reviewed and a single report, organized by technical subject, was prepared. The Eastern European practices, however, represented only one view of the rail technology issues. Therefore, United States railway practices have been included for each of the major topic areas, and comparisons and contrasts were drawn between Eastern European and U.S. practices.

The report is organized by technical subject. Within each chapter, the observed Eastern European positions are presented, followed by the current U.S. railroad practices.

A total of five major topics are covered as follows:

1. Description of Railroad Systems and Research Programs (Chapter 2)
2. Ballast Research (Chapter 3)
3. Lateral Resistance (Chapter 4)
4. Buckling of Track (Chapter 5)
5. Tie Research and Rail Fasteners (Chapter 6)

In addition, descriptions of Rumanian railroad research outside the scope of the prior chapters and the Polish and United States cooperative agreement are described briefly in Chapters 7 and 8.

RESULTS

Railroad systems and research organizations in each of the three Eastern European countries are centralized, government run agencies, with system mileage comparable to a U.S. Class I railroad.* Maximum allowable axle loading are generally lighter than for some U.S. railroads, although the Polish National Railroad (PKP) allows 30.25 ton/axle loads, the highest allowable loadings in Europe. Traffic volumes are heavy, with the 9,300 mile Hungarian National Railroad (MAV) system carrying 154 MGT per year, and the 14,800 mile Polish PKP system carrying 500 MGT per year. Rail weights on Eastern European railroads are generally lighter than in the United States. The MAV system in Hungary uses rail weighing between 97-109 lb/yd; whereas, the Rumanian railroad is replacing its typical 99 lb/yd rail with 121-131 lb/yd rail. The PKP Railroad system of Poland uses rail of 121 lb/yd weight on most mainline tracks. Concrete ties are extensively used in all three Eastern European countries, and rigid K-type fasteners predominate on all three Eastern European systems.

Research facilities and programs in each country visited are extensive. Rumania maintains a vehicle performance test track and Poland maintains a complete laboratory complex; whereas Hungary considers its entire rail system a research facility and emphasizes track performance research.

The Hungarian Railroad Scientific Research Institute (VTKI), has conducted extensive studies of ballast gradation, ballast density and fouling, ballast cleaning, filter fabric application and related research. The VTKI has developed a specification for a uniform gradation ballast of finer particle sizes than normally used in the U.S. under concrete ties. This gradation has not been judged acceptable by other European railroads and would probably not be accepted in the U.S. because of the potential for early fouling. Hungary has developed a nuclear density measuring device which provides accurate measurements of ballast density through the use of a cobalt probe inserted into the ballast. In contrast, a device based on a water replacement concept has been developed in the United States at the State University of New York at Buffalo. Although the U.S. device is less convenient to use, the measurements are presumed to be more accurate since the ballast is not disturbed as much as by the Hungarian apparatus. The results of the Hungarian method, however, have been used to program ballast undercutting operations based on the level of ballast fouling.

---

*Class I: Carriers having annual carrier operating revenues of $50 million or more.

Ballast undercutting operations in the Eastern European countries are similar to U.S. operations except that vibratory compaction is often used as a final step in the track maintenance process. Filter fabric application during undercutting has been performed in both Hungary and Rumania, but has not been used extensively because of the high cost of the material.

Hungary has conducted extensive research on lateral resistance, including thousands of track panel pull tests, to examine the effects of tamping, vibratory compaction, shoulder construction, and tie shape on resistance to lateral movements. Test results determined that neither tamping nor compaction restored the lateral resistance of unconsolidated ballast to the level which existed in the undisturbed ballast. Although machine tamping achieved improved ballast consolidation over hand tamping or no tamping, machine tamping did not provide sufficient resistance to insure against lateral track movement. However, vibratory compaction is most effective in restoring a sufficient degree of lateral resistance to ballast (which has been distributed by maintenance) to prevent buckling and allow traffic to move without slow orders over continuously welded rail. Research in the U.S. has indicated that the beneficial effects of compaction are short-lived, as adequate levels of lateral resistance are achieved on recently maintained tracks after a moderate amount of train traffic.

Poland uses compaction only where the danger of buckling exists. Reseachers in Poland have found preliminary evidence indicating that vibratory compaction reduces overall track settlement, but increases differential settlement. Vibratory compaction is not used extensively in the U.S., except on the Northeast corridor. Tamping does not restore lateral resistance to the level required to prevent the buckling of continusouly welded rail. Consequently, slow orders are often imposed over CWR stations until adequate compaction is achieved. Hungary's VTKI found that machine tamping was significantly more effective than hand tamping or no tamping in restoring some degree of lateral strength.

The VTKI has experimented extensively with varying shoulder sections including upward sloping and level shoulders of several widths. From these experiments, the VTKI has concluded that shoulders with a 1:5 upward slope provide increased lateral stability as long as the cribs between ties remain filled with ballast. VTKI, PKP and U.S. researchers at FAST have determined that 12-14 inch shoulders provide the optimal lateral resistance benefit, and that wider shoulders seem not to provide significant increases in lateral strength.

The Hungarian VTKI has also analyzed the effects of concrete tie design on lateral resistance, finding that concrete ties with reduced center sections and bottom indentations provided significant increases in lateral track resistance. Concrete ties were judged far superior to wood ties in providing lateral resistance as a result of their heavier weight.

The VTKI has also performed extensive research on track buckling. Initially, destructive testing was utilized; however since 1967, a non-destructive test has been used which stresses the track to the "onset of buckling" an increment just beyond the elastic limit. The rail is heated using a metal induction heated element welded to the web of the rail. U.S. researchers contend that this heating system effectively changes the cross section of the rail, and have thus developed a direct current heating method. Buckling tests on U.S. railroads have only recently begun, with an initial effort to design a test methodology and develop the heating system. The VTKI uses the pure empirical data obtained from buckling tests to dictate buckling safety standards and specify the temperature ranges for CWR installation and maintenance. The FRA, in contrast, is planning to use a more analytical approach with a limited number of destructive buckling tests.

The VTKI test results are used by the MAV rail system to closely control CWR installation and maintenance temperatures. During the past five years, no track buckling incidents have occurred on the MAV system. However, during the previous five years, nine incidents occurred with seven attributable to maintenance tamping when rail temperatures were higher than the allowable limit. In contrast, over 100 buckling related derailments occurred in the U.S. during 1980. The AREA and VTKI rail installation temperatures ranges differ significantly. VTKI researches also determined that loosened fasteners, misalignments, and track curvature strongly influence the loss of stability via buckling.

Concrete ties are used extensively in Poland, Hungary and other European countries primarily because of a general shortage of timber on the European continent. In the U.S. however, concrete tie use is currently limited to the Northeast corridor, the Florida East Coast Railroad, Kansas City Southern, Seaboard Coast Line, and test installations on several other railroads. Concrete ties have demonstrated a longer service life and better performance than wood ties in both the U.S. and Europe; however, problems with fastening system designs substantially impact the overall system service life and maintenance requirements. Specifically, failure of concrete tie systems in both the U.S. and Europe is due primarily to plate slippage and fastener breakage.

Both Poland and Hungary have conducted research on tie and fastener systems. Dual-block tie systems have been tested in Poland and Hungary, with the conclusion that the system is not useful under normal railroad operating conditions. Dual-blocks were found to provide less lateral resistance than mono-block ties and the connecting metal is expensive and scarce in Eastern Europe. The U.S. and Poland are pursuing a rail fastener testing program as well as tie renewal research program under a cooperative agreement. The fastener testing program will include static load, longitudinal creep, rail rollover resistance, and tie insert resistance tests on K-type, Omega and Pandrol fastener systems.

The tie renewal research program will examine the factors which affect wood tie service life and predict the need for renewal as a function of these factors. Poly-impregnated tie inserts have been researched by the Polish Central Agency for Research and Development of Railroad Technology (COBiRTK) to determine their value in extending wood tie service life by preventing plate cutting. The inserts have performed well. The higher cost of poly-impregnated tie insert systems, as well as other modified wood tie systems which have been tested in the U.S., focuses attention on the requirement for improved performance of such systems over conventional systems. To date, such improved performance has not been demonstrated.

The rail research emphasis of Rumania's Institute for Research and Technology Design for Transportation (ICPTT) is on vehicle and mechanical component acceptance testing. Wear and performance studies have been conducted on brake shoes with varying phosphorous contents designed to reduce brake shoe wear. Unfortunately, wheel rim wear increased proportionally to the decrease in brake shoe wear, resulting in the conclusion that high phosphorous brakeshoes were not cost effective. Rumania has also developed and tested a bi-level passenger car and car recognition and optical Automatic Car Identification (ACI) scanning systems.

EASTERN EUROPEAN TRACK STRUCTURE
TECHNOLOGY AND RESEARCH

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

ILLUSTRATIONS

TABLE OF CONTENTS (CONT'D)

TABLES

TABLE OF CONTENTS (CONT'D)

PHOTOGRAPHS

TABLE OF CONTENTS (CONT'D)

PHOTOGRAPHS (CONT'D)

ABBREVIATIONS

CoBiRTK (Poland)	Central Agency for Research and Development of Railroad Technology (Centralnyo Ośrodka Badańi Rozwoju Techniki Kolejniotwa)
ICPTT (Rumania)	Institute for Research and Technology Design for Transportation (Institutul De Cercetari Si Proilctari Tehnologice in Transporturi)
MAV (Hungary)	Hungarian Railroad System (Magyar Állami Vasut)
ORE	Office of Research and Testing (Office De Recherches et D'Essais)
OSZD	Eastern European Equivalent of ORE
PKP (Poland)	Polish National Railroad (Polskie Koleje Państwowe)
RITT (Rumania)	Rumanian Institute of Transportation and Telecommunications (Institutul de Transporturilor Si Telecomunicatiilor din Republica Socialista Romania)
UIC	International Union of Railroads (Union Internationale de Chemis de Fer)
VTKI (Hungary)	Railroad Scientific Research Institute (Vasuti Tudomańyos Kutató Intézet)

CHAPTER 1
INTRODUCTION

BACKGROUND

Cooperative agreements between the United States and the Eastern European countries of Poland, Hungary and Rumania provide for the exchange of technical research and operational railroad information. To obtain on site as well as published information on topics of specific interest to the Federal Railroad Administration (FRA), a United States delegation visited the railroad research laboratories, spoke with railroad experts, and explored the railroad operational systems of these three countries. This delegation, comprised of Mr. Philip Olekszyk (Federal Railroad Administration), and Mr. Andrew Sluz and Dr. Andrew Kish (Transportation System Center) visited these countries between April 8 and April 25, 1979. The agenda was scheduled to include railroad practices on which the countries were conducting extensive research or possessed researchers renowned in the field. However, some countries established the agenda and the flexibility to explore other facilities or discuss additional topics was limited. Therefore, the information collected and the insights gained varied both in substance and depth by country.

Initial evaluation of the numerous reports and observations resulting from this trip revealed that the information obtained was of interest not only to FRA but to the U.S. railroad industry.

OBJECTIVE

Realizing the value of the accumulated data, FRA contracted to have prepared a technical report useful to the railroad industry. Preparation of a separate report was necessary since most of the material was written in chronological order by each of the three delegates and for each of the three countries. Thus, U.S. railroad experts would be required to read all nine reports to extract information on their topic of interest. Therefore, a review was made of all reports, the material was segregated into major technical topics, issues clarified and additional information obtained to provide effective presentation and convenient access to the material.

Presentation of the Eastern European practices, however, represents only one view of rail technology issues. Therefore, Unites States railway practices are described for each of the major technology issues, and comparisons and contrasts are drawn between the presented information. To accomplish this second objective, the project team reviewed existing railroad literature, including where applicable, the American Railway Engineering Association Manual, and interviewed FRA and TSC research personnel with known expertise in each technical area. The appendix to this report contains a list of the individuals interviewed and a bibliography of materials reviewed.

REPORT ORGANIZATION

The chapters of this report have been organized by technical subjects, first presenting the Eastern European practices followed by current U.S. railroad practices. Chapters 7 and 8 describe only the Eastern European side.

Chapter 2 - Description of Railroad Systems and Research Programs

Chapter 3 - Ballast Research

Chapter 4 - Lateral Resistance

Chapter 5 - Buckling of Track

Chapter 6 - Tie Research and Rail Fasteners

Chapter 7 - Miscellaneous Rumanian Railroad Research

Chapter 8 - Polish and United States Cooperative Agreement

Chapter 7, Miscellaneous Rumania Railroad Research, presents information which is in addition to the major topics discussed in the prior chapters. Due to the variety and brevity of these topics, no discussion of U.S. research is provided. Chapter 8 briefly discusses the tie and fastener research being conducted specifically under the Polish and U.S. Cooperative Agreement.

CHAPTER 2
DESCRIPTION OF RAILROAD SYSTEMS AND RESEARCH PROGRAMS

SECTION A: EASTERN EUROPE

THE HUNGARIAN RAILROAD SYSTEM

(a) System Description

The Hungarian Railway System (MAV) is divided into six operating directorates by location. Those facets of the railroad that are system wide are controlled by additional directorates. For example, Dr. Telek, a trip host in Hungary, is the Director in charge of Section II, responsible for all construction and maintenance of track. The track construction and maintenance section includes 36 regional divisions. Each of these divisions has three tiers: bridges, construction, and maintenance. These three tiers are subdivided into further responsibilities. For example, the construction tier has 9 segments consisting of 6 track, 1 bridge, 1 high elevated structures and 1 tooling and machine production segment. The overall system is supported by 3 large factories supplying switches and components, general tooling and fabrication, and heavy equipment and machinery.

(b) Track Structure

The Hungarian system is comprised of a 15,000 km (9300 mile) railway line containing approximately 17,000 switches operated on a combined freight and passenger mode of traffic. Of this length, 8,000 km (4960 miles) is single track, and 7,000 km (4340 miles) is double.

Freight traffic volume is heavy with the system carrying 140 million gross metric tons (154 million tons) annually. This figure equals the combined tonnage of the Italian, Swiss and Austrian Railroads.

Two types of track superstructure are currently in use: mainlines are constructed of 48 kg/m (96.88 lb./yd.) and 54 kg/m (108.99 lb./yd.). All new construction is strictly 54 kg/m rail. Some secondary lines are still operating on 23 or 34 kg/m (46 lb./yd. or 68 lb./yd.) which was scheduled to be replaced by 1980. Overall 90 percent of the track is standard European gage, while the remaining 10 percent of the track is the wider Soviet gage (1535 mm).

Maximum speed is currently 100 km/hr (62 mi/hr.) although 120 km/hr (74.4 mi/hr.) is allowed over some recently constructed track. These speeds are low compared to U.S. standards. Design speed (i.e., horizontal and vertical alignment), however, is 140 - 160 km/hr (86.8 - 99.2 mi/hr.). All high speed tracks are constructed using continuously welded rail (CWR) and concrete ties are used in all new construction.

German K-type fasteners are used most frequently, although three years ago experiments with the new German elastic SK-2 and SK-3 were undertaken. Testing is still continuing and final results are not available. Photographs of these fastening systems are provided at the end of the chapter (see photographs 2-1, 2-2, 2-3 and 2-4).

Railroad personnel estimate the current percentage of CWR and concrete tie track in service at 25 percent and 60 percent, respectively. Railroad officials have found that concrete ties have durability and performance advantages over wood ties. Concrete ties are designed for an axle loading capacity of 21 metric tons (23 tons). However, the primary decision criteria for adopting a concrete tie replacement program was economic, since hardwood timber is scarce in Hungary resulting in high prices for wood ties.

Given the fairly extensive use of a concrete tie track structure, the following information was provided:

1. Rail corrugation was not in evidence on main line track. However, there was some evidence of corrugation on transit track.

2. No difference was found in rail wear on concrete ties versus rail wear on wood ties. Reported wear rate is 1 mm. (.04 in.) in 10 million metric tons (11 million tons) of traffic.

3. Ballast size is smaller for concrete 20/40*mm (.75 / 1.5 in.) compared to 20/60 mm (.75/2.5 in.) which is used for wood.

Track maintenance is referred to as "large machinery maintenance" since it is performed using automatic line, lift/tamper, compactor, and ballast distributor. Track construction is accomplished using two methods: 1) A two step system using Soviet built "Platov" cranes and portal cranes on special rail guideways; 2) A one step system using Track Laying System (TLS) unit.

---

* 20/40 is the inclusive range, in mm, of the ballast particles.

(c) Research Organization

The Railway Scientific Research Institute (VTKI) in Budapest conducts most of the railway transportation research for MAV. The institute, established in 1951, is currently under the direction of Dr. Jozsef Nagy. In this position, Dr. Nagy is responsible for the operation of the Institute's nine divisions including Fixed Installations (track, bridges, etc.), Rolling Stock, Traffic Control Technology, Railway Economics, Management and Technical and Administrative Support Services. The institute is supported by a total staff of about 200. VTKI conducts collobrative research with UIC/ORE and most European railway research institutes.

Although the VTKI conducts a broad spectrum of research, the institute's studies most relevant to U. S. Railroad practices are in the areas of: track stability and buckling test investigations, track lateral resistance, ballast research and related maintenance practices, and tie/fastener research. These topics are discussed in greater detail in subsequent chapters of this report.

Since the 1950's the Railway Research Institute on track has pursued extensive investigative programs on track lateral stability. Thousands of track lateral characteristics measurements and hundreds of buckling tests have been performed under both static and dynamic conditions. Despite this program, Dr. Nagy anticipates that increasing speeds, loads and traffic volumes will require that even greater emphasis be placed on track stability research and related ballast research. Hungary has considered eliminating ballasted track in favor of slab track. However, economic feasibility is an important variable. Therefore, slab track research has not been actively pursued since the initial costs involved are 4-5 times that of conventional track and limited economic data is available on long term performance. Instead, research efforts have continued to be focused on improving track lateral stability characteristics.

The major results of the Institute's research are documented annually in the "Hungarian Railroad Scientific Research Institute Yearbook"*. The yearly publications are in Hungarian with English, Russian, German and French summaries.

---

* See Bibliography, Appendix.

(d) Track Buckling Test Facility

The Hungarian test facility is located near Herceghalom (about 25km or 15.5 miles southwest of Budapest). Tests are conducted from May to August. The facility utilizes a section of the Budapest to Vienna line which was abandoned when a newly reconstructed (high speed) line was opened. The test track consists of 3 sections: (1) a 716m (780.4 yd.) long tangent section referred to as the "speed track" where vehicles are accelerated to the required speeds to be pushed through the actual test section, (2) the curve test section which is 525m or 572.2 yds. long (the curve adjustable section being 300 meters or 275 yds., (3) and a braking section where the accelerated vehicles for the dynamic tests are brought under control (this section has a .35% slope to assist in the braking). The acceleration and braking sections both employ wood ties at 77cm (30 in.) spacing with 48kg/m (96.81 lb./yd.) rail. The test sections use old design concrete ties with 60 kg/m (121.1 lb./yd.) rail, with 56cm (21.8 in.) tie spacing in the curves and 60cm (23.4 in.) spacing in the tangent section. Currently, GEO (K-type) fasteners are used. Pictures of the test facility are included at the end of Chapter 5.

Both static and dynamic tests are conducted on wood vs concrete ties, tangent vs curved track, with varying track conditions. The dynamic tests are conducted using 4 cars with 21 metric tons (23 ton) axle loads pushed by a locomotive. The consist travels at 50-60 km/hr (31-37 mph) over the electrically heated rail. Braking is triggered automatically at the end of the tangent test section. A diesel locomotive situated on an adjacent track generates the heat for the rail through heating elements welded to the rail web.

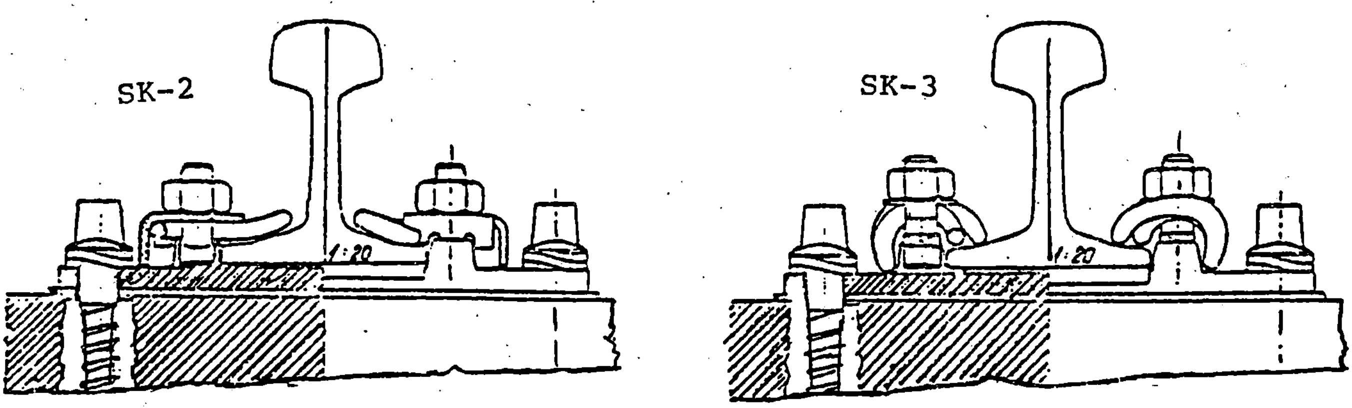
Through an intensive research program on track buckling, the Hungarians have developed detailed specifications for CWR. Installation procedures are necessitated by ambient temperatures which range from -30^{o} to $+40^{o}C$ (-22 to $+104^{o}F$). Under these ambient conditions, rail temperatures have been found to range from $-30^{o}C$ to $+60^{o}C$ (-22 to $+140^{o}F$). Rail is usually laid at $\pm 5^{o}C$ ($\pm$ $9^{o}F$) from the mean temperature of $15^{o}C$ ($59^{o}F$).

Projected buckling test schedules for the summer of 1979 called for the determination of the effects of track misalignment (but within standards) on lateral stability, on 350m. (approximately 5^{o}), 500m. (approximately 4^{o}) and 600 (approximately 3^{o}) radii curves with good and bad fastening conditions.

The test schedule for the summer of 1980 was to include buckling tests over a section containing a new type of tie - "UIC 54," which has indentures on the bottom. These indentures are in the shape of 70mm (2.8 in.) squares 10mm (.4 in.) deep. The new tie is 262 kilograms (576.4 lb.) and 2.55 m (8.36 ft.) in length. Standard tie weight is 242 kg. or 532.4 lb. The tie is constructed of pre-stressed concrete with 12 small diameter rods. Two new fastener systems, SK-2 and SK-3, illustrated in Figure 2-1 below was to be used in conjunction with the experimental ties. The test sequence was to conclude with a complete buckling out of the "bad" track under dynamic conditions (risking possible derailment of the test consist).

Figure 2-1

FASTENER SYSTEMS



THE POLISH
RAILROAD SYSTEM

(a) Track Structure

Poland's railroad system ranks with other European countries having highly developed railroad transport systems. The Polish railroad carries annually approximately 30% of all passenger traffic and 20% of all freight traffic. 25% of the railway system carries 75% of the traffic. The annual volume of freight traffic is approaching one half billion tons and steadily growing. The main freight traffic is bulk cargo transported over long distances. Shorthaul traffic and general cargo are carried primarily by road transport. The increasing role of freight traffic has required the expansion of the rail system, organizational changes and new technology research. The length of standard gage track now totals 24 thousand km (14.8 thousand miles) and the entire rail system has constantly been upgraded. The maximum allowable axle load is 27.5 metric tons (30.25 tons) with occasional overloads up to 10% allowed.

Improvements in the railroad system have included:

- Electrification of more than 6,000 km (3720 miles) of track
- Automation of rail traffic and wagon switching in classification yards
- Increasing shuttle service trains for freight movement
- Increasing the gross weight capacity for freight trains which is at present the largest in Europe
- Developing automatic couplers in cooperation with Rumania (ICPTT)

(b) Research Organization

In 1951 The Polish State Railroads (PKP) established The Railway Research Centre (COBiRTK) as the sole organization responsible for operational and technical railroad issues. The Railway Research Centre staff currently totals 1,000 members of which 450 have advanced degrees. At present, the Railroad Research Centre consists of 12 research departments and 2 independent divisions. Ten of the research departments form 2 major groups. The departments comprising the first group are responsible for upgrading and modification of railway operation methods, rational organization of traffic including customers service, and the use of electronic data processing for the purpose of freight transport control and management. The second group is involved primarily with the modernization and maintenance of rolling stock, track, and railroad signalling and telecommunications systems. Departments which assist the other groups comprise the third group. The scope of work for the third group includes developing prototype models, test rigs, instruments and other devices required by the research departments.

(c) Test Facility and Equipment

The Railway Research Centre site is located at Olszynka Grochowska, Warsaw. The Centre extends over approximately 10 hectares (24.7 acres), and buildings capacity is over 115 thousand cubic metres covering the usable floor area of 11,500 sq.m.

The COBiRTK, as part of Poland's committment to the Office of Research and Tests (ORE), has been testing several track sections and substructures on a full-scale out-door dynamic vertical load test facility. This facility consists of approximately 150 feet of track on grade and a rigid frame bridging the section. This frame serves as a reaction for two actuators that deliver approximately one maximum wheel loading (10T) at a low frequency. The objective of the test program is to simulate actual track loading and measure the settlement and deterioration of various track structures and ballast thicknesses. The practical applicability is directed at predicting the integrity of the rail, fastener, and tie system, rather than in evaluating overall track system performance because vertical loading cannot simulate a rolling load. However, details of the program were only sketchily presented by the Polish representatives.

The research centre possesses the test rigs and research equipment to conduct typical tests of rolling stocks, tracks, ballast and power transmission system. Included in the centre is a hump yard to test vehicle behavior at the moment of collision, toughness tests of the rolling stock, automatic coupling tests, shock absorbers for auto-couplers and other types of the rolling stock bumpers.

Tests for special programs can also be conducted using other specialized equipment and facilities:

- A climatic room used to conduct tests at the temperatures between -50°C (-58°F) to +100°C (212°F) and relative humidity between -10% and +95%

- An air washer designed for accelerating the ageing of materials including simulation of changeable climate conditions, extended exposure to changing temperatures as well as X-rays and infra-red radiation

- A catenary simulator which measures wear on catenary wires and power units

- Dynamic wheel set calibration facilities which allow the calibration of instrumented wheel sets to approximate the speed at which field measurements are taken

- Facilities for appling static and dynamic loads to wagon components or to whole wagons for life cycle testing of freight cars.

In order to carry out field tests the Railway Research Centre possesses numerous test cars outfitted with modern devices and equipment.

- A test car designed to measure the overhead catenary contact line interface with the current collector at high speeds and for static measurements

- A test car designed for traction testing -- traction vehicle characteristics measurement, investigation of locomotive tractive power and energy consumption.

Many of the research programs discussed with the Polish representative were activities proposed under a U.S./Polish cooperative agreement. This agreement divides the research program into Tasks by technical topics. Research in fastener design and testing were conducted under Task 2 of the agreement, and tie renewal was investigated under Task 3. These projects are discussed in Chapter 6 of this report.

THE RUMANIAN RAILROAD SYSTEM

(a) Rumanian Track Structure

Typical track construction in Rumania consists of both wood and concrete ties 2.6m (8.4 ft.) in length on 49 kg/m (98.8 lb./yd.) rail. Wood tie track construction is strictly adhered to on curved track territory where the radius is less than 400m

(1312 ft.), and under switches. Recently, however, a new "resin" tie concept for switches was introduced and has performed successfully. Apparently, no problems with stiffness variations at the joints have been experienced from track in concrete territory with wooden ties at the joints. Typical tie spacing is 60 cm (23.4 in.); Rumanian practice calls for 50 cm (19.5 in.) tie spacing in heavy curve territory. Bolted K-type fasteners were utilized in past concrete tie construction; however, an elastic fastener is used in new track construction. (Photographs 2-5 and 2-6.)

Although CWR is used for new track construction, to date only six percent of the total system mileage is estimated to be CWR. Track design loads are 21 metric tons (23.1 tons)/axle with projection to 24 metric tons (26.4 tons)/axle by 1980. All new mainline rail is 60-65 kg/m (121-131 lb./yd.) whereas most existing rail and secondary track rail is 48 kg/m (96.87 lb./yd.). Ballast shoulder width is 30 cm (11.7 in.) on curves with a radius less than 500m (1640 ft.). A granite or basalt aggregate with gradation 25/70 mm (1.0/2.8 in.) is used. Limestone ballast is currently used on secondary lines. Ballast compactors are not used in the Rumanian system. At one time ballast was piled on the shoulders of curves with CWR, but this practice has been discontinued. Obtaining ballast of sufficient quality for track construction is somewhat difficult since granite and other igneous ballast is not available within Rumania.

Maximum and minimum ambient temperatures in Rumania range between +45^{o}C/-30^{o}C (113^{o}F/-22^{o}F). Given this ambient temperature range, Rumania allows installation temperature to range between 17^{o} to 20^{o}C (62.6^{o}F-68^{o}F). No information was available on the frequency or existence of buckling incidents. Rail is replaced on a programmed renewal basis at 280 million metric tons (308 million tons). This figure represents the wear condemning limit for track greater than 800 m (2624 ft.) radius, as well as the fatigue (flaw) condemning limit for track less than 800 m radius curvature.

(b) Research Organization

The Institute for Research and Technology Design for Transportation (ICPTT) is responsible for conducting research in all aspects of transportation relating to the design, operation and maintenance of bridges, highways, buildings, railroads and waterways. To conduct the required research, the Institute maintains laboratories, test facilities and a staff of 500 engineers and specialists. The ministries responsible for railroads, highways, and ports, as well as the manufacturers supplying materials and components, pay the institute for services, research, and certification testing. Organizationally the Institute has three functional sections: Railways, Highways and Waterways. Although there is some overlapping of responsibilities, each section functions autonomously. Specifically the Railway Section is subdivided into 5 divisions:

- Propulsion -- Responsible for motor power research including fuel economy and performance optimization studies.
- Vehicle Dynamics -- Primarily responsible for developing performance specifications for various types of vehicles, and conducting classification testing.
- Rail Automation -- Responsible for developing techniques, methods, and prototype systems to automatize all aspects of rail transportion.
- Tracks and Bridges -- Responsibility for all aspects of track and bridge research, with current research emphasis on higher axle loads, heavier rail, and improved fasteners.
- Electrification -- Responsible for the development and improvement of catenary and pantograph systems in conjunction with minimizing overall energy consumption.

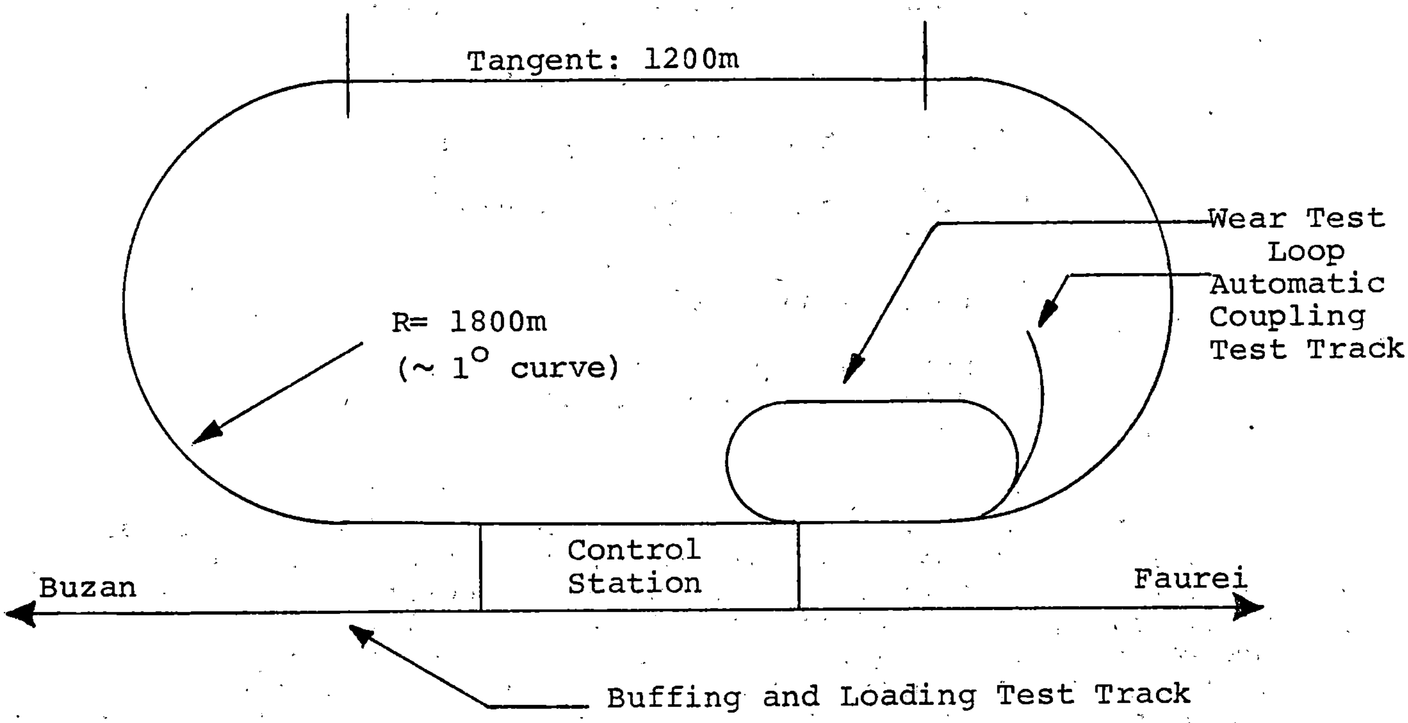
A container branch is responsible for the study of container system problems, rail tests on container handling equipment, and testing of new types of containers for acceptance standards. Container research is important to Rumania since containers are handled in many large cities and at the Constanza Harbour. ICPTT also supports a laboratory which conducts soil research.

(c) Vehicle Test Facilities

The U.S. delegation toured the Faurei Test Loop (FTL). FTL is primarily a vehicle acceptance test facility. The FTL facility is located 150 km (93 miles) SE of Bucharest. The loop itself has been in operation since September, 1978, and is still suffering the growing pains of a new test facility. The Rumanians believe this is the 8th such facility, world-wide. Comparable facilities are known to be located in the USSR, China, U.S., and Czechoslovakia. West Germany will build a test facility in 1981 if they can solve location problems.

Figure 2-2

FAUREI TEST LOOP



Faurei is a 17 km (10.54 mi) loop with an elevation of 130 mm (5.2 in) in the curves (which can be increased to 150 mm or 6 inches). This elevation permits speeds up to 200 km/hr (124 mi/hr). The loop has two 1,200m (1308 yd.) tangents and 1,800 m (5904 ft.) radii in the curves.

The large track is used to test rolling stock, and catenaries, although some track components, (e.g. ties and special fasteners) are also tested. The track also has a branch line with several short radius curves. More curved tracks, to be constructed as smaller loops within the larger loop, were planned for completion by 1980 for conducting extensive tests on bogie and car behavior. These new curves on grade will be used to test buffers and underframes and the effect on goods, since problems exist in freight loss and damage.

A separate electric substation services the larger loop, which is completely electrified. Various electrification/energy related tests are being contemplated for this loop.

Currently testing is focused in the following areas:

- Locomotive performance (acceptance) tests
- Electric energy/fuel consumption
- Ride quality, braking performance
- Vehicle dynamics and track vehicle interaction
- Catenary shunt studies
- Support to OSZD (Eastern European ORE) especially in automatic coupling research.

Catenary tests are scheduled at the Faurei Loop to evaluate various catenary designs. The catenary program includes: testing catenaries for train speeds up to 214 km/hr(132.7 mi/hr); designing systems for train speeds up to 160 km/hr (99.2 mi/hr); seeking substitute materials for steel and copper components; studying catenary/pantograph interaction; examining current distribution in leads; and testing reinforced catenary poles without a poured base.

The Institute is actively engaged in cooperative research with the International Union of Railroads (UIC), and the OSZD (Eastern European equivalent of ORE). Automatic coupler research and rail longitudinal force measurement are among the topics currently being jointly pursued by these organizations.

(d) Laboratory Facilities

The delegation was given a tour of selected ICPTT laboratory facilities. The most notable observation included:

- Cab Simulator -- A computerized cab mock up capable of simulating actual operating conditions. The cab is currently set up only for an electric locomotive, but a diesel locomotive simulator is planned. The cab can hold the engineer and two observers. The upcoming track image is sequenced by computer to the hydraulic actuator and is projected onto a front screen. Techniques have been developed to introduce unusual operating situations. The engineers' reactions to these situations are recorded. The Rumanians reported that the locomotive cab simulator has the capability to simulate track image, noise, acceleration in two directions, braking, and variable train length from single locomotive to 2,400 trailing tons. The Deputy Director of the institute indicated that simulator training prepares a class for graduation in three months compared to one year by traditional methods.

- Brake Shoe Test Facility -- A full scale brake shoe and disc brake test stand. This traditional test stand has 24 channels of strip chart recording capability to record temperature and brake shoe forces. Current tests on composite brake shoes have indicated a problem with surface cracking.

- An Instrumented Wheel Set Calibration Stand -- The stand as well as several instrumented wheels were viewed. The Rumanians prefer the British spoked wheel technique. The Rumanians also have a test procedure for loading a wheel laterally at the flange on a moving freight car to study rail lateral stability. This test car is scheduled for modification to provide on-board actuators to put vertical loads on the vehicle as well.

- Car Counter and Optical ACI -- These car identification systems were demonstrated in the laboratory and are described in Chapter 7 of this report.

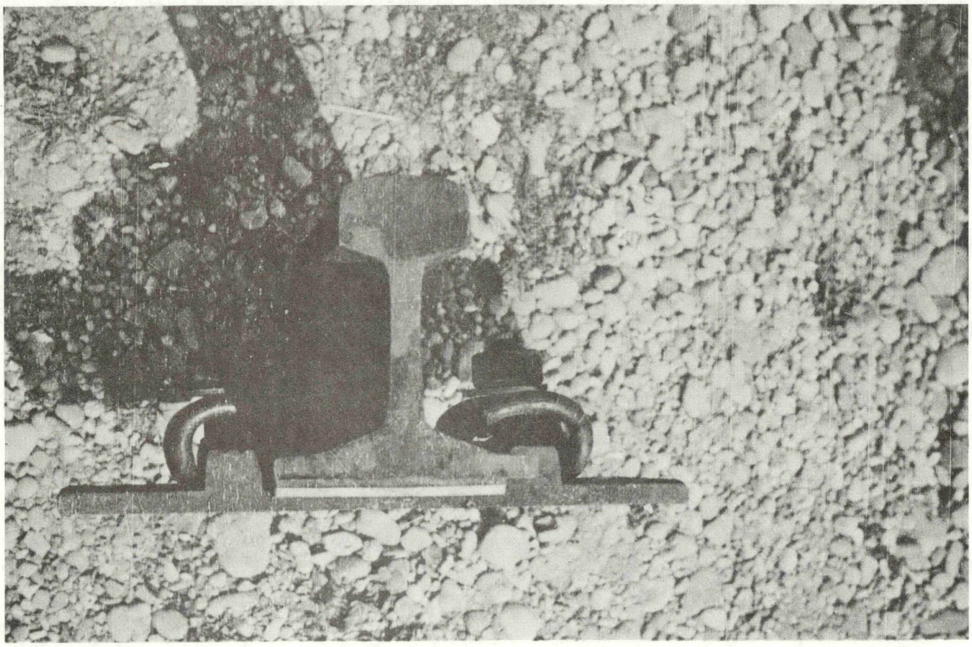


Photo. 2-1. SK-3 Fastening System (Hungary)

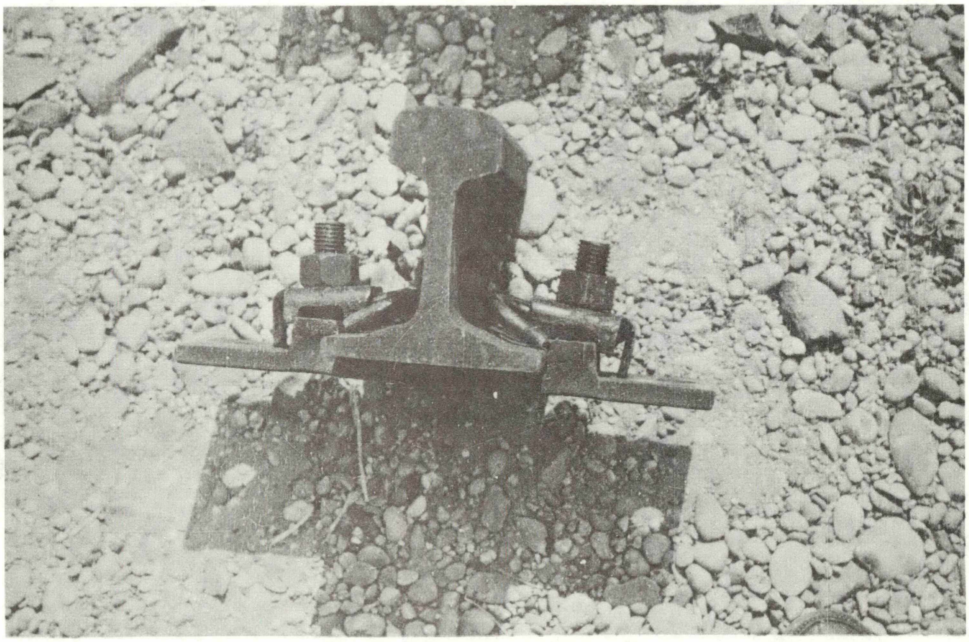


Photo. 2-2. SK-2 Fastening System (Hungary)

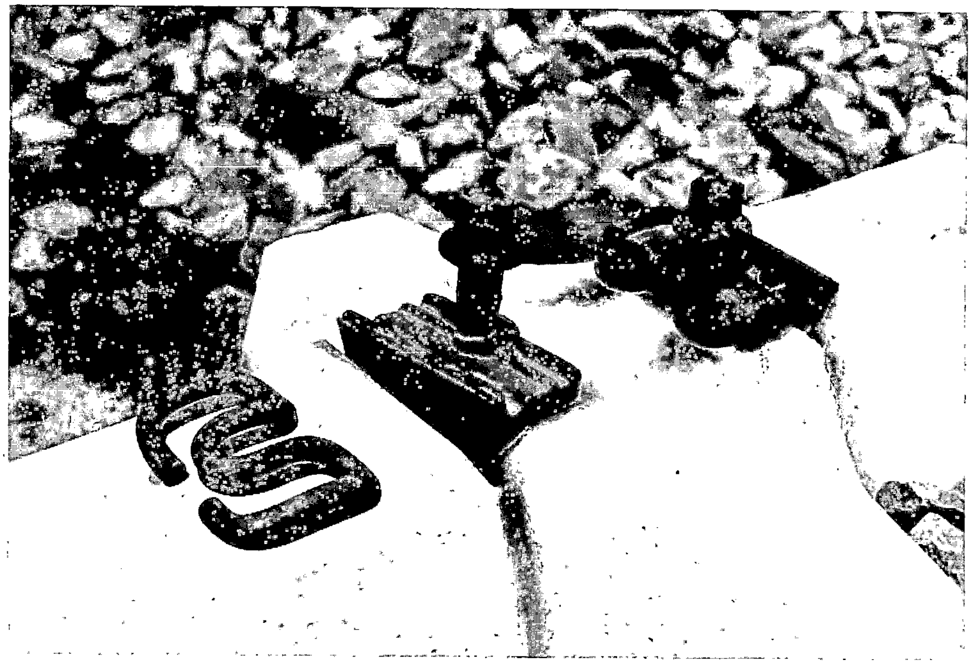


Photo. 2-3. SK-1 Fastening System (Hungary)

Photo. 2-4. Fastening Systems (Hungary).
Left to right: SK-3, SK-2, K-Type

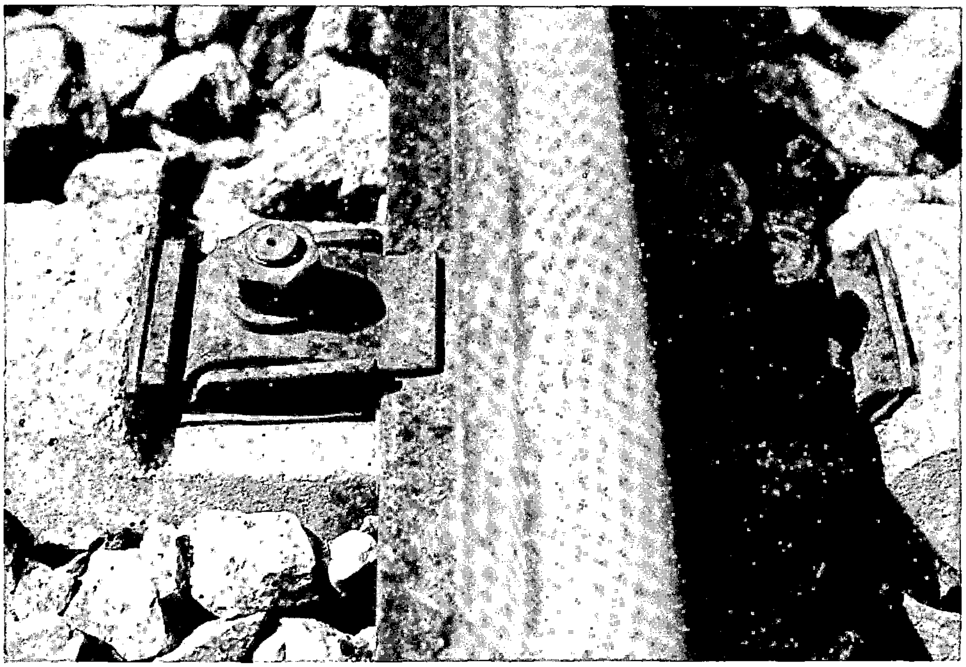


Photo. 2-5. Rumanian Elastic Fastening System.

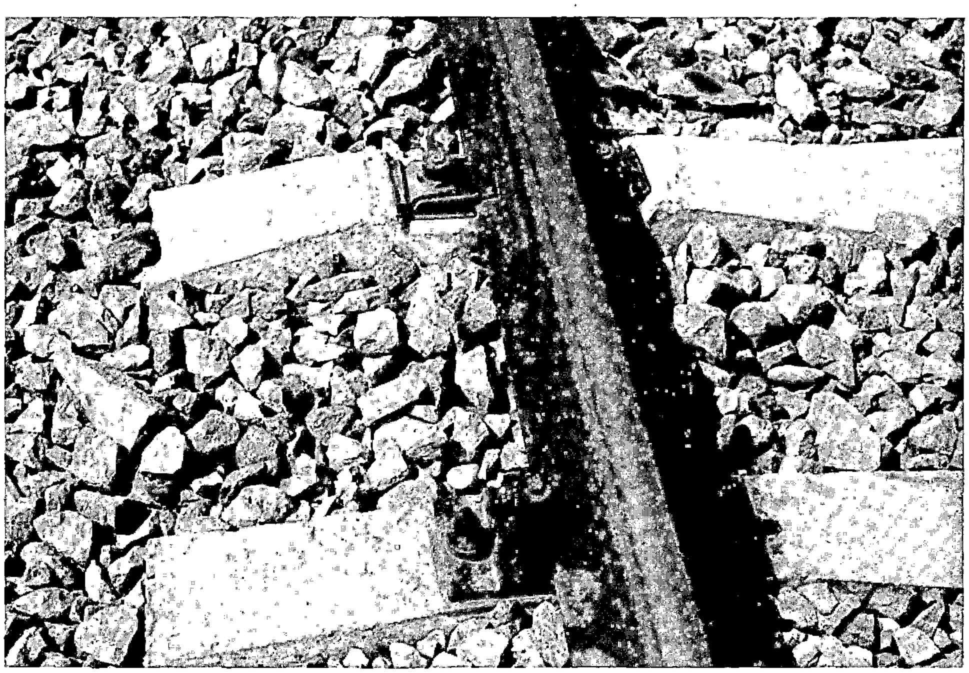


Photo. 2-6. Fastening Systems; K-Type (Foreground) Rumanian Elastic Fastener (Background)

CHAPTER 3
BALLAST RESEARCH

SECTION A: EASTERN EUROPE

BALLAST GRADATION -- HUNGARY

The Hungarians use a uniform gradation ballast with particle sizes up to 40mm (1.6 in.) under concrete ties and sizes up to 60mm (2.4 in.) under wood ties. The more uniform, smaller gradation allows for greater ballast compaction and provides better interlocking for lateral and longitudinal resistance. Only igenous rock (primarily basalt) is used currently for ballast, although several limestone ballast sections still exist which are more than 34 years old.

The Hungarians have investigated the influence of ballast particle size on lateral resistence. Results of this research using a uniform gradation between 40mm. and 64mm., (1.6 in. and 2.56 in.), as a resistance base of 100% show:

- A mixture of 25/65 mm (1/2.6 in.) and 25/40 mm (1/1.6 in.). A 1:1 ratio provides an increase of 20%
- 40/65 mm (1.6/2.6 in.) and 25/40 mm (1/1.6 in.). A 1:1 ratio provides an increase of 16%
- 25/65 mm or 1/2.6 in. (only). Provides a 13% increase
- 25/40 mm or 1/1.6 in. (only). Decreases resistance by 12%.

The best results, an improvement of 25 to 35%, were achieved with a graduation of 30/65mm (1.2/2.6 in.) and 25/55mm (1.0/2.2 in.). From these tests, the current MAV specifications were established at 20/55mm (.8/2.2 in.).

Final dressing of ballast to achieve a close tolerence profile by using a very fine material, 10/25 mm (.4/1 in.) or 5/15 mm (.2/.6), directly below the ties was found very useful in eliminating settlement. However, this method is not currently employed since hand tamping, which is a time consuming process, must be used in conjunction with machine tamping, slowing the entire tamping process.

BALLAST DENSITY AND FOULING -- HUNGARY

Hungarian research has indicated decreased lateral resistence with ballast fouling (from both material working up from the subgrade and coal dust settling from the top). Although dry, fouled ballast demonstrates three times the lateral resistance of clean material, this support is highly inelastic and the lateral resistance disappears rapidly when the material is moistened by precipitation. Fouling was measured as the percent of normal ballast voids filled with fouled material. Decreases in lateral stability for varying degrees of fouling by coal and sand subgrade were found to be:

% Fouling	% Decrease in Lateral Stability	
	Concrete Ties	Wood Ties
10%	- 4%	- 5%
25%	-18%	-19%
30%	-21%	-25%
40%	-27%	-32%

If the voids, however, are filled with a wet mixture of coal dust and clay, then for a 40% fouled condition, stability with concrete ties is decreased by 59%, and with wood ties by 63%. The degree of fouling is measured on the MAV by isotopic means. When a measurement of 40% fouling occurs at a ballast density of 2.1 kp/cm^3 (76 $lb./in^3$) the ballast is machine cleaned. The normal range is 1.8-2.3 kp/cm^3 (65-83 $lb./in^3$). The lateral single tie resistance method was used previously but this method has been replaced by the quicker and more effective isotopic procedure.

The procedure for radioactive isotope measurements of ballast density/fouling is to immerse a cobalt 60 probe into the ballast and then to measure radiation using a calibrated Geiger counter to determine density.

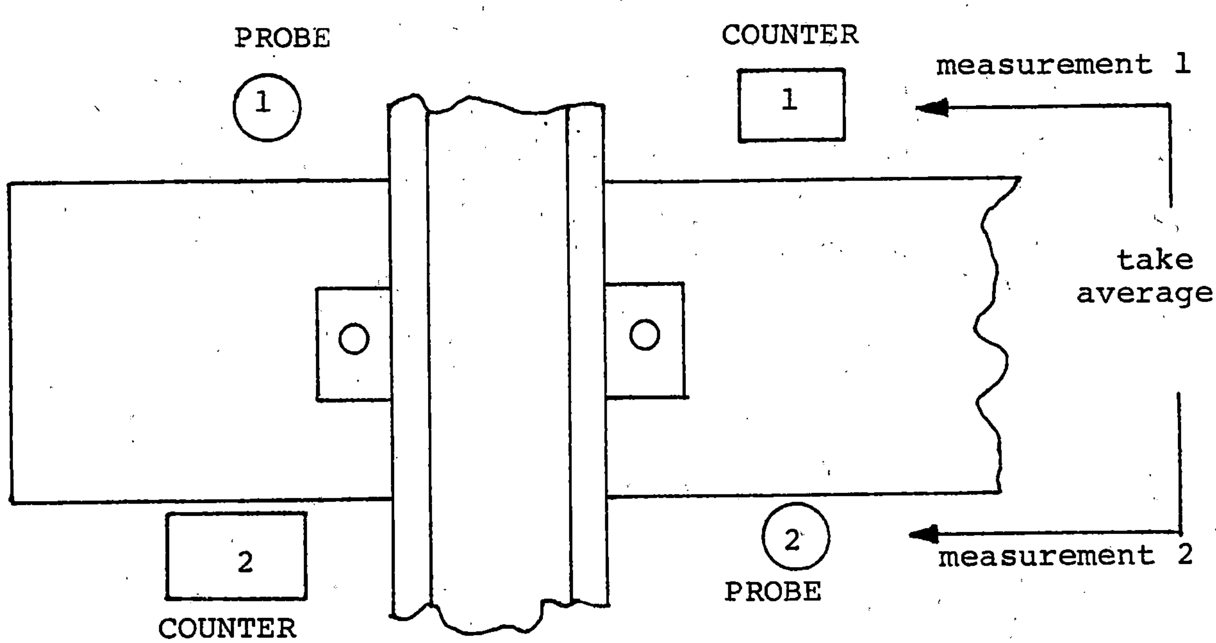
First, the cribs on each side of a tie are cleared out. A circular rod is pounded into the ballast next to the tie to a depth of approximately 8 inches, then removed creating an annular void. The isotopic measuring system is placed over the tie with the probe inserted into the annular void. The system automatically places a Geiger counter at the tie base opposite the isotope rod; thus the distance from source to counter is fixed with this device. The device records the isotope charges measured by the counter per time unit. The calibration curve is used to translate the isotope count to a density. The measurement procedure is performed on both sides of the rail. The results are then averaged. By using this procedure the average density value is approximately that of the ballast directly below the tie under the rail seat.

The MAV is the only railroad system which extensively uses the isotope method. Other systems report problems with the accuracy of the readings which are affected by several environmental variables including moisture, gradation, fouling and type of fouling. In addition, the procedure for inserting the probe tightens loose ballast and loosens tight ballast.

The figure below illustrates the placement of the probe for isotopic measurement of the ballast.

Figure 3-1

PROCEDURES FOR MEASURING BALLAST DENSITY



Three levels of fouling were established as follows:

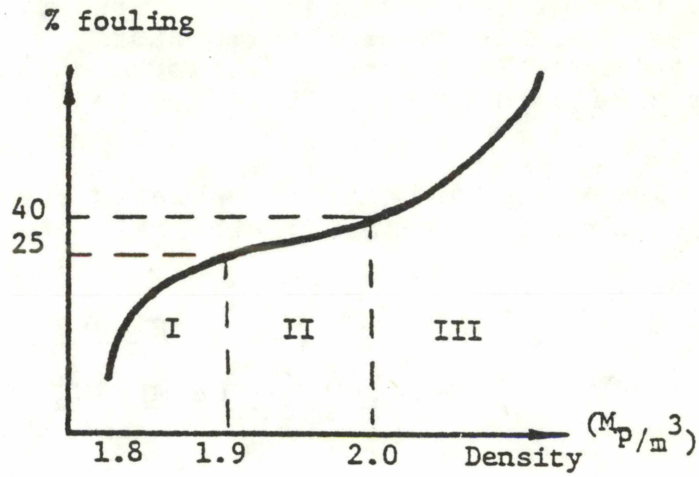
Figure 3-2

LEVELS OF BALLAST FOULING

REGIME I: 25% fouling

REGIME II: 40% fouling

REGIME III. 40-100% fouling

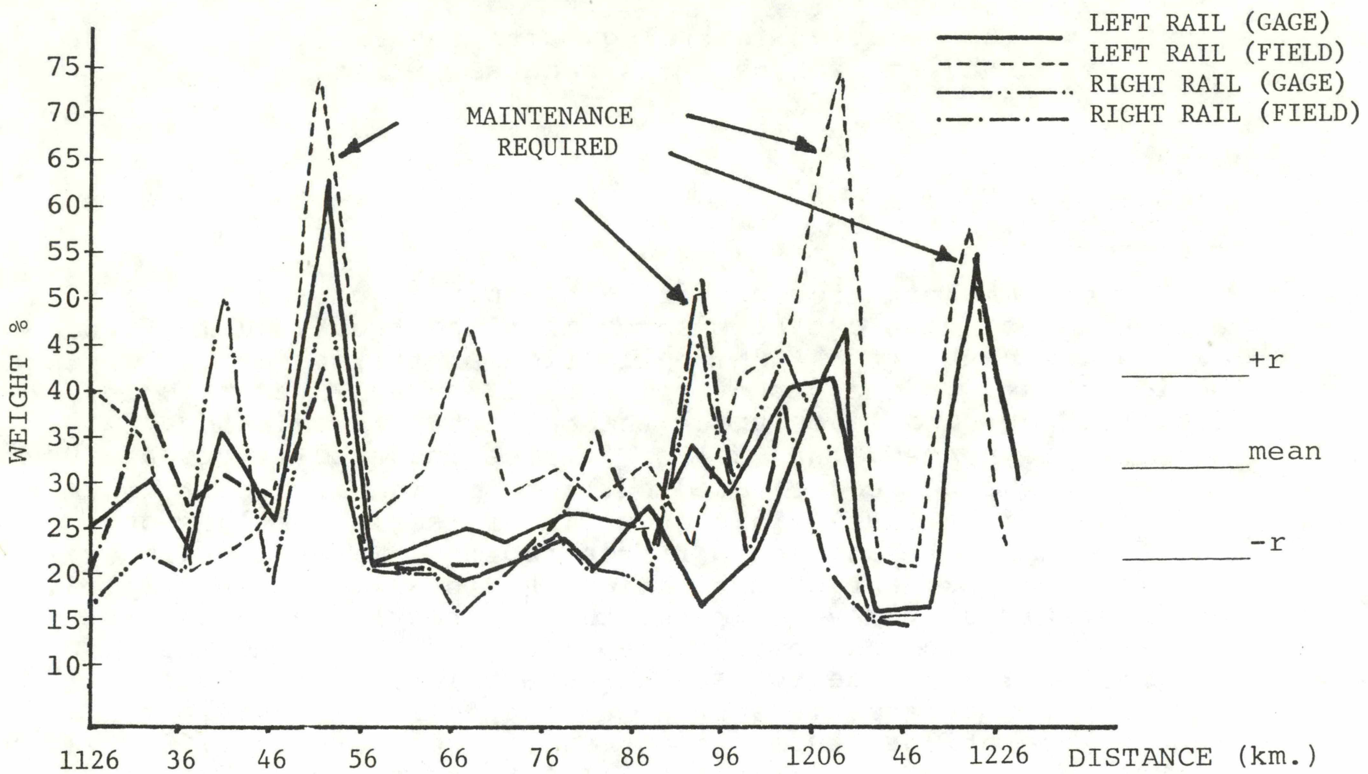


Measurement values ranged between 1.55-2.3 Mp/m^3 (m^3 = 35.34 cubic feet). 1.8-2.3 Mp/m^3 is considered a fouled condition. Fifty percent fouling occurs typically around 2.0-2.1 Mp/m^3. Using this system, optimum density was established at P = 1.8 Mp/m^3. These types of guidelines can be used since uniform ballast gradations are specified for all MAV lines. New calibrations would be needed if various types of ballast gradations were used.

A typical ballast fouling diagram for a 100 km (62 mi.) taken at 5 km (3.1 mi.) intervals is shown below:

Figure 3-3

TYPICAL BALLAST FOULING DIAGRAM



Ballast cleaning can be programmed using this diagram.

This radioisotope technique for the measurement of density/ fouling has several advantages:

- Considerable time saving (1/10 the time of other methods)
- Substantial cost saving (average 18% of the cost of gradation analysis)
- Minimal ballast disturbance

For these reasons, this isotopic method has been used by the MAV to program ballast cleaning for the last 10 years (800 km or 496 mi. per year).

The radioactive isotope technique is used extensively in other areas of transportation technology in Hungary.

- Soils/subgrades in highway engineering
- Wheel/rail wear assessments
- Auto/truck tire highway wear evaluation
- Lubrication technology with regard to moving machine parts such as pistons.

PROCEDURES FOR BALLAST CLEANING -- HUNGARY

Current MAV practice specifies cleaning 50cm (19.5 in.) of ballast in one undercutter pass on mainline track, 40cm (15.6 in.) on secondary track and application of filter fabric. Filter fabric is used as the structural equivalent to 20 cm (7.8 in.) of ballast or sand layer under the ballast. If additional structure is needed, then filter fabrics and sand layers are used together. The current cleaned ballast section is usually 50cm (19.5 in.) of ballast laid over a filter fabric, or laid over 20cm (7.8 in.) of sand and a filter fabric. Normal working time for cleaning and fabric application is 3 hrs/km (4.8 hrs/mile). Representatives of MAV indicated that currently seven undercutters are operating on their system. One of these machines is used primarily for the two step sand application (although all their Plasser undercutters have that capability). Ballast cleaning operations usually progress at 180-200 m/hr (196.2-218.5 yd./hr) or at 100-120 m/hr (109.3-130.8 yd/hr)when fabric is added. The average production for all seven machines on a yearly basis, including the sand layer application operation, is 130 m/hr (141.7 yd/hr).* Currently 80 to 90 km (49.6 to 55.8 mi.) of filter fabric is in place on the MAV system. Performance is continually evaluated by excavating each year several pre-selected sections to examine the fabric for wear.

The U.S. delegation observed the cleaning process on a double track segment reconstructed in 1963. The substructure was therefore approximately 15 years old. Each track carries approximately 11 million metric tons (12/MGT) per year with a maximum axle

---

* These figures differ somewhat from those given by other sources.

load of 21 tons (23 tons). The ballast appeared to be moderately to heavily fouled with a fine material appearing to be predominantly coal dust on an embankment approximately 20-30 feet high. The old ballast dated from the last reconstruction and contained a much larger particle size than current MAV specifications allowed. Many "rocks" up to 5-6 inches in diameter could be seen mixed into the ballast. In contrast, the new ballast appeared to be more uniformly crushed and of smaller average size (although the maximum particle sizes appeared to be larger than the current MAV 55 mm (2.2 in.) maximum size specification).

The maintenance operation, machine consist and sequence was typical of standard MAV procedure. MAV maintains 22 such work ensembles (only seven undercutters, which are in continuous operation when weather permits). The first operation was ballast cleaning and filter fabric placement, both operations being performed by the Plasser undercutter. Soil was wasted on the side of the embankment. The filter fabric was placed directly on top of the undercut surface and the cleaned ballast placed directly on top of the fabric. The fabric itself was placed from two rolls, with an overlap of approximately one foot. It appeared that the larger stone left from the cleaning operation were placed directly on the fabric, with the smaller cleaned stone placed on top.

A tamper/liner followed the undercutter which was in turn followed by a regulator/distributor. The last machines in the operation were two Hungarian-made consolidators. Two consolidators are required to keep pace with the tampering and lining operation. See Photographs 3-1 through 3-8 at the end of the Chapter.

The MAV is currently completing an evaluation of a dynamic stabilizer which grasps the rail head and vibrates the track structure vertically to achieve sttlement. Three test sections totaling approximately 15 km (9.3 mi.) have been stabilized using this machine and the performance of those sections is being measured. Performance is evaluated by comparisons of all surfacing operations, measurements of track geometry, ballast density, and single tie lateral pull tests in stabilized and normally maintained sections. Preliminary findings indicate that this form of stabilization achieves better ballast density and lateral resistance than consolidation, and that no traffic speed restrictions are required after maintenance.

FILTER FABRIC APPLICATION AND RESEARCH

(a) Hungary

Filter fabrics are commonly used in all track reconstruction in Hungary. 90 km (55.8 mi.) of track currently have fabric under the ballast. Placement is accomplished during the normal course of ballast cleaning, with the fabric covering the full width of undercutting (approximately 4m wide (4.37 yd.).

Application of filter fabrics in track began in 1973 as part of an in-track service testing experiment to prevent ballast fouling and increase track stability. The motivation for the experiment was that approximately 75% of MAV lines were constructed on subsoil consisting of clay, coal dust and sandy clay/ coal dust mixtures. This relatively weak substructure often required considerable time consuming maintenance.

The experiment* demonstrated that fabrics did increase track stability and prevent fouling but were expensive to purchase and install. MAV therefore began a comparative test of three fabrics: FIBERTEX (Danish), BIDIM (French), and TERFIL II (Hungarian). The tests indicated that all these fabrics possessed advantages, but the Hungarian fabric was more economical because of its local production.

The Hungarian produced TERFIL II has the following properties:

Material:	polypropelene
Weight:	400 gm/m^2 (11.7 oz/yd^2)
Thickness:	3-4 mm (.12-.16 in.)
Tensile Strength:	70-100 kp (154.3-220 lbs) longitudinal 60-80 kp (132.3-176.6 lbs) transverse
Permeability**:	3.5×10^{-3} cm/sec. (1.37 in/sec.)

* Experimentation in Hungary means actual in track service tests since the whole rail system is regarded as a laboratory. Therefore new equipment or procedures are placed in the rail system and their performance is evaluated against the current standard.

** Permeability is the property which indicates the ease with which water will flow through a substance.

In normal operations, filter fabric is estimated to be equivalent to 20 cm (7.9 in.) of subgrade material (sand) with a potential 50% cost savings.

When 40 cm (156 in.) of sand are estimated to be required, a two step process is used. A Plasser undercutter places a 20 cm (7.8 in.) layer of sand between the cleaned ballast and the filter fabric. The filter fabric is rolled off two large spools attached to the underframe in total width extending approximately six feet beyond the tie ends and overlapping in the middle about one foot. The laying of the fabric is followed by the tamper, regulator and the compactor. Overall the operation appears effective both in speed and efficiency. Photographs 3-3 and 3-4 at the end of the chapter illustrate the installation procedure.

Current investigations regarding the usage of filter fabrics have included applications for: 1) drainage pipes 2) highway construction and 3) at railroad crossings, switches, and rail joints. Tests indicate that a great percentage of low joints could be eliminated by installing filter fabric spanning six ties in jointed track. Filter fabric has been used with drainage systems as a covering for perforated pipe to prevent culvert clogging. Current MAV practice calls for all perforated pipes to be covered by fabric. To date, approximately 9 km (5.6 mi.) of fabric covered drains are in place.

(b) Rumania

Rumania has participated in 3 to 4 years of cooperative research with the Hungarians on fabric use. This research resulted in the placement of 5-6km (3.1-3.7 mi.) of fabric in track. Additional research is planned in specific regions which exhibit ballast problems. The Rumanians are not committed to extensive use of filter fabric because of escalating costs resulting from increases in petroleum prices.

RUBBER EMULSION COATED BALLAST -- POLAND

Poland has conducted tests of ballast coated with a rubber emulsion for increased cohesion. The dynamic test track section was used to evaluate performance against an unstabilized section. The Polish representatives were reluctant to discuss results. The statement was made, however, that the stabilized ballast section would be more difficult to maintain. Whether this disadvantage and additional cost are offset by superior track performance cannot be determined without the test results. However, this type of ballast is not currently used on the Polish Railroad system.

SECTION B: UNITED STATES

BALLAST GRADATIONS

In 1944, the AREA established recommendations for ballast gradations. Today, the AREA specifications do not vary substantially from these initial recommendations. The AREA recommends five ballast gradations for crushed stone or crushed slag, described in Table 3-1 below, for use under varying classes of track.

Table 3-1

AREA GRADATION SPECIFICATIONS FOR BALLAST
CRUSHED STONE AND CRUSHED SLAG

		Amounts Finer Than Each Sieve (Square Opening) Percent by Weight									
Size No.	Nominal Size Square Opening	3"	2 1/2"	2"	1 1/2"	1"	3/4"	1/2"	3/8"	No. 4	No. 8
24	2 1/2"-3/4"	100	90-100		25-60		0-10	0-5			
3	2"-1"		100	95-100	35-70	0-15		0-5			
4	1 1/2"-3/4"			100	90-100	20-55	0-15		0-5		
5	1"-3/8"				100	90-100	40-75	15-35	0-15	0-5	
57	1"-No. 4				100	95-100		25-60		0-10	0-5

Few experiments on varying ballast gradations have been conducted in the United States because of the general acceptability of these recommended gradations. Research at the University of Illinois and at Queens University of Canada, however, showed that well-graded material exhibits better performance than uniformly graded material,* provided that particle sizes are larger than 1/4 to 1/2 inch to avoid problems with drainage. Use of well-graded material is not a general practice on U.S. railroads since the concept has been accepted that well-graded ballast fouls faster than uniformly-graded ballast, and will also encounter frost problems earlier.

In addition, FAST** is currently conducting experiments on ballast gradation. Under the Phase II Ballast Experiment, sections constructed with AREA #3 and AREA #24 gradations of

---

* Well graded - aggregates with a gradual gradation in size from coarse to fine
Uniformly graded - an aggregrate mix with a predominance of particles in given size range.

** The Facility for Accelerated Service Testing which is located at the Transportation Test Center, Pueblo, Colorado.

granite and traprock will be compared for performance under accelerated loadings. Comparisons will also be made to the performance of the AREA #4 Wyoming granite used during the Phase I tests.

Most American railroads use about the same size (AREA 3 and 4) and more uniform gradations of ballast than Hungary with the largest sizes of aggregate used under concrete ties and heavily travelled track. Hungary, furthermore, appears to be the only country recommending smaller ballast sizes for use under concrete ties. The Hungarian ballast specification is contradictory to policies of the AREA, and Poland, as well as many other European rail systems. The Hungarian rail system, however, has much lighter loadings than U.S. railroads. Final dressing of the ballast with fine material beneath the ties is not practiced in the U.S.

BALLAST
DENSITY AND FOULING

Railroad researchers in the United States have not specifically studied fouling as a measure of track performance as in Hungary. Generally, the railroad industry views fouling as detrimental primarily when it results in pumping. Decisions concerning maintenance of ballast sections, including undercutting are generally made by maintenance of way engineers based upon visual inspection, with emphasis on correcting major track structure problems. Undercutting is a rather recent maintenance technique on U.S. railroads, and most of this nation's major rail lines have, at most, been undercut only once. A means for measuring the percent of fouling has not been developed, and ballast density research has been limited, although a field density measuring device has been successfully tested.(1)

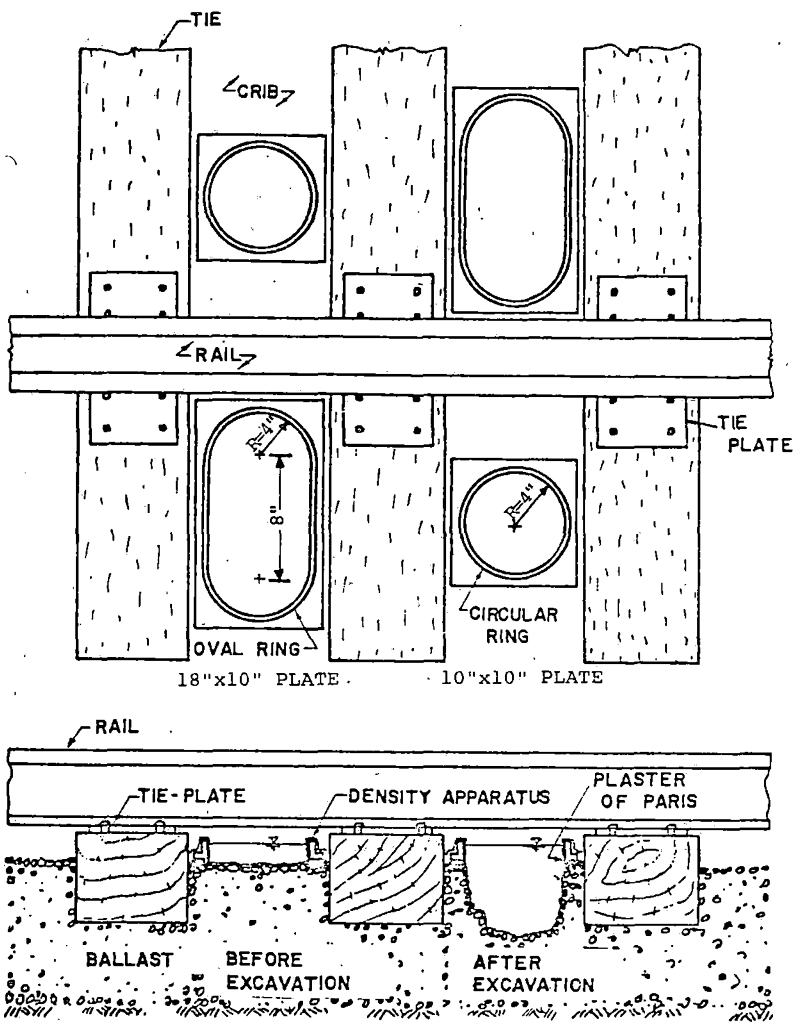
This apparatus, shown schematically in Figure 3-4, was developed at the State University of New York (SUNY) at Buffalo, and uses a water replacement concept. A similar concept was used in Poland but abandoned because of inconvenience. Poland has since experimented with using tie damping methods for measuring the uniformity and quality of tie support provided by the ballast.

---

(1) C.M. Panuccio, T.S. Yoo, E.T. Selig, Mechanics of Ballast Compaction, Volume 3: Field Test Results For Ballast Physical State Measurement, USDOT, Transportation Systems Center, Cambridge, MA.

Figure 3-4*

IN-SITU BALLAST DENSITY MEASUREMENT



The figure also illustrates the test configuration. Templates with circular and ovular openings are placed over the cribs of a track structure at both the inside and outside of the rail. Plaster of Paris is used to form a seal and flat seat for the plates resting on top of the ballast. The ballast within the template is excavated to the depth shown, and a latex membrane inserted in the void. The membrane and apparatus are then filled with water. The volume of water required to fill the void is measured, and finally the excavated ballast is weighed and the density calculated. The device was first tested on the Canadian National Railroad in 1976, and has since been tested on the Southern, Illinois Central Gulf, and at FAST. The results of this method have been adequate and relatively accurate.

* Sources for U.S. figures are listed in the appendix to this report.

This density apparatus has also been used extensively in tests conducted by SUNY at Buffalo to study the effects of tamping and vibratory compaction on ballast properties.

Laboratory research concerning the effects of settlement and frost behavior on fouled ballast were conducted at the University of Illinois.(2) This research concluded that fouled ballast becomes a relatively poor material in terms of stability after repetitive freeze-thaw cycles.

The isotope measurement technique developed in Hungary has not been used in the United States, and most other European countries. Railroad experts in these countries question the accuracy of this method since the immersion of the cobalt probe into the ballast actually disturbs the ballast and therefore may change the density. Other nuclear techniques commonly used to measure soil densities in the U.S. are not suitable for railroad application because of backscatter resulting from the large voids existing in the ballast layer.

BALLAST CLEANING, FILTER FABRIC APPLICATION AND RESEARCH

U.S. railroads use the same process of ballast cleaning as Hungary, except that vibratory consolidation is usually not performed as a final step. Unlike Hungary, ballast cleaning on U.S. railroads is a relatively new procedure, and most lines have been undercut only once, if at all. Most undercutters currently in use are equipped or can be modified to install filter fabric during the ballast cleaning process, but such application has been minimal in the U.S.

United States railroads use filter fabrics sparingly. Use has generally been confined to experimental sections where poor subgrades are known to exist, or turnouts and grade crossings where use of fabric is generally accepted and often specified. One notable exception is a freight yard in the Southeast which was constructed totally over filter fabric.

---

(2) W. W. Hay, H. C. Peterson, D. E. Plotkin, P. T. Bakas, Lateral Stability of Ballast, Report #FRA/ORD-77/61, September, 1977.

Although one reported advantage of filter fabrics is the reduction of required sub-ballast material, most maintenance of way engineers oppose a reduction of sub-ballast, fearing a loss of roadbed strength. However, the primary reason for the general lack of use of filter fabrics in conjunction with undercutting is cost. Fabric installation would raise ballast cleaning expenses by increasing materials costs, and slowing the speed of undercutting operations. Programs have not been conducted to evaluate the cost effectiveness of the general use of filter fabric, or under what physical conditions filter fabric would prove to be cost effective. Some U.S. railroads do accept filter fabric as cost effective for turnouts and grade crossings.

Part of one section at FAST has been constructed using filter fabrics, which is currently being tested under accelerated loading. At specified accumulations of gross tonnage, sections of fabric are excavated and inspected to determine fabric durability, and control of fine material migration due to pumping action. Results to date have been limited. However, problems have been encountered with fabric puncturing due to the hard subgrade at FAST. Fabrics of high tensile strength generally punctured more easily than fabrics of lower tensile strength. No other experiments concerning filter fabrics have been conducted by FRA or TSC.

Significant filter fabric research is being conducted independently by various railroads and manufacturers, as well as by the U.S. Forest Service and Federal Highway Administration for other applications. In contrast, railroad experimental use of filter fabrics has occurred primarily where subgrade problems are experienced.

RUBBER EMULSIFIED
COATED BALLAST

Rubber emulsified coated ballast was tested on a portion of the TTC Urban Mass Transit Administration (UMTA) test loop at Pueblo, Colorado. The coated ballast appeared effective initially, but the bonding property deteriorated significantly with time. Furthermore, the coating created maintenance problems by sticking to tamping heads. TSC personnel evaluating these tests expressed no further interest in this material.

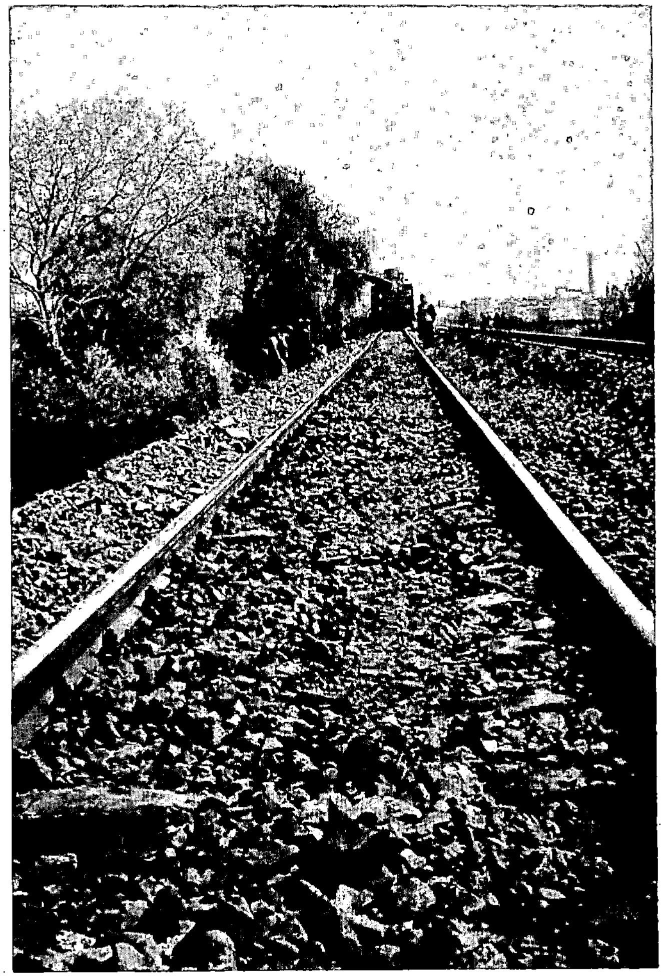


Photo 3-1. Track Section Before Undercutting. (Note Coarseness of Ballast.)

Photo. 3-2. Undercutter Wasting Fouled Material

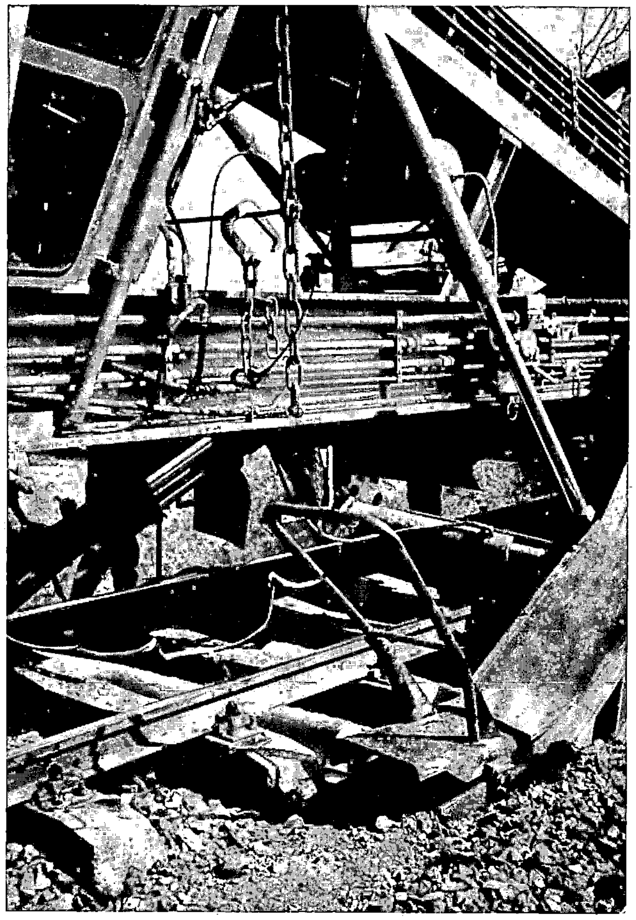


Photo. 3-3. Undercutter Installation of Filter Fabric.

Photo. 3-4. Closeup of Filter Fabric Application

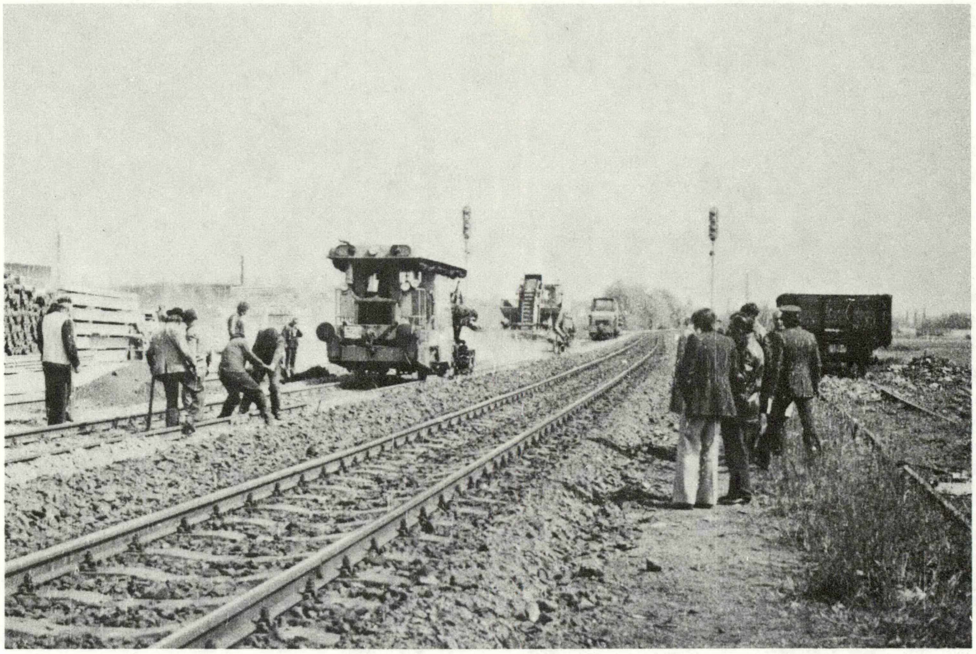


Photo. 3-5. Hungarian Track Maintenance Operation Showing From Foreground to Background: Vibratory Compactor, Ballast Regulator, Linter/Tamper.

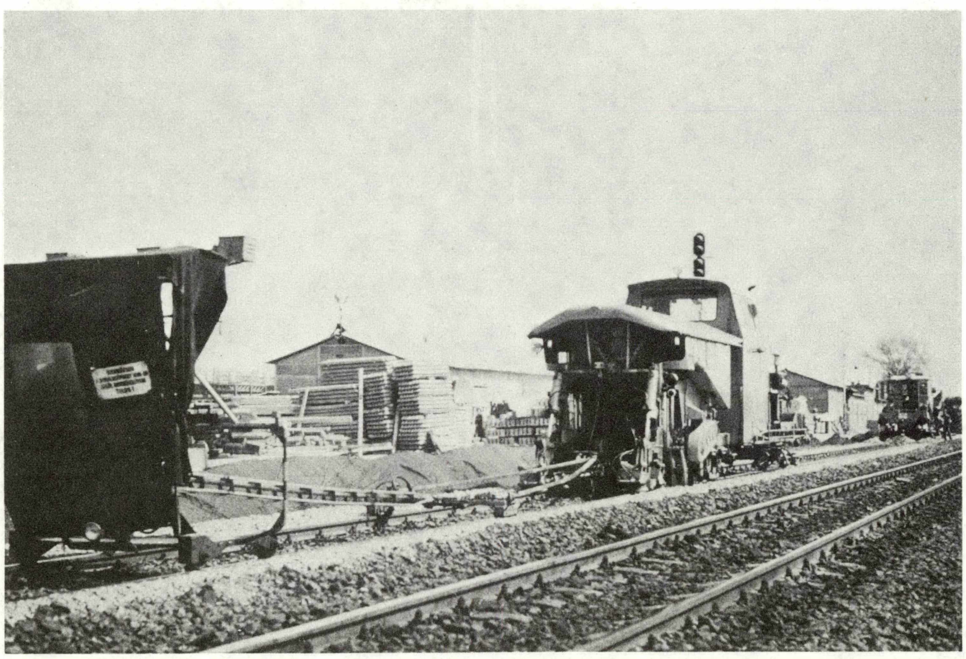


Photo. 3-6. Liner/Tamper.

Photo. 3-7. Ballast Regulator.

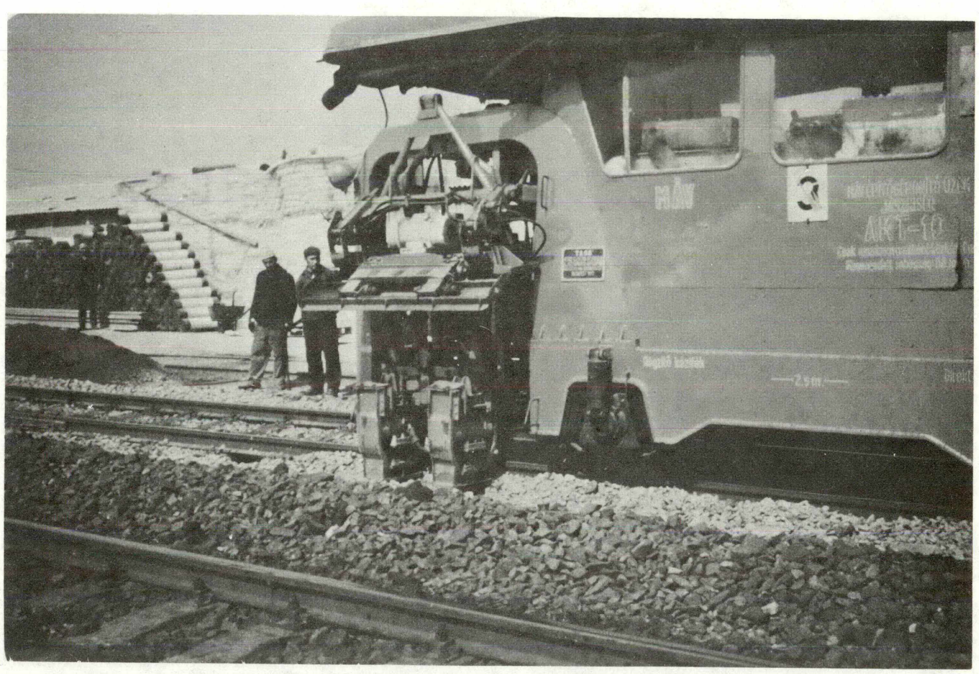


Photo. 3-8. Hungarian Built Vibratory Compactor

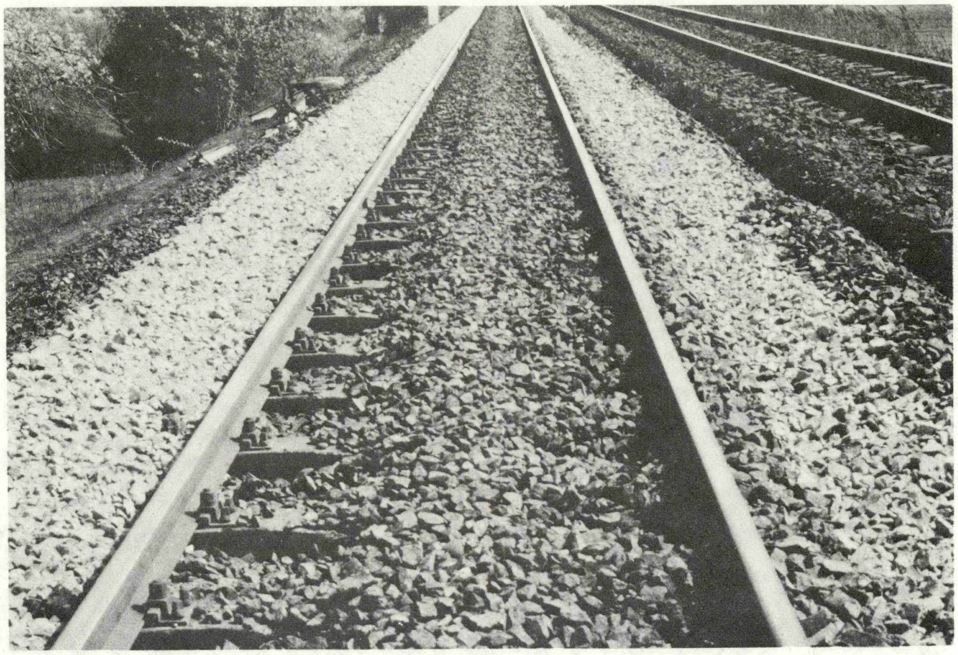


Photo. 3-9. Track Section Following Undercutting.

Photo. 3-10. Hungarian Switch Tamper.

Photo. 3-11. Hungarian Switch Tamper.

CHAPTER 4
LATERAL RESISTANCE

SECTION A: EASTERN EUROPE

LATERAL RESISTANCE TESTS -- HUNGARY

Ballast serves as a three dimensional support for railroad track, and is especially important for resisting internal buckling forces in continuously welded rail. The lateral resistance provided by ballast offers about 60% of a track panel's stability. The other 40% is supplied by rail stiffness and panel torsional rigidity, estimated at 10% and 30% respectively.

The Hungarian Railway Research Institute conducted several thousand lateral resistance tests during the 1962-1968 period. The purpose of these investigations was to determine lateral resistance (coefficients) under the following parametric influences

a. Vertical load due to rolling stock, V

b. Vertical load due to track's own weight, Q

c. Tie spacing, tie type, and tie shape

d. Ballast configuration, shoulder width, and shape

e. Ballast type, size, consolidation

f. Ballast fouling

g. Temperature effects (e.g., frozen ballast)

COMPUTATION OF
LATERAL RESISTANCE

In view of the basic principle that total panel resistance can be expressed as:

$$q_s = q_{ts} + q_{hs} + q_{vs}$$

Total panel lateral resistance	=	Tie bottom shear resistance	+	Tie side shear resistance	+	Tie end face resistance

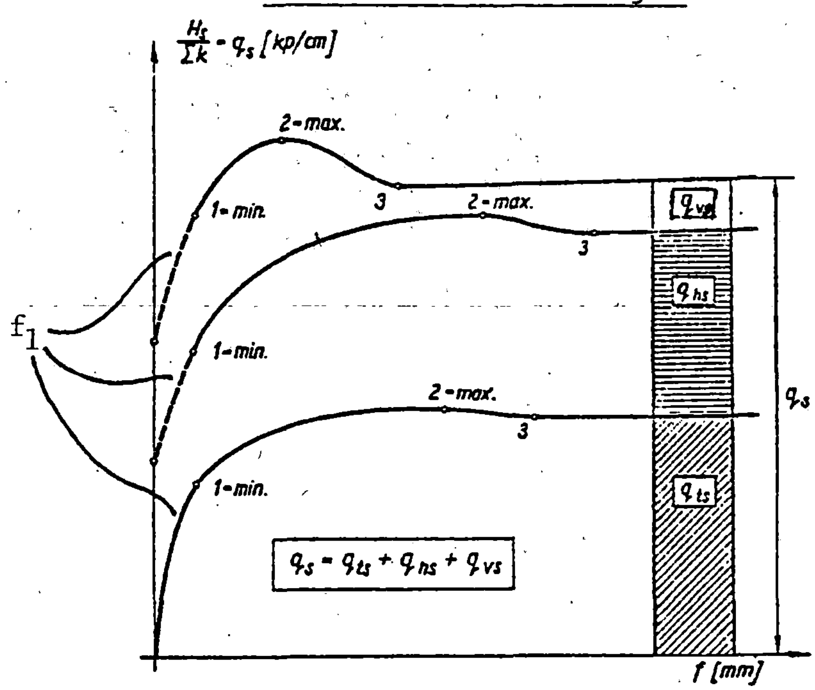
Total panel lateral strength, H_s can be calculated from:

$$H_s = q_s \cdot k$$

where k is the tie spacing. Schematically:

Figure 4-1

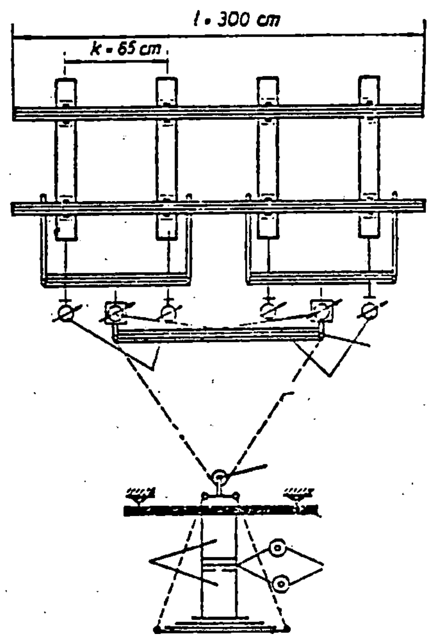
Panel Lateral Strength



Based on the numerous tests and measurements, empirical coefficients were determined which were subsequently utilized for the determination of q_s. Using the following test setup, many pull tests were performed.

Figure 4-2

Pull Tests for Measuring Lateral Resistance



THE EFFECT OF TAMPING

The results of extensive tests demonstrating the influence of tamping method on lateral resistence is presented in Table 4-1. These results are for an unloaded track with k = 65 cm. (25.35 in.) and a 40/60 mm. (1.6/2.4 in.) ballast. In addition, Table 4-2 provides the percentage distribution for the statistics in Table 4-1.

Table 4-1

Effect of Tamping on Lateral Resistance Components

Type of Tamping	Concrete Ties kp/cm @ f_1*				Wood Ties kp/cm @ f_1			
	q_{ts}	q_{hs}	q_{vs}	q_s	q_{ts}	q_{hs}	q_{vs}	q_s
Untamped (just shoveled)	3.32	2.03	0.29	5.64	1.85	2.13	0.31	4.29
Hand tamped (one layer)	3.32	2.30	0.41	6.03	1.85	2.44	0.44	4.73
Hand tamped (two layers)	3.32	2.73	0.47	6.52	1.85	2.85	0.59	5.27
Machine tamped	3.32	3.04	0.60	6.96	1.85	3.20	0.73	5.78

*f_1 = Limit of elastic response - see Figure 4-1

Table 4-2

Percentage Distribution of Lateral Resistance Components

Type of Tamping	Concrete q_s = 100%			Wood q_s = 100%		
	q_{ts}	q_{hs}	q_{vs}	q_{ts}	q_{hs}	q_{vs}
		%			%	
Untamped	58	37	5	43	49	8
Hand tamped (one layer)	55	38	7	39	51	10
Hand tamped (two layers)	51	41	8	35	53	12
Machine tamped	47	43	10	31	55	14

Based on Table 4-2, the Hungarians estimate that the approximate contribution of each of the components to total ballast resistance, q_s, is

- q_{ts} = 50%
- q_{hs} = 40%
- q_{vs} = 10%

The relatively small influence accorded the component of resistance at the tie ends, q_{vs}, indicates the relatively small contribution of the ballast shoulder to lateral resistance. In contrast, because of the comparatively large influence of the tie bottom, unloaded track can be in great danger of buckling when rail temperatures reach 43°C (109°), especially where voids exist under the tie. In fact, lateral resistance of loaded track was found to be 2 to 3 times greater than lateral resistance of unloaded track.

The effectiveness of tamping on total lateral resistance (q_s) is illustrated below (values shown are increases in qs over the untamped value):

Table 4-3

Increase in Lateral Resistance by Type of Tamping

Tamping Technique	Increase in Lateral Resistance Concrete Ties	Increase in Lateral Resistance Wood Ties
One step tamping	8%	12%
Two step tamping	16%	22%
Machine	21%	30%

Hand tamping techniques cannot achieve the necessary ballast densification on newly constructed or recently maintained sections. Therefore, the Hungarian's use a vibratory compactor with a 950 kn(kilonewtons) force at 1700-2300 HZ to achieve additional densification. This compaction method increased lateral resistance to between 13-20% of its maximum possible value for concrete ties and 17-24% for wood tie tracks. Additionally, the results of numerous tests have also shown that a typical freshly laid (untamped) track behaves in an almost inelastic fashion;

that is, given any lateral displacement, permanent deformations occurs. Similarly, machine tamped track remains elastic only to the order of 1 to 2mm (.04 to .08 in.) lateral deformation.

THE EFFECT OF BALLAST COMPACTION

(a) Hungary

The MAV experience indicates that ballast compaction is a necessity for maintaining good track alignment. Compaction is, in fact, specified as an integral part of all surfacing operation. No track is perfectly aligned, and therefore when rail temperatures reach +60°C (140°F) (the maximum found in Hungary) lateral track displacements will occur. A track which lies on a well-compacted ballast section will displace up to 1.4mm (.056 in.), but sufficient elasticity remains in the ballast after machine compaction for all the displacement to be recovered. Track on an uncompacted ballast section, however, can have initial displacements of 2 to 5mm (.08 to 2 in.). In this case, approximately one half of the displacement will be recovered when the rails cool at night. For this reason, ballast compaction is always specified.

(b) Poland

The PKP's recent emphasis on post-maintenance ballast compaction has been focused on attaining a maximum level of track homogeniety rather than maximum track stiffness. That is, the maintenance philosophy is to reduce differential track irregularities rather than the total amount of track movement. Preliminary Polish experiments with ballast compactors have demonstrated that the total track settlement is reduced after compaction; however, the differential settlement is increased. Consequently, the PKP uses ballast compactors only where the potential for lateral track buckling exists; that is, on newly laid track with CWR. Post-maintenance tamping is used only where the danger of buckling is minimal.

THE EFFECT OF BALLAST SIZE

The effect of ballast size and gradation on lateral resistance is summarized in Table 4-4 below. The recommended ballast gradation of the MAV is 30/65mm (1.21/2.6 in.) or 25/55mm (1/2.2 in.), but the actual standard is 20/55mm (.8/2.2 in.). Table 4-5 presents the effect of ballast fouling on lateral resistance . Current MAV practice is to accept 40% fouling as the limit before requiring complete ballast cleaning. A more detailed discussion on ballast was presented in Chapter 3 of this report.

Table 4-4

Effect of Ballast Size

Tie Type	Ballast Size mm**	q_s @ f_l* %
Concrete	40/65	100
Wood	40/65	100
Concrete	25/65 and 25/40, 1:1 mix	120
Wood	25/65 and 25/40, 1:1 mix	120
Concrete	40/65 and 25/40, 1:1 mix	116
Wood	40/65 and 25/40, 1:1 mix	116
Concrete	25/65	114
Wood	25/65	113
Concrete	25/40	90
Wood	25/40	88

* f_l = Limit of elastic response
See Figure 4-1

** 25mm = 1 in., 40mm - 1.6 in., 65mm = 2.6 in.

Table 4-5

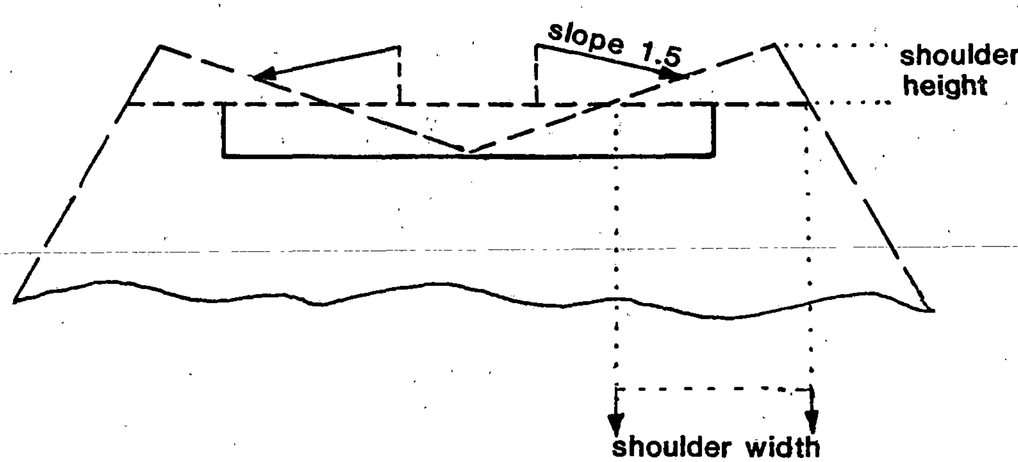
Effect of Ballast Fouling on Lateral Resistance

Type	% Fouling by WT.	% Decrease of q_s	
		Concrete	Wood
Sand/Coal	10%	4%	5%
	25%	18%	19%
	30%	21%	24%
	40%	27%	32%
Wet Clay/Coal	40%	59%	63%

THE EFFECT OF SHOULDER CONSTRUCTION -- HUNGARY

The Hungarians have investigated the effect on lateral resistence of sloped shoulder construction as illustrated below:

Figure 4-3



Tests of sloped ballast shoulders (i.e. shoulders sloping upwards at a 1:5 ratio instead of being horizontal) show a net increase in lateral resistance of 5-7% at a 45 cm (17.55 in.) shoulder width, if the cribs remain full. However, if the additional ballast material is borrowed from the crib then there is a loss of side resistance which results in a 18-25% net total loss of lateral resistence.

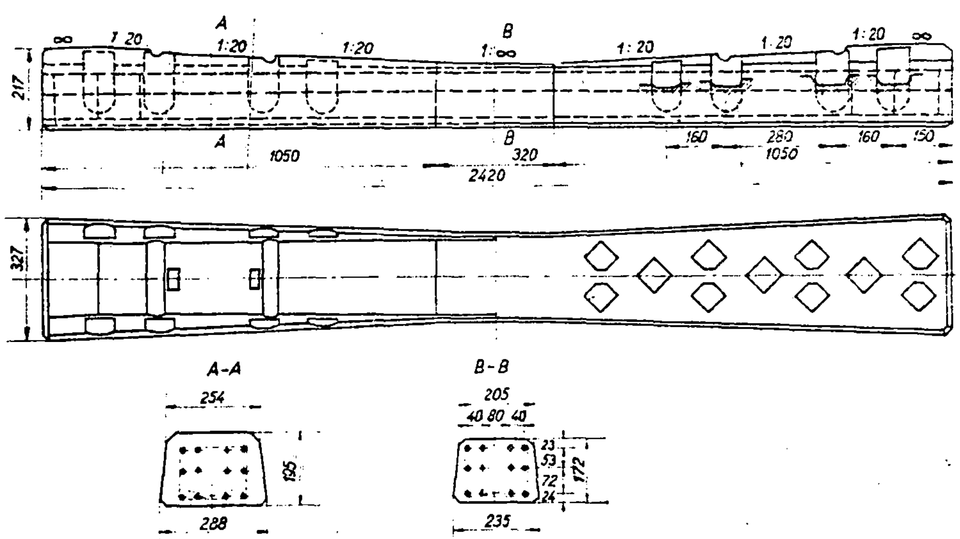
The Hungarian experiments were conducted on a track section with a standard MAV ballast shoulder width of 40cm (15.6 in.). In U.S. practice, with wood ties spaced at 19 1/2 inches and concrete at up to 24 inches on centers, this would translate to effective ballast shoulder widths of 9 3/4 inches for wood ties and 12 inches for concrete. Given a possible ±2 inch deviation in tie spacing, indications are that ballast shoulder widths of 12 inches and 14 inches for wood and concrete respectively would give maximum benefit to the track for resistance to lateral displacements.

THE EFFECT OF
TIE SHAPE -- HUNGARY

The MAV has also conducted experiments on increasing the side and bottom resistance by using different shapes and surface indentations. These experiments demonstrated that reducing the width of the tie in the center would increase lateral resistance by as much as 24%. MAV's recommendation is to develop concrete ties for future use with narrow centers and indented bottoms as illustrated below:

Figure 4-4

Experimental Concrete Tie Design



The theory is being considered that side indentations would provide an even further increase. Tests conducted on narrow center ties with bottom identations indicate that increased lateral resistance values up to 35% can be achieved if this configuration of tie is employed with side indentations.

The Hungarian research has demonstrated the importance of tie weight in lateral resistance. For this reason, concrete ties are considered 2 to 3 times better than wood for resistance to lateral displacements. The stiffness of concrete ties, however, is a draw back. Elastic fastenings have been used experimentally to improve compliance characteristics.

LATERAL RESISTANCE TESTS ON CONCRETE TIES - POLAND

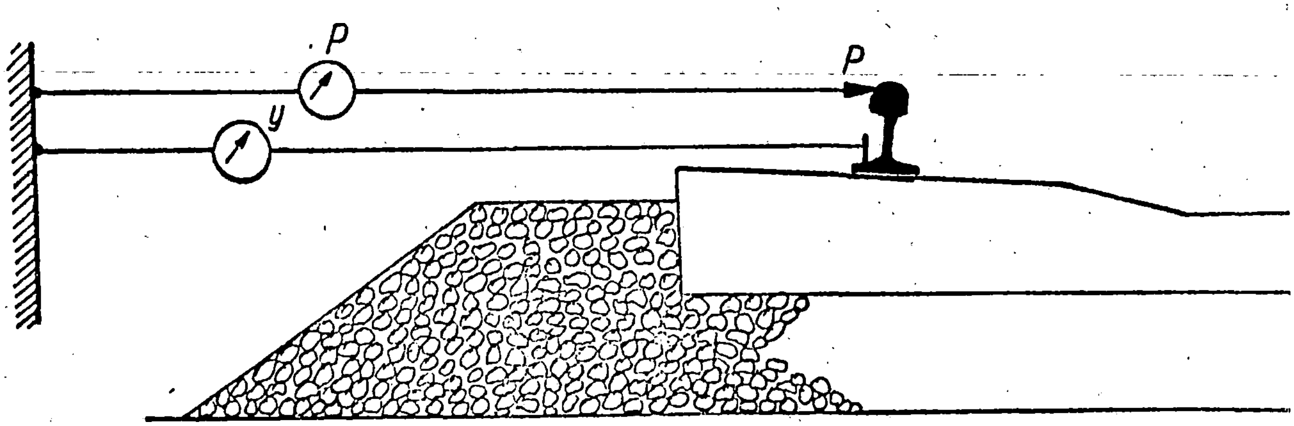
The COBiRTK has conducted numerous lateral resistance tests in their laboratory using a push test as shown in photographs 4-1 through 4-3 at the end of the chapter. These tests included lateral resistance measurements of individual ties and complete track panels. The test variables are described in Table 4-6.

(a) Lateral Resistance of Individual Ties

The relationship was measured between the forced "P" applied to the tie and its effect, that is, the displacement "y" of the tie as illustrated in Figure 4-5.

Figure 4-5

Schematic of the Lateral Resistance Test for an Individual Tie



In the course of the test, two rail portions were fastened to each tie, having a length equal to the tie spacing. The actual loading of a tie in a track carrying no traffic load was thus simulated. A horizontal "P" force, parallel to the tie center line was applied to the rail head at 14 mm (0.55 in.) below the tread. The lateral tie displacement "y" was recorded using mechanical detecting devices of an 0.01 mm (0.0004 in.) accuracy, the measuring point being selected at the fastener bolt.

Table 4-6

Test Variables for Lateral Resistance Tests on Concrete Ties

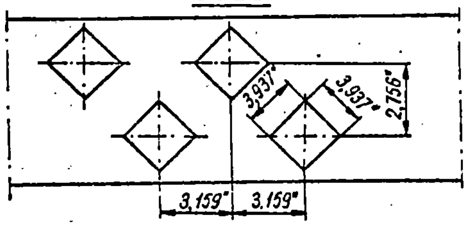
Types of Ties:

DOT1, DOT2, DOT3, INBK3, 1NBK7. Characteristics of these ties are presented below:

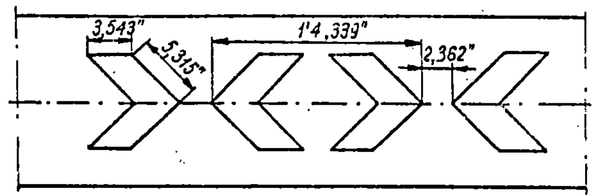
Type of tie	Mass (kg)	Mass (lb)	Bearing Area (cm^2)	Bearing Area (sq. in)	End Area (cm^2)	End Area (sq. in.)
DOT1	314	692	7968	1235	535	82.9
DOT2	306	675	7968	1235	535	82.9
DOT3	306	675	7968	1235	535	82.9
INBK3	235	518	5473	848	292	45.3
INBK7	262	578	6402	992	440	68.2

DOT1, INBK3 and INBK7 have a smooth non-recessed bottom. DOT2 and DOT3 have 10mm (.39 in.) deep recesses as shown below:

DOT2



DOT 3



Type of Rail: S60 rail

- Mass — 60.34 kg/m (121.64 lbs/yd)
- Height — 172 mm (6.77 in.)
- Railfoot width — 150 mm (5.91 in.)
- Moment of inertia — 3055 cm^4 (73.4 in^4)

Type of Fasteners: K-Type fasteners

Ballast Gradation:

Crushed granite ballast of two different grades: 30/60 mm. (1.2/2.4 in.) and 30/40 mm. (0.79/1.57 in.)

Ballast Shoulder Width:

Tie shoulder width was varied to 152.4 mm. (6 in.), 304 mm. (12 in.) and 457.2 mm (18 in.)

Tie Spacing:

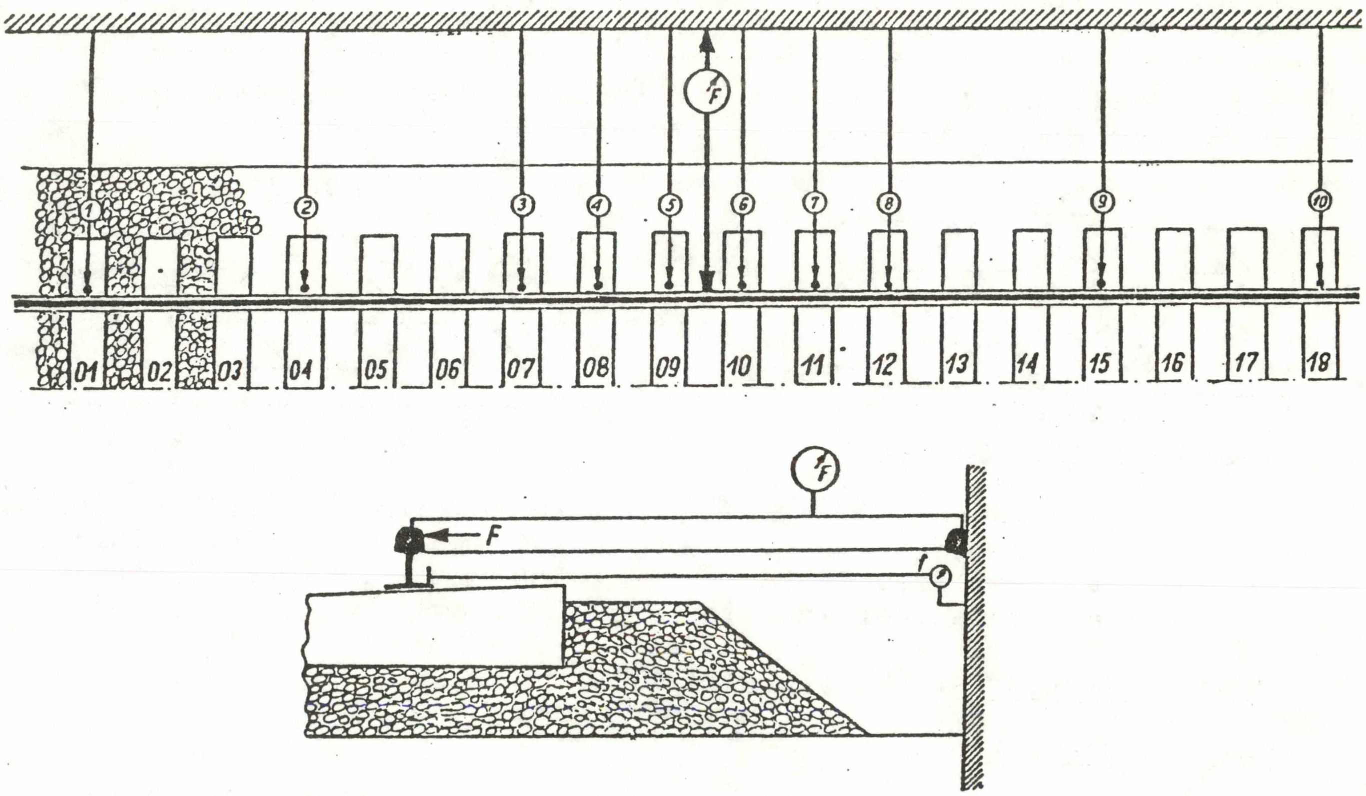
The ties were spaced for the test of 53.34 cm. (21 in.) and 60.96 cm. (24 in.)

(b) Lateral Resistace of Track Panels

The relationship was determined between the force "F" applied to the rail head at 14 mm (0.55 in.) below the tread and the panel's displacement "f" under this force at its mid-span as illustrated in Figure 4-6.

Figure 4-6

Schematic of Track Panel Lateral Resistance Measurements



The displacement "f" was calculated as the arithmetic mean of the displacements of the two ties adjacent to the application point of "F". At the same time, the displacements were measured for other points of the track panel, including the two ties at its extremities.

The "f" displacement of each individual tie was measured using a mechanical device of a 0.05 mm. (0.002 in.) accuracy. The measuring points were located at the fastener bolts.

The lateral resistance of a panel was accepted as the "F" force under which the panel displaced itself over f=5 mm (0.02 in.) at its mid-length. This is an arbitrary but accepted criterion which could be used, for example, to analyze the lateral stability of a continuous welded track.

No displacement was found in any of the tests at the panel extremities, within the whole "F" range. This observation was used for a correct selection of the track panel length. The number of ties within this length was determined by their spacing. With a 21 in. spacing, 20 ties were assembled into the panel, with a 24 in. spacing their number was 18.

The lateral resistance values for individual tie displacements are presented in the Table 4-7 and for track panel displacement in Table 4-8.

The analysis of correlation between the lateral resistance of individual ties and the entire track panels indicated the following conclusions:

- A significant correlation (a coefficient greater than 0.8) between the lateral resistance of individual ties and that of entire track panels.
- The lateral resistance value is influenced by the configuration of the tie; for example, such parameters as the area of its end and bottom surface, varied cross-sections in the center and at the ends of the tie.
- The recessed bottoms on ties (DOT2 and DOT3) insignificantly effected lateral resistance in comparison with the smooth bottom tie (DOT1)
- Diverse ballast grades had an insignificant effect on lateral resistance.

- Ballast shoulder width significantly effected the lateral resistance of both individual ties and track panels.

- Considerably greater variations may be observed in the lateral resistance of track panels than in that of individual ties.

The last conclusions may be partially explained by the track conditions. In this specific experiment, the heterogenity of the ballast layer, both under the ties and at both shoulders may have affected lateral resistance.

The non-homogenous fastener conditions, unequally tightened bolts, gaps between the railfoot edge and the sole plate ribs, may also influence this conclusion.

Lateral resistance values for individual ties/displacement y = 1 mm/
$\bar{P}$ - mean value [kN]
S_p - standard deviation [kN]
n - number of measurements taken

Type of tie	Ballast grade [mm]	Shoulder width [inch]											
		0			6			12			18		
		$\bar{P}$	Sp	n	$\bar{P}$	Sp	n	$\bar{P}$	Sp	n	$\bar{P}$	Sp	n
DOT1	30/60	1.50	0.30	146	10.70	1.23	156	11.10	1.16	162	11.30	1.30	156
	20/40	1.80	0.29	150	10.10	1.25	156	10.70	1.20	160	10.80	1.38	156
DOT2	30/60	1.90	0.29	154	-	-	-	-	-	-	-	-	-
	20/40	2.00	0.30	162	-	-	-	-	-	-	-	-	-
DOT3	30/60	2.10	0.25	164	-	-	-	-	-	-	-	-	-
	20/40	2.30	0.38	148	-	-	-	-	-	-	-	-	-
INBK7	30/60	2.40	0.26	160	5.30	0.64	156	5.80	0.59	160	-	-	-
	20/40	1.40	0.28	154	5.10	0.56	156	5.40	0.51	152	-	-	-
INBK3	30/60	1.40	0.16	156	4.60	0.45	156	4.80	0.40	146	-	-	-
	20/40	1.30	0.18	156	3.90	0.43	156	4.10	0.42	160	-	-	-

TABLE 4-7

LATERAL RESISTANCE VALUES FOR INDIVIDUAL TIES

Lateral resistance values for track panels /displacement f = 5 mm/
$\bar{F}$ - mean value [kN]
S_F - standard deviation [kN]
n - No of measurements taken

Type of tie	Tie spacing [inch]	Ballast grade [mm]	Shoulder width [inch] 0			6			12			18		
			$\bar{F}$	S_F	n	$\bar{F}$	S_F	n	$\bar{F}$	S_F	n	$\bar{F}$	S_F	n
DOT1	21	30/60	32.0	3.3	4	56.3	5.6	4	70.2	7.0	4	74.0	7.0	4
		20/40	25.0	2.8	4	46.2	4.6	4	57.4	5.8	4	62.5	6.0	4
	24	30/60	25.0	2.2	4	47.8	4.8	4	60.0	5.6	4	63.8	6.0	4
		20/40	22.3	2.6	4	42.5	3.9	4	54.2	5.2	4	57.0	5.8	4
DOT2	21	30/60	34.0	3.0	4	-	-	-	-	-	-	-	-	-
		20/40	32.6	3.9	4	-	-	-	-	-	-	-	-	-
	24	30/60	27.5	2.6	4	-	-	-	-	-	-	-	-	-
		20/40	26.5	2.5	4	-	-	-	-	-	-	-	-	-
DOT3	21	30/60	34.5	3.6	4	-	-	-	-	-	-	-	-	-
		20/40	32.4	3.7	4	-	-	-	-	-	-	-	-	-
	24	30/60	28.5	2.4	4	-	-	-	-	-	-	-	-	-
		20/40	28.0	3.1	4	-	-	-	-	-	-	-	-	-
INBK7	21	30/60	16.8	1.3	4	41.8	4.0	4	56.0	5.2	4	-	-	-
		20/40	15.2	1.2	4	38.2	3.5	4	51.1	4.6	4	-	-	-
	24	30/60	15.0	1.2	4	39.5	3.6	4	53.0	4.9	4	-	-	-
		20/40	13.2	1.1	4	35.1	3.6	4	46.0	4.8	4	-	-	-
INBK3	21	30/60	15.7	1.4	4	40.4	4.0	4	55.0	6.2	4	-	-	-
		20/40	13.3	1.3	4	33.6	3.0	4	46.8	5.4	4	-	-	-
	24	30/60	14.2	1.4	4	37.4	3.5	4	50.0	4.8	4	-	-	-
		20/40	12.0	1.3	4	31.4	3.0	4	41.9	4.0	4	-	-	-

TABLE 4-8

LATERAL RESISTANCE VALUES FOR TRACK PANELS

SECTION B: UNITED STATES

Track lateral resistance measurements to ascertain the influences of wood versus concrete tie track, ballast type and shoulder width, and consolidation by tonnage have been undertaken in the United States only to a minimal degree. The effects of ballast size, degree of compaction/settlement, and traffic conditions on lateral resistance are summarized in Lateral Resistance of Railroad Track(1) and Evaluation of Lateral Track Strength Measurements at FAST(2). These studies, conducted from 1977-1980, assessed track lateral strength using panel pull test techniques.

Additional lateral resistance tests employing a single tie push technique have been conducted at FAST, and more recently at Readville, Massachusetts on AMTRAK (3). This test technique however proved to be disadvantageous because of extreme variability of ballast condition from tie to tie, which necessitated numerous individual tests to produce an aggregate average panel resistance number.

Further research currently under way at Readville is focused on determining the proper test technique to measure track lateral resistance, and is being conducted by the Transportation Systems Center (TSC) for the FRA. This research involves the comparison of "rigidized" panels (sections of rail cut out from contiguous track and cross-braced) to "contiguous" panels (rail section in place in contiguous track, and without cross-bracing), to determine the applicability of these test configurations. Controlled laboratory tests similar to the track panel pull tests performed in Hungary are being conducted at the AAR Track Laboratory in Chicago under the direction of TSC. The primary intent of these tests is to determine the influence of ballast shoulder width, ballast consolidation, and testing technique on lateral resistance.

---

(1) I.A. Reiner, Lateral Resistance of Railroad Track, FRA/ORD - 77/41, Department of Transportation, Federal Railroad Administration, August, 1977.

(2) Francis E. Dean and Andrew Kish, Evaluation of Lateral Track Strength Measurements at FAST, June, 1980.

(3) Goldberg-Zoino and Associates Inc., Single Lateral Tie Push Tests, Readville, Massachusetts, December, 1980.

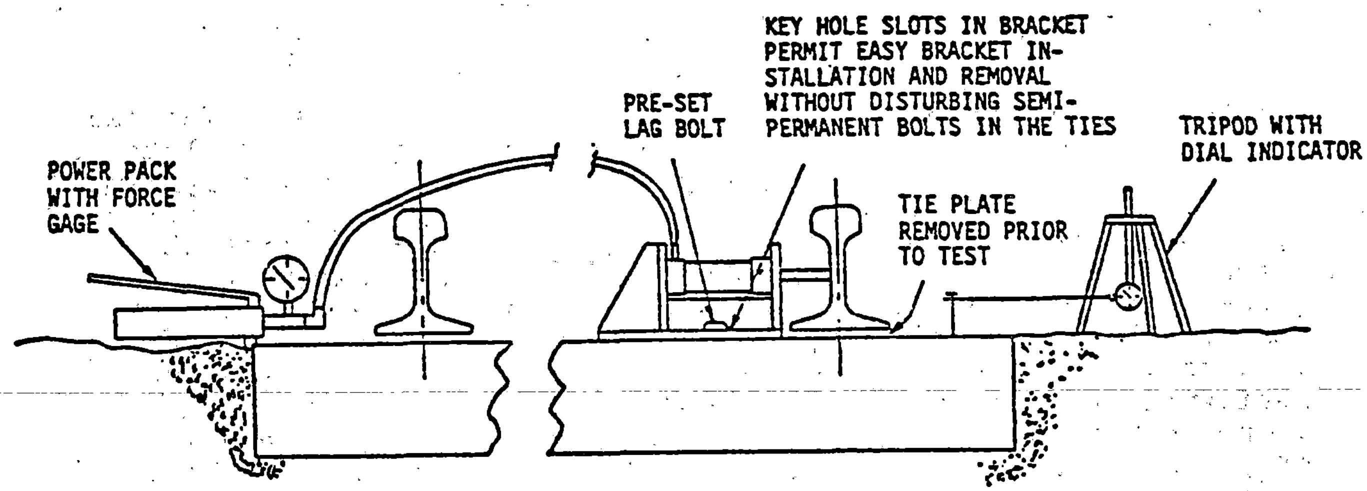
THE EFFECTS OF
TAMPING AND COMPACTION

Unlike Hungary, vibratory compaction of ballast is not a standard practice in the U.S. Currently, only 36 vibratory consolidators are in use on U. S. railroads, 9 of which are operated by Amtrak on the Northeast corridor. Several railroads are currently evaluating vibratory compactors for potential use in regular track maintenance.

Experiments conducted for the FRA using individual tie push techniques indicated increases in lateral resistance with ballast consolidation.(4) A diagram of the individual tie push test technique is shown in Figure 4-7 below.

Figure 4-7

Instrumentation for Lateral Tie Resistance Test



Tests conducted on the Chessie Railroad System using panel pull techniques indicated increases in lateral resistance with vibratory compaction under several conditions.(5) Figure 4-6 below indicates the relative lateral track resistance based on yield forces. Panel resistance for wood ties in undisturbed in-situ ballast was the control statistic set at 100%.

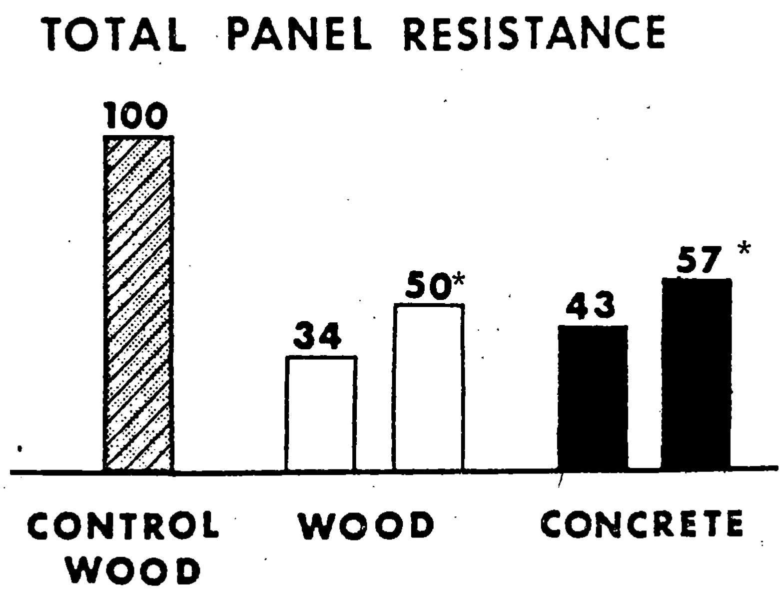
---

(4) E.G. Cunney, J.T. May, H.N. Jones, Effects of Accelerated Ballast Consolidation, March, 1977.

(5) Reiner, Lateral Resistance - Ibid.

Figure 4-8

Relative Lateral Track Resistances Based on Yield Forces
(All Panels)



*Compacted

Researchers at FAST collected experimental data immediately before and after tamping, as part of the investigation of the lateral instability in a 5-degree curve. The tamping resulted in a reduction in lateral load at 0.2" deflection of 4 kips in the first test and 4.5 kips in the second test for an average reduction of 31 percent. This indicates that sun kinks or lateral instabilities are more likely to occur just after maintenance affecting ballast compaction. A sun kink which occurred at 61 MGT was preceded by an unusual amount of such maintenance.

Studies were also conducted at the State University of New York (SUNY) at Buffalo to measure the difference in lateral resistance and other properties when ballast sections were subjected to vibratory consolidation versus mechanical tamping.[6] These tests were conducted on the Canadian National, Illinois Central Gulf, and Southern Railroads. Measurements of lateral resistance were obtained before and after tracks maintenance using the single tie push test technique.

The results indicated that mechanical tamping caused a significant reduction in the lateral resistance of the ballast when compared to lateral resistance for undisturbed ballast. Reductions in lateral resistance also occurred when ballast was subject to vibratory compaction, but the decrease was less then for mechanical tamping. Figures 4-9 and 4-10, respectively, illustrate a typical vibratiory compactor and the positioning of the ballast crib and shoulder compaction plates.

THE EFFECT OF BALLAST SIZE

Specific research has not been performed in the U.S. on the effects of ballast gradation and fouling on lateral resistance. Ballast gradations in the U. S. have been established for many years by the AREA and fouling is not considered detrimental by industry maintenance personnel except when pumping occurs.

---

(6) Carmen M. Panuccio, Tai-Sung Yoo, Earnest T. Selig, Mechanics of Ballast Compaction, Volume 3, Field Test Results for Ballast Physical State Movement, U.S. DOT, Transportation System Center, Cambridge, Mass.

Figure 4-9

Typical Ballast Crib and Shoulder Compaction Machine

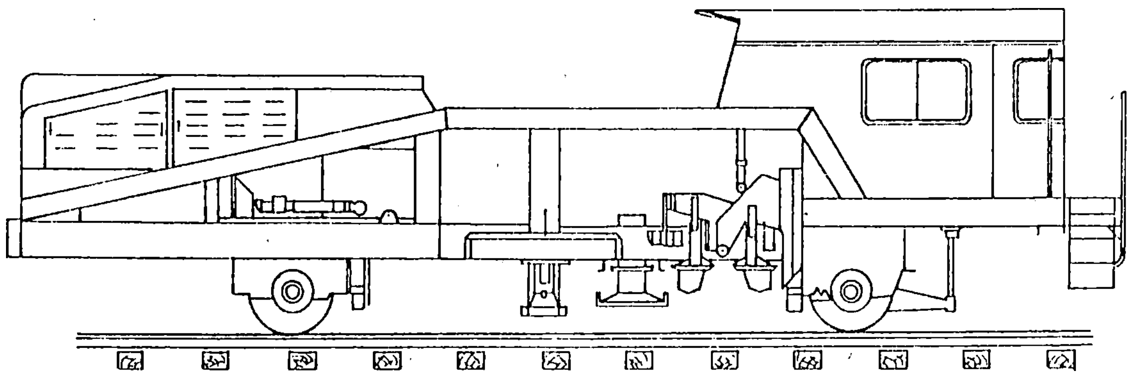
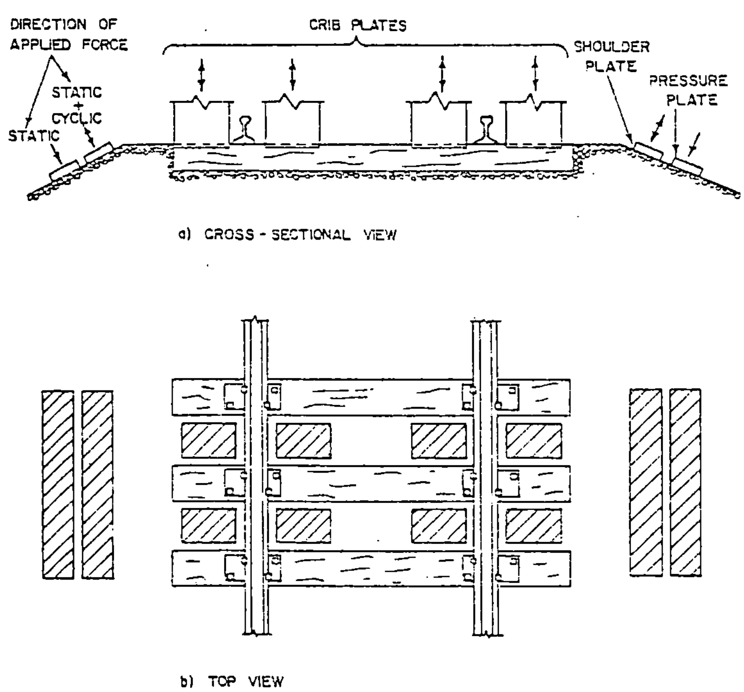


Figure 4-10

Location and Size of Ballast Crib and Shoulder Compaction Plates



THE EFFECT OF SHOULDER CONSTRUCTION

Current AREA ballast specifications recommend 6 inch shoulder widths to provide adequate lateral resistance. However, shoulder widths of 6 inches are often considered inadequate on curves, and widths of 12-16 inches are frequently considered necessary. Experiments were conducted at FAST between 1976 and 1980 to determine the characteristics of maintenance required on a tangent built with shoulder widths of 6 and 18 inches respectively. Maximum tonnage over the tracks was 325 million gross tons. Although measurements of lateral resistance forces were not conclusive in this experiment, test results indicated that track with 6 inch shoulders required significantly more rail joint maintenance than track with 18 inch shoulder (7). Experiments conducted by University of Illinois (8) and other research facilities indicated that lateral resistance increased as shoulders were widened to 12 to 14 inches. However, at shoulder widths greater than 12 to 14 inches, only minimal incremental increases in lateral resistance were noticed. Further insight into the most effective shoulder width for adequate lateral resistance on curves should result from the previously discussed controlled laboratory lateral resistance tests currently being conducted by the AAR Track Laboratory.

Results of Hungarian research similarly indicated that no substantial improvement in lateral resistance occurred when shoulder widths were increased beyond 30 cm (12 inches). However, unlike Hungary, the U.S. has not conducted formal research on sloped ballast sections, although some railroads do practice piling ballast on the shoulders of tight curves.

---

(7) A. Sluz, B. Bosserman, FAST Ballast Shoulder Width Experiment, to be published.

(8) W.W. Hay, H.C. Peterson, D.E. Plottsin, P.T. Bakas, Lateral Stability of Ballast, Report # FRA/ORD - 77/61, U.S. DOT, FRA, September, 1977.

THE EFFECT OF TIE SHAPE

The effect of tie shape on lateral resistance has not been investigated in the U.S. However comparisons of lateral resistance between concrete and wood ties over a 10 tie span were made at FAST during the period from 1976 to 1979.(9)(10) Measurements of the lateral strength of unloaded track showed that concrete tie track had consistently higher strength than wood tie track. In comparing overall mean loads for the two track systems, the concrete tie track had 149 percent greater mean lateral strength at small deflections of .05 inches and 62 percent greater mean lateral strength at larger deflections of 0.2 inches.

Measurements of lateral strength were taken at infrequent intervals on tangent or spiral concrete and wood tie track. Pull type tests were conducted by applying a lateral load through a yoke to two points on a rail where the rail intersected the line of action of the force, and on five ties either side of the line of action. Load application was continued until a rail deflection of 0.25 inches was obtained. No vertical loads were applied. Figure 4-11 illustrates this procedure for testing lateral resistance.

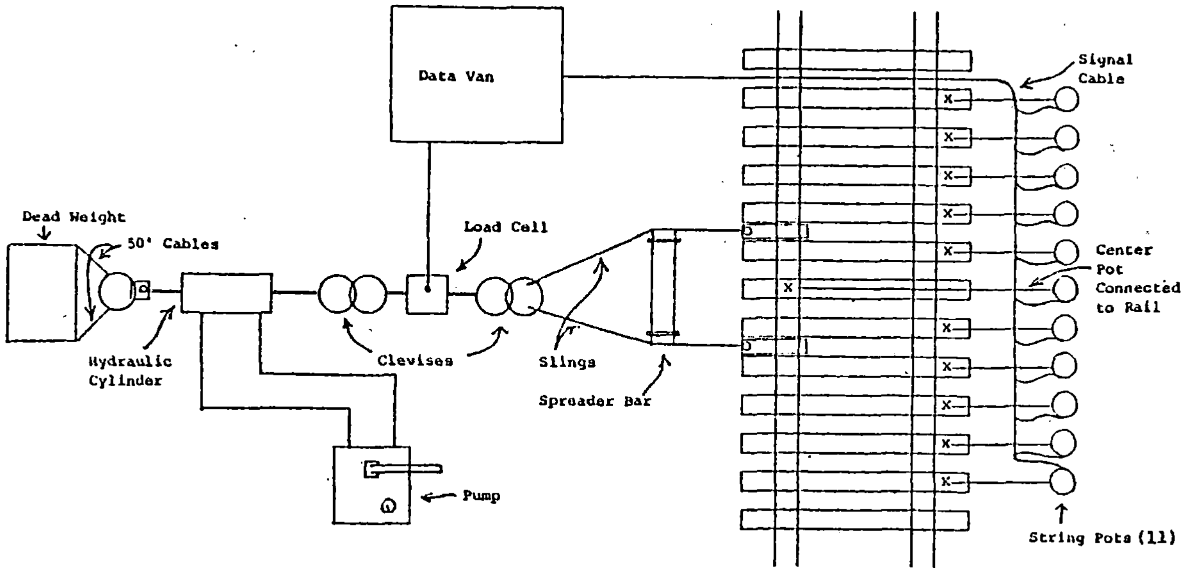
---

(9) Concrete and Wood Tie Performance Through 150 Million Gross Tons, FAST Transportation Test Center, Pueblo, Colorado, Interim Report # FRA/TTC - 80/02, March, 1980.

(10) Francis E. Dean, Concrete and Wood Tie Track Performance Through 425 Million Gross Tons at the Facility For Accelerated Service Testing, Battelle, Columbus, Ohio, August, 1980.

Figure 4-11

Equipment for Lateral Track Stiffness Test



Tests were run on track with the following characteristics:

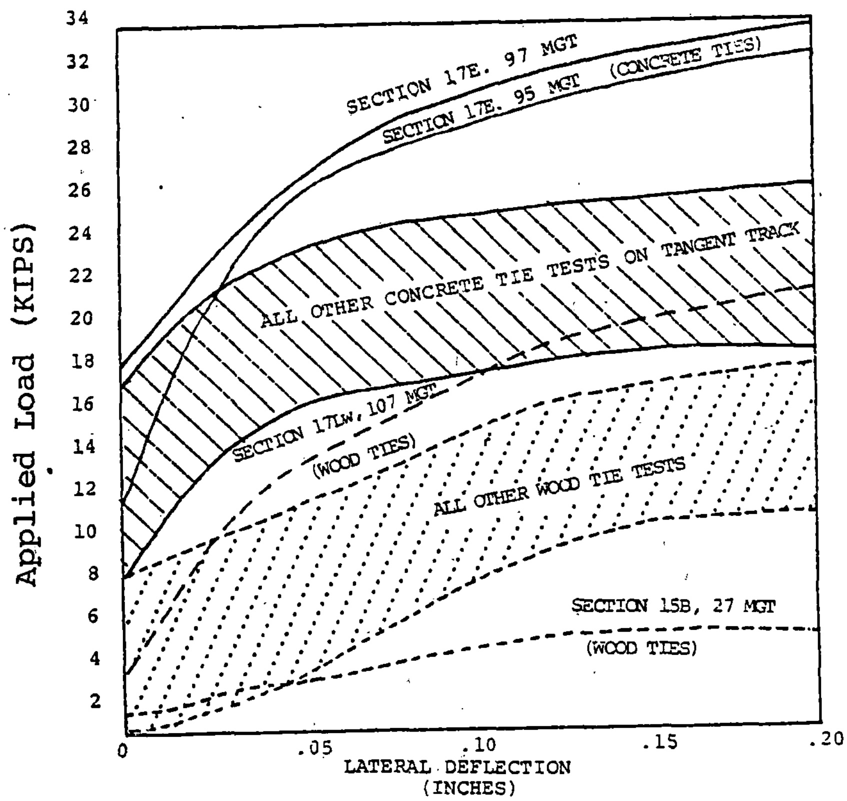
Tie Type	Tie Spacing	Contour	Rail	Ballast Shoulder	Segment***
Concrete	24"	Tangent	CWR	12"	17-E
Concrete*	24"	5° Curve	CWR	12"	17-D
Wood	19.5"	Tangent	BJR**	6"	15-A
Wood	19.5"	Tangent	BJR	18"	15-B
Wood	19.5"	Tangent	CWR	12"	$17\text{-}L_2$

* One-time-only test
** Bolted Joint Rail
*** Segments of the FAST track--see Figure 2-3

The purposes of the tests were to determine the possible effects on both small-displacement lateral stiffness and ultimate yield load of factors such as wood vs. concrete ties. The regular-interval measurements produced only one consistent trend. The concrete tie track produced consistently higher results both in the initial, small displacement phase before ballast yielding and in the eventual yield load. Figure 4-12 illustrates this trend.

Figure 4-12

Ranges of Applied Load vs. Lateral Deflection for all Wood Tie and Concrete Tie Tests on Tangent Track



The figure provides plots of the extreme cases of lateral load vs. lateral displacement as individual curves and an enclosed range for the rest of the data for each type of track. The mean load at the "large" lateral deflection of 0.2 inches was 62 percent higher on concrete tie track than on wood tie track (22.5 kips for concrete ties vs. 13.9 kips for wood ties). At the "small" deflection of 0.05 inches, the mean load on concrete tie track was 149 percent higher than that on wood tie track.

The two enclosed ranges of points shown in Figure 4-10 differ in these important respects:

a. Concrete tie track demonstrate higher initial stiffness than wood tie track as evidenced by higher initial breakout loads (loads at zero displacement) and larger increments of slippage in the small deflection range, and

b. Concrete tie track shows consistently higher maximum lateral resistance loads than wood tie track.

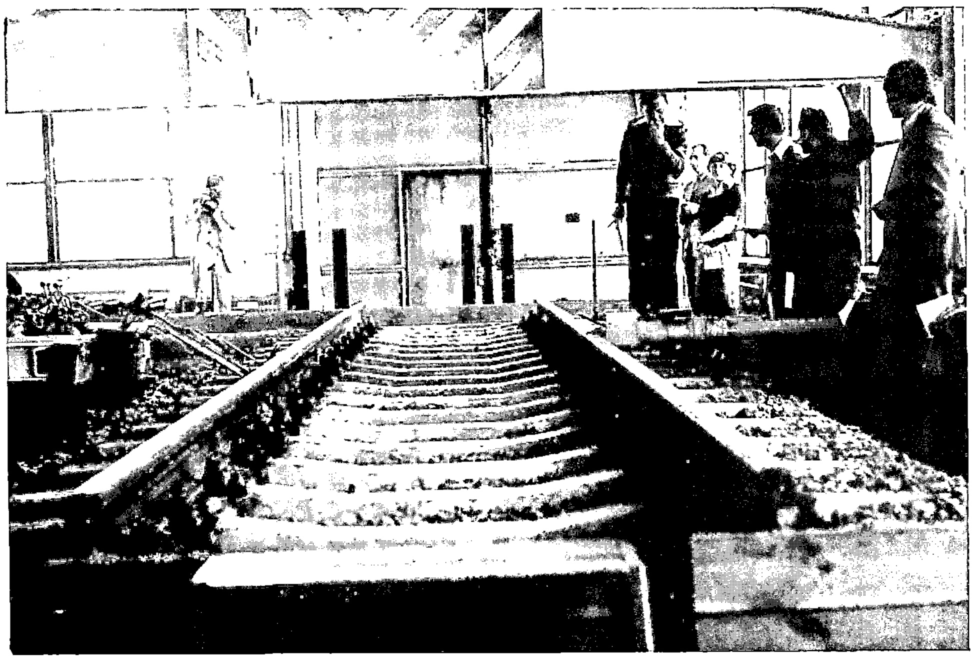


Photo. 4-1. Polish Laboratory Lateral Resistance Testing. Arm at Right Pushes Against Rail.

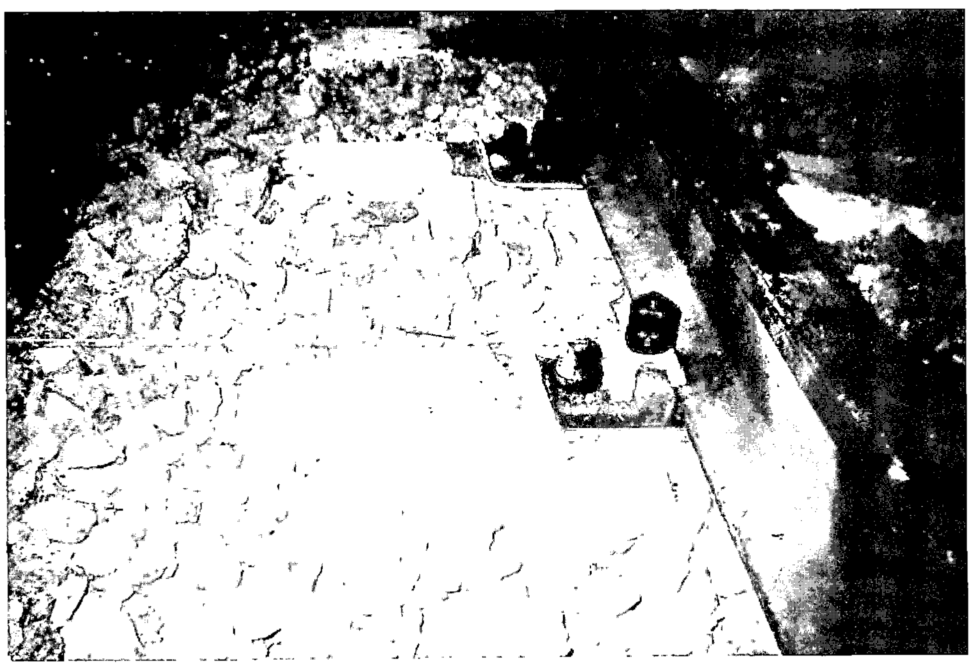


Photo. 4-2. Polish Laboratory Lateral Resistance Testing. Attachment of Deflection Measurement Wire To Fastening System.

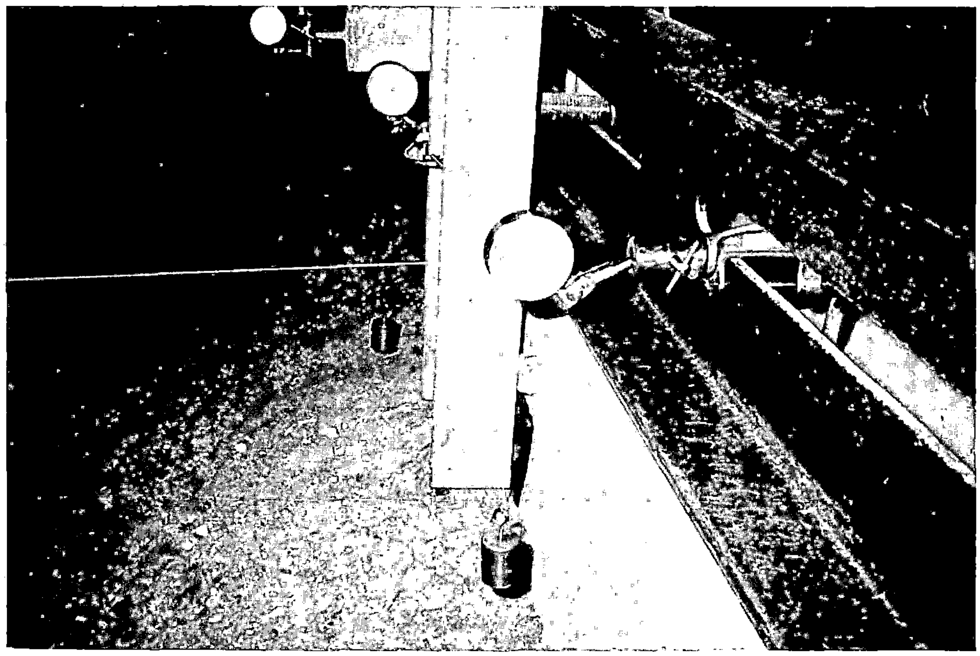


Photo. 4-3. Polish Laboratory Lateral Resistance Testing. Deflection Measurement Gages.

CHAPTER 5
BUCKLING OF TRACK

SECTION A: EASTERN EUROPE

BUCKLING TESTS -- HUNGARY

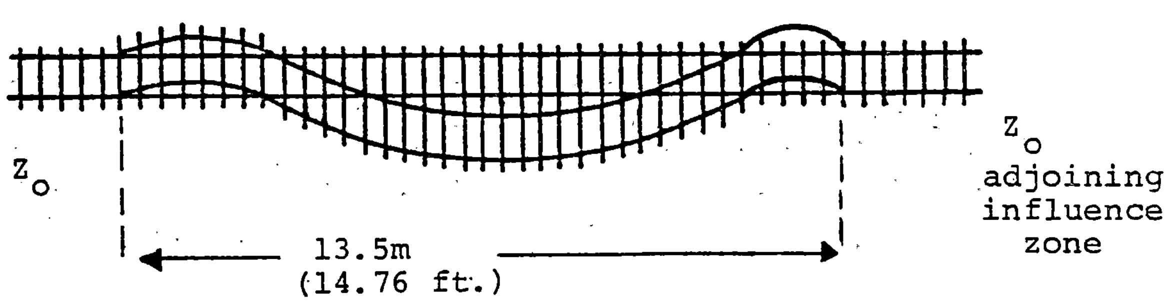
As early as 1930, the Hungarian Railroad Scientific Research Institute (VTKI) initiated studies on the stability of long welded rails. In early experiments near Moragy, a section of track with one end fixed was pushed longitudinally using hydraulic jacks to simulate thermal load. The results were inconclusive, and further investigations were discontinued until the 1950's when new analytical and experimental studies were initiated under Dr. Nemesdi primarily in the areas of:

- o Determination of the length of rail influenced by buckling
- o Determination of track rigidity, EI, including the effect of fastener torsional resistances
- o Development of analytic expressions for critical buckling loads and comparisons with test results.

Based on several buckling tests, Nemesdi concluded that the primary buckled zone typically is about 13.5 meters or 44.28 yds.

Figure 5-1

Primary Buckled Zone and Typical Mode Shape



In addition, several longitudinal resistance panel push tests indicated the following values for longitudinal resistance, r_o;

$r_{o_{avg}}$ = 10 kp/cm (typical)
(56.5 lb./in.)

$r_{o_{frozen}}$ = 20-30 kp/cm (very stiff)
(113-165.5 lb./in.)

$r_{o_{wet}}$ = 1-3 kp/cm (5.7-17 lb./in)
(extremely high moisture content)

These values in conjunction with typical values of axial loads in the rails implied an adjoining zone, z_o, of about 30-80 meters (99-264 ft.) depending on the quality of the track. This value together with the value of 13.5 meters (44.28 ft.) for the primary buckled zone defines a total buckled influence zone of 173.5 meters (569.08 ft.). The design choice for subsequent buckling tests was substantially influenced by these results and was set at 192 meters (629.8 ft.).

Various tests for the determination of track lateral rigidity included:

1. Hanging a 13.5 meter (44.28 ft.) long track panel under its own weight and measuring deflections. The elastic beam equation was utilized to compute EI.

2. Loading a 13.5 meter (44.28 ft.) track panel (without ballast) laterally with a load P, and measuring the corresponding deflection δ_o; EI was computed from the simply supported beam bending expression:

$$(EI)_{panel} = \frac{(13.5)^3 \cdot P}{48\ \delta_o}$$

Using the measured and computed values for EI, r_o and lateral resistance, Nemesdi's analytic prediction for critical buckling load was of the order of 200-220 metric tons (220-242 tons) per rail. These values could not be experimentally confirmed. (Note: typical values for buckling loads are approximately 80-120 metric tons or 88-132 tons per rail.)

The continued installation of CWR has resulted in a growing concern for safety because of possible loss of lateral stability. In 1960 the VTKI conducted a new series of buckling test investigations aimed at determining the critical buckling temperatures for various track parameters and conditions including:*

- Concrete and wood tie track
- Tangent track subject to varying degrees of tamping
- Tangent track with built in imperfections
- Curved track (with varying degrees of curvature)
- Tangent and curved track with fasteners loosened
- Tangent and curved track under dynamic loads (e.g., under load imposed by moving vehicle)
- Combinations of the above.

Some of the important test design parameters are summarized in Table 5-1. Photographs of the test facility are presented at the end of the chapter.

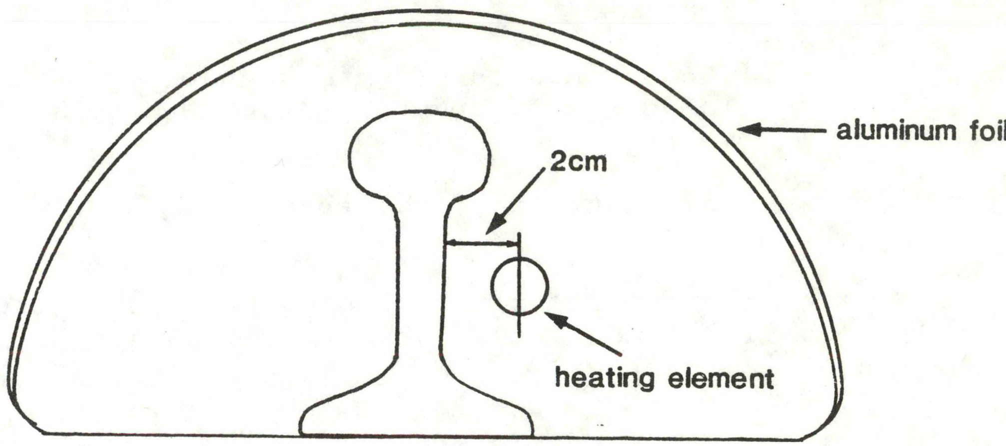
---

* The results of some of these investigations are available in the various yearbooks of the Railway Scientific Research Institute. See Bibliography in the Appendix.

Table 5-1

Test Methodology

Test set up:	192 meter (629.76 ft.) long test section with 48.3 kg/m (97.39 lbs/yd) rail, and GEO (K) type fastener, 65 cm (25.35 in.) tie spacing, 45 cm (17.55 in.) shoulder width. 50 cm (19.5 in.) ballast depth, consisting of 40/65 basalt ballast.
Rail heating:	2m (6.54 ft.) long, 220 volt, 7 watt/cm (2.7 watt/in) heating elements were placed 2 cm (.78 in) from the web of rail on the outside. To prevent heat loss, the rails were covered with .09 mm (.0036 in.) aluminum foil (illustrated below and in Photograph 5-3).



Power source:	Initially from an overhead catenary, transformer; subsequently from an M44 type diesel-electric locomotive.
Measurements:	Lateral, vertical, and longitudinal displacement with .01 mm (.0004 in.) accuracy deflectometers; rail temperatures using both thermocouples and contact thermometers with readings taken at about 10 minute or 10 degree intervals.
Dynamic loading:	In several test series involving dynamic loads, load was imposed by 10 open XP type 2 axle box cars loaded with ballast and concrete cross ties to 25 ton (27.5 tons) capacity (Photograph 5-4). The loaded cars were rolled in two groups - one three car consist and one four car consist at speeds of 40-50 km/hr. (24.8-31 mi/hr), so that the locomotive pushing the cars did not contact the test section (for safety reasons).

The first series of tests conducted through 1967 consisted of completely buckling the track. Representative results are as follows:

1. A concrete tie test section, with an imperfection of 2 cm (.8 in.) over a length of 13.5 m (44.28 ft.) and hand tamped, buckled out at a Δt = 83.5°C (150.3°F) corresponding to P_{cr} = 254 metric tons (279 tons) . The buckled region was 43.8 m (143.67 ft.) with 6 half-wave shapes with maximum amplitude of .37m (1.21 ft.).

2. The test section as described in 1 above for machine tamping (instead of hand tamping) results in a Δt = 177°C (318.6°F) with P_{cr} = 341 tons (375 tons). The buckled region was 34.4m (112.8 ft.), with 9 half-wave shapes with maximum amplitude of .31m (1.01 ft.).

3. Test section as described in (1) except without imperfections yielded a P_{cr} = 262 metric tons (288.2 tons) and a Δt = 86°C (154.8°C). No explanation was available for the higher P_{cr} for (3) versus (1).

4. Test section as described in (1) except within the 13.5m region the GEO (K type) fastener bolt was 1/2 turn loosened, resulting in a Δt = 70°C (126°F) corresponding to P_{cr} = 213 metric tons (234.3 tons).

In general the range of the buckled region varied from 22 to 56 meters (72.15 ft.-183.66 ft.). Typical wave shapes consisted of 6-10 modes varying in length from 5 to 14m (16.41 to 45.93 ft.) and amplitudes 26-52 cm (10.14-20.28 in.). Most of the tests were accompanied by some vertical uplift varying from .002 to 3.31mm (.00008 to .1324 in.). Concrete ties exhibited lower buckling values than wood.

No explanation was provided for the very high values of ΔT required to induce buckling. Upon reviewing some ofthe Hungarian literature in this connection, it was found that substantial end displacement occurred between the heated and unheated zones, resulting in a partially constrained thermal expansion, hence a high ΔT.

Completely buckling the track entails considerable cost and requires a great number of tests of each series to obtain the lowest possible P_{cr}, which defines the smallest admissible safe temperature increase. Because of the cost and number of tests required, the VTKI changed the concept and philosophy of subsequent buckling tests. Starting with the 1967 experiments, the stability of the track was investigated to an increment just beyond the elastic limit (or to a point defined as the distortion limit or onset of buckling). The principle is illustrated in Figure 5-2 below:

Figure 5-2

Track Buckling

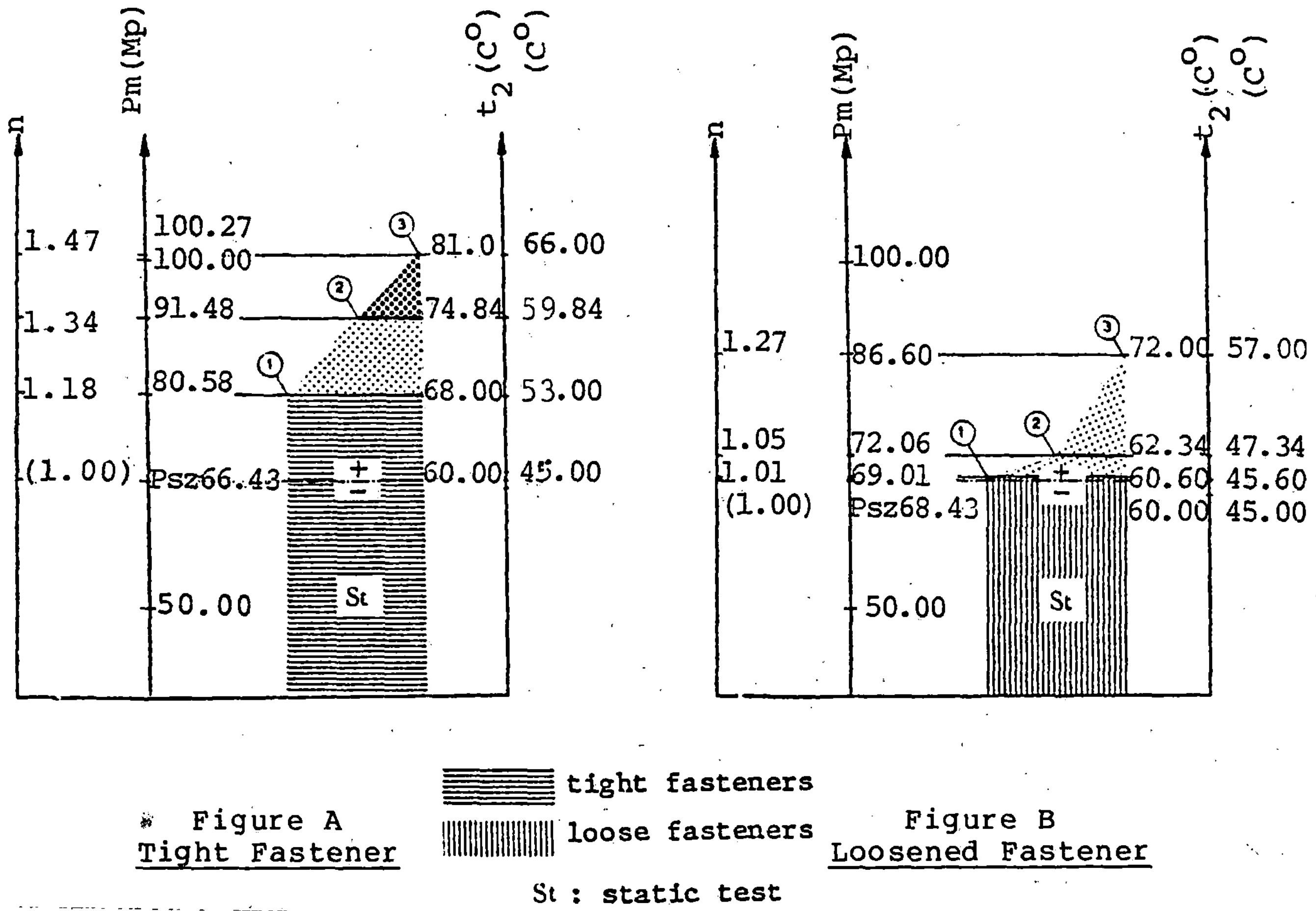


Figure A
Tight Fastener

Figure B
Loosened Fastener

This figure presents a sample of the results of tests conducted on a tangent, imperfection-free track comparing the affect of tightened and loosened bolt fastener condition. A reference point that VTKI set from which stability aspects are measured (changing from - to + on the figures) is 60°C (140°F) which is the maximum rail temperature experienced under Hungarian climatic conditions. Figure A is for tight (normally torqued) GEO (K-type) fasteners and Figure B is for the fastener in loosened conditions. Points 1, 2 and 3 denote:

1. Onset of deformation
2. Limit of track elastic deformation
3. Onset of buckling (initiation of large deformation)

The actual rail temperature is denoted as t_2, Δt is the temperature change from a 15°C (59°F) laying temperature, P_m is the longitudinal load in the rails and n denotes the ratio of Pm/P_{sz} where P_{sz} corresponds to the longitudinal load at the reference temperature of 60° (140°F). VTKI considers point 2 to be most important. Beyond this limit, permanent deformations take place resulting in track imperfections potentially leading to lower critical buckling temperatures in subsequent tests.

As the figure illustrates, the effect of loosened fasteners result in a 29% "lowering of stability" (n_2 = 1.34 vs. n_2 = 1.05). At Point 2, the buckling region was 55-57m (180.49-186.96 ft.) long with deformation consisting of many small waves of 1.3 to 1.8mm (.052-.072 in.) amplitude for the tightly fastened section. For the loosened fastener section, the buckled region for the same Point 2 was 60-62m (196.80-203.34 ft.) with wave shapes of 1.83 to 1.93mm (.073-.077 in.) amplitudes.

The same test as described above was conducted under dynamic conditions; that is, a short consist consisting of 3 or 4 cars was pushed through the test zone at 40-50 km/hr (24.8-31 mi/hr) at each 10°C (18°F) interval. The effect of dynamic loads on the loss of stability are indicated by the following stability coefficients:

$(n_2)_{tight} = 1.03$

$(n_2)_{loose} = 0.97$

Subsequent tests run on a tangent section 13.5m (44.28 ft.) long with a 2 cm (.78 in.) amplitude imperfection and in a loosened fastener condition yielded:

$(n_2)_{static} = .96$

$(n_2)_{dynamic} = .85$

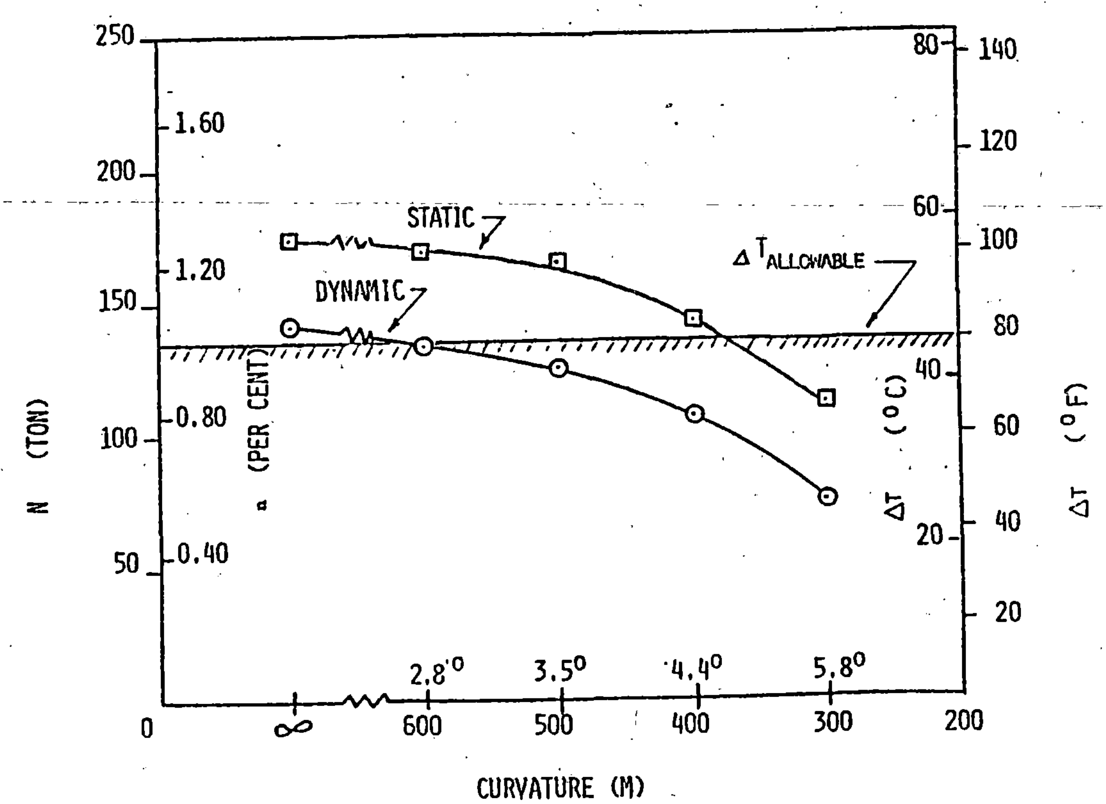
Additional static and dynamic tests on curved track resulted in the following stability coefficients:

Radius	(n_2)static	(n_2)dynamic
600 m (1968 ft.)	1.29	.98
500 m (1640 ft.)	1.26	.92
400 m (1312 ft.)	1.10	.78
300 m (984 ft.)	.81	.55

Corresponding axial load/temperature plots are shown in Figure 5-3. From these and other tests, VTKI recommends radii greater than or equal to 600m (1968 ft. or 2°-55') curves for CWR. However, MAV allows curves of 500m (1640 ft. or 3°-30') for exceptionally well maintained tracks.

Figure 5-3

Effect of Curvature On Lateral Deflection



In subsequent discussions, it was found that although the mean rail installation temperature is 15°C (58°F), for added safety the current practice is to install rail at 20C (68°F) from which the allowable deviations are -10°C (18°F) and +5°C (+9°F). A special permit is required to install CWR in radii of 400-600m (1312 to 1968 ft. or 4°-22' to 2°55'). In curves less than 400m (1312 ft. or 4° 22'), no CWR is allowed. In the last 5 years, no buckling incidents have occurred; in the last 10 years, 9 incidents occurred. Seven of these incidents were attributed to maintenance (tamping) when rail temperature were higher than the allowed temperature limit.

A new phenomenon has been observed during the past two years. In early spring, many small amplitude waves of 1mm (.04 in.) in length formed in the rails. During mid-spring, these anomalies disappear. The reason for this phenomena is unknown, but speed restrictions are imposed when this condition is observed.

SECTION B: UNITED STATES

Unlike Hungary, the United States railroad industry has performed little research on track buckling. Recently, interest in such research has been growing since American railroads have experienced over 100 derailments per year which were attributable to this mode of instability.

Full scale buckling experiments were first conducted in 1979 by the Transportation System Center (TSC) and the Southern Railway System under FRA sponsorship. The purpose of these initial experiments was to demonstrate the feasibility of inducing track buckling by locomotive heating of the rails. This method required modification of a locomotive to deliver direct current for thermal load development. In contrast, Hungarian researchers used induction heating of rods welded to the web of the rails(1). These rods however effectively change the cross section of the rail, and thus may create some inaccuracies in the measurement of critical buckling factors. A second objective of the initial tests was to determine buckling temperatures of straight track segments with and without imperfections.

Two full scale buckling tests (testing to failure) were conducted during the initial experiments: (1) a test on nearly "perfect" track; (2) a test on a 56 foot length track with imperfections of 2.5 inches. Track parameters and conditions are summarized as follows:

- 100 meter test section, tangent track, 112 lb/yd. AREA continuously welded rail (CWR), good alignment
- Wood tie section, slag ballast, 8 inch shoulders

---

(1) Andrew Kish, Transportation Systems Center, Cambridge, Massachusetts, interviewed March 1, 1981.

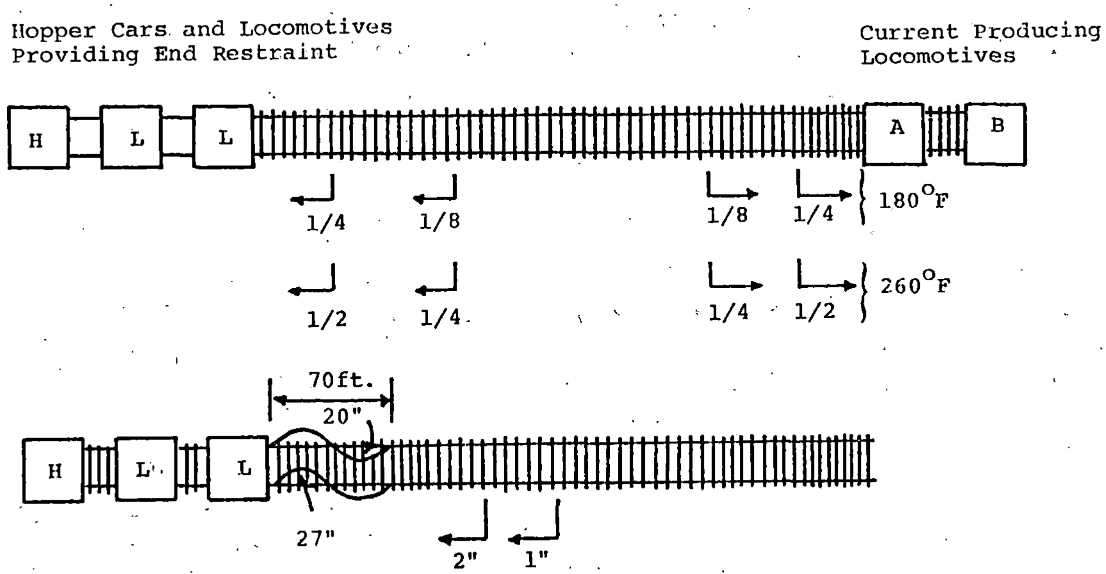
- Rail anchors on alternate ties
- Rail de-stressed at 59°F prior to tests
- End restraint provided by locomotives and hopper cars

Specific factors measured included rail temperature, pre and post buckling shape, and longitudinal displacement.

Figure 5-4 indicates the longitudinal and lateral track displacement at increasing temperatures on nearly "perfect" track. Buckling occurred violently at a rail temperature of 303°F. The total change in temperature (ΔT) to failure was 244°F after a period of one hour at a heating rate of 5-6°F per minute.

Figure 5-4

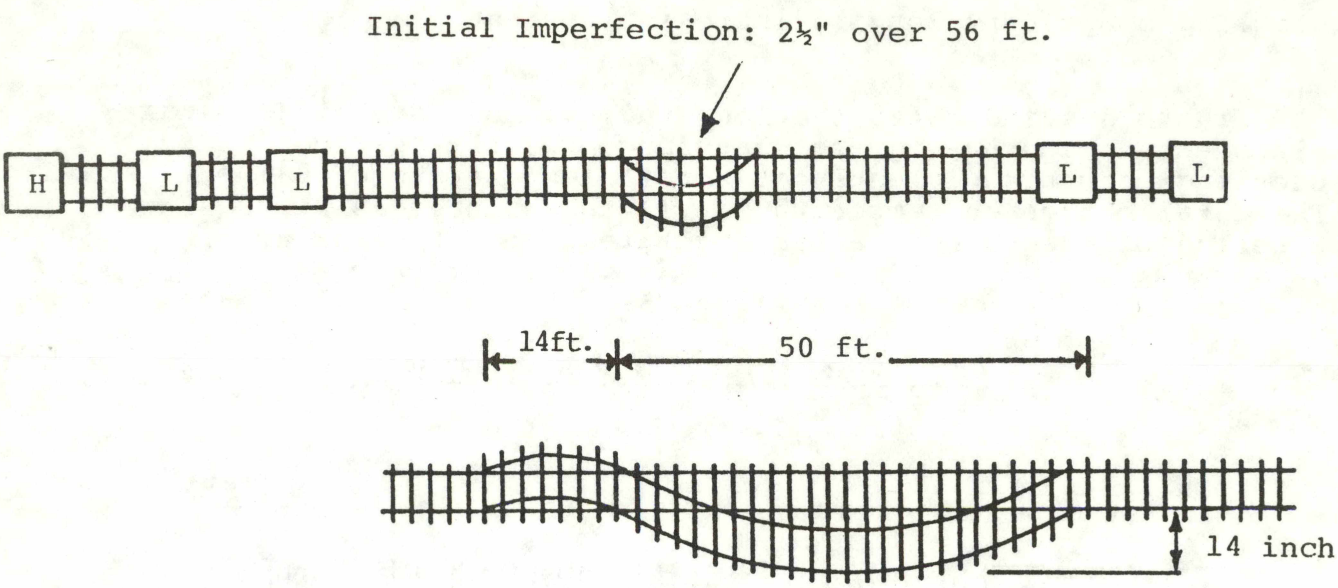
Test Observations "Perfect" Track



Similarly, results of the buckling test on track with an imperfection are indicated in Figure 5-5. Buckling occurred at a rail temperature of 172°F, and a ΔT of 113°F. The buckling action was less violent than in "perfect" track. Total heating time was 25 minutes.

Figure 5-5

Test Observations Imperfect Track



Observed Buckle Mode Shape

Under conditions of track imperfections, a significant reduction is noted in the ΔT required to induce buckling compared to the large ΔT required for near perfect track. This observation supports rail buckling behavior theory and the results of other tests.

The methodology developed in these initial experiments will be employed to conduct full-scale main line buckling tests beginning in June, 1981 on the Southern Railway near the Plains Virginia.[2] The U.S. research approach is to conduct a limited number of full scale buckling tests (buckling to failure) to obtain basic buckling characteristics. These characteristics

---

(2) Additional details for the track buckling tests are available in Andrew Kish, Test Requirement Definition for Track Buckling Test, U.S. Department of Transportation, Transportation System Center, Cambridge, Mass., January, 1981.

will then be analytically extrapolated to all other track parameters and configurations. To the extent possible, the experimental data and the analytical predictions will be utilized to develop safety performance criteria, and relevant recommendations to prevent derailments due to the loss of track lateral stability.

The United States approach of combining analytical and experimental data differs significantly from the Hungarian and Russian philosophy of using pure empirical data to dictate buckling safety requirements.

The United States railroads, in investigating the 100 or more buckling related derailments which occurred during 1980, concluded that the probable cause of many of these derailments were inadequate installation temperature considerations and performing track maintenance at high temperatures. Current U.S. railroad practices to install and maintain CWR vary from railroad to railroad, and from region to region, although the AREA publishes recommended criteria for CWR installation. The AREA manual specifies ranges of rail laying temperatures for corresponding annual ranges of rail surface temperatures as indicated in Table 5-2.

Table 5-2

AREA Specifications for Laying Continuously Welded Rail(3)

Temperature Range Degrees F	Laying Temperature (Referring to Mean) Max.	Min.
100°	-5	-15
110°	0	-10
120°	+5	-5
130°	+10	0
140°	+15	+5
150°	+20	+10
160°	+25	+15
170°	+30	+20

(3) AREA Railway Engineering Manual, Bulletin 670, Chapter 5, November-December, 1978. pp. 175-180.

Example: In an area where CWR is to be laid, the maximum summer rail temperature is 125°F and winter -35°F. The mean temperature is 125 - (160/2) = 45°F. Referring to Table 5-2, for a range of 160°F, the rail is to be laid between (the minimum mean temperature +15), and (the maximum mean temperature +25), or between 60°F and 70°.

The manual prescribes that the rail should be heated or cooled as necessary to the desired laying temperature, or adjusted mechanically at a later date.

In the United States, the AREA specifies a tighter rail temperature range which is not usually centered on the mean rail temperature as in Hungary. In contrast, the MAV specifies a single ambient temperature range of -30°C to 40°C (-22°F to 104°F) characteristic of the climate of Hungary. Maximum and mean rail surface temperatures of 60°C (140°F) and 15°C (59°F) respectively were determined. MAV practice is to lay rail within +5°C (+9°F) of the the mean rail temperature, with anticipation that a ΔT of 45°C (81°F) will not buckle the track.

For comparison purposes, to lay rail in Hungary, with an annual rail temperature range of 160°F (-22°F to 140°F is the normal range in rail temperatures) and a specified Hungarian mean rail temperature of 59°F, U. S. practices would specify a rail laying temperature range of 74°F to 84°F, compared to 50°F to 68°F, using the Hungarian criteria. This difference in rail laying criteria may suggest an area for future U.S. investigation, especially given the number of experiments performed by the Hungarian State Railways.

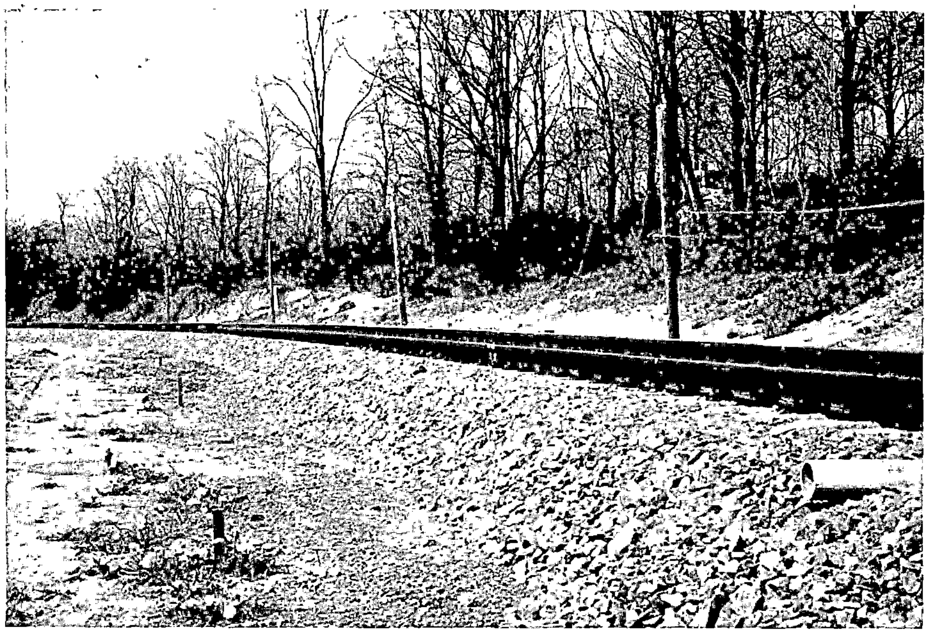


Photo. 5-1. Hungarian Track Buckling Facility. Concrete Squares at Left Are Reference Points For Deformation Measurements.

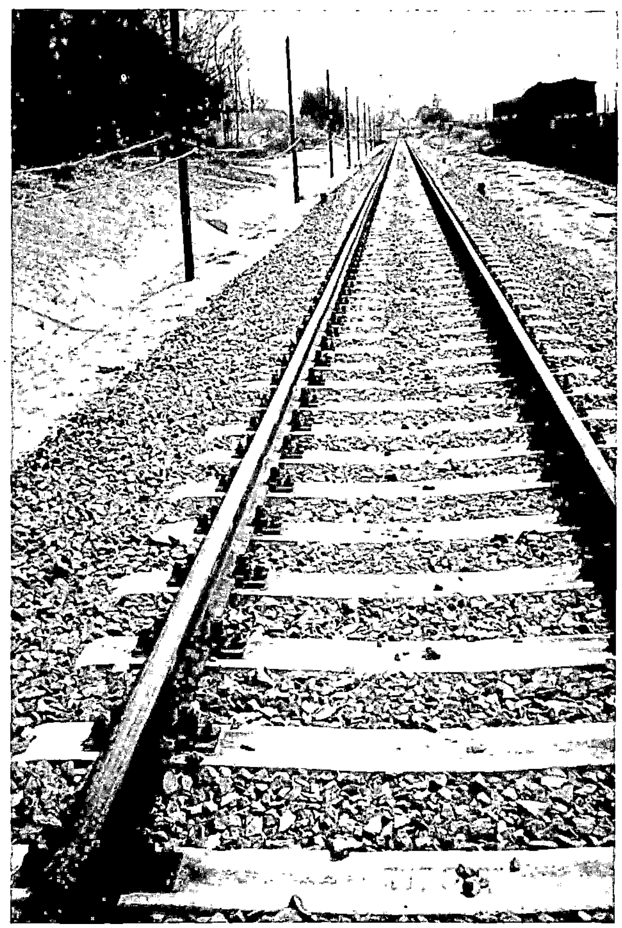


Photo. 5-2. Hungarian Track Buckling Tangent Test Segment.

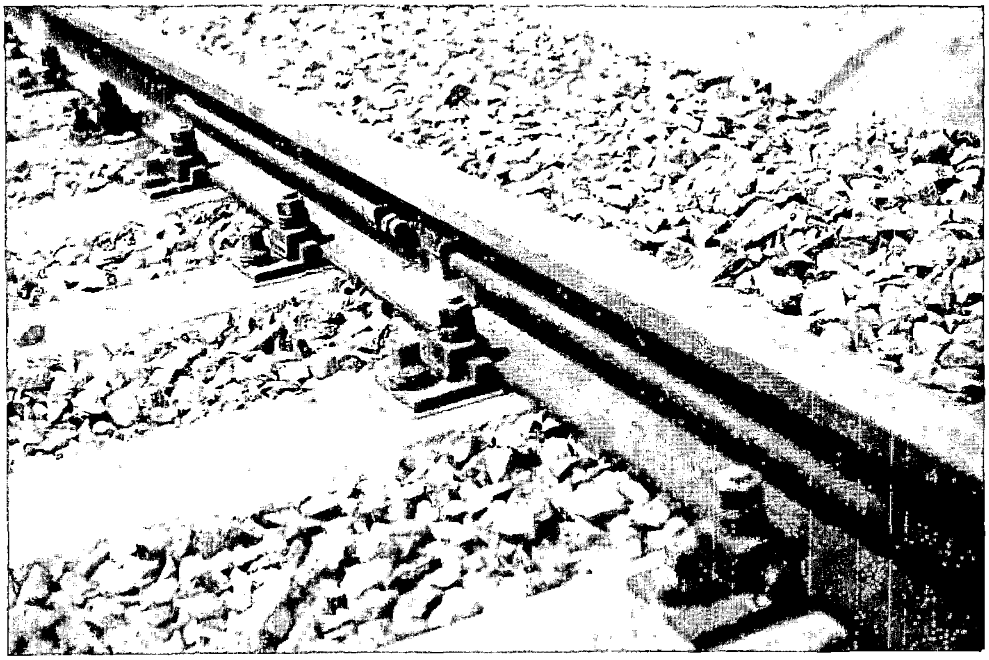


Photo. 5-3. Hungarian Track Buckling Facility. (Note Heating Elements and K-Type Fasteners.)

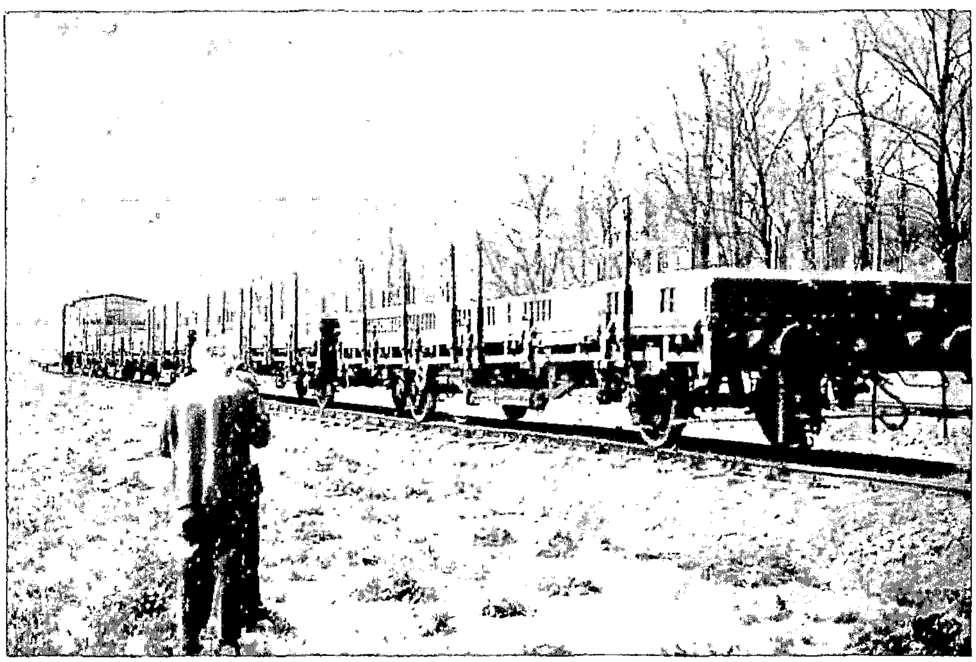


Photo. 5-4. Hungarian Track Buckling Test Facility. Showing Test Car Consist for Dynamic Tests.

CHAPTER 6

TIE RESEARCH and RAIL FASTENERS

SECTION A: EASTERN EUROPE

CONCRETE TIE SYSTEMS -- HUNGARY

In Hungary, concrete ties have been installed almost exclusively in track for the last 8-10 years. Currently 60 percent of the system has concrete ties with plans for eventual installation over 100 percent of the system. The current criteria is to use concrete ties on all track where axle loads exceed 21 metric tons (23 tons), but by the end of 1980, this requirement will be lowered to 18 tons. Hungarian State Railway officials assume that concrete ties are less expensive than wood ties in all applications. Concrete ties are used exclusively in construction and reconstruction, except under switches. The length of switch ties makes concrete ties too unwieldly and standardization of concrete tie for switch application is impossible. Twenty-two years ago bonded wood ties were tried experimentally for use in switches. These ties are still in good enough condition to be removed, cut up, and used in different applications. Some experimentation of mixing concrete and wood ties has taken place, but current standards do not allow this practice.

DUAL-BLOCK TIES

(a) Poland

The Polish test facilities are presently conducting an investigation sponsored by ORE on the performance of the French dual-block ties. The project had been completed, but details of results were not presented. The Poles expressed no further interest in the dual-blocks because they are not useful as sleepers in ordinary usage for reasons which were not provided. A similar conclusion with more factual documentation was presented by the Hungarians. Similar dubious results have been reported by the Rumanians and Austrians. Photographs of dual-block ties are presented at the end of the chapter.

(b) Hungary

The French concrete tie system with dual concrete blocks is impractical according to a Hungarian representative. The small percentage of additional resistance contributed by end restraint (approximately 10 percent) is negated by decreases in side and bottom resistance. The Hungarians also hypothesize that dual concrete block ties will also be inferior in longitudinal resistance. Additionally, the metal needed for connecting the dual blocks is too scarce in Hungary to be used for this purpose.

THE EFFECT OF TIE SPACING ON LONGITUDINAL RESISTANCE -- HUNGARY

Experiments were conducted on a 10m (32.8 ft.) long piece of track to determine the effect of the tie spacing on longitudinal resistance. Three different tie spacings were used and the 10m (32.8 ft.) long section was pushed by jacks. The force was measured in kilograms and displacements in millimeter to an accuracy of 0.1 mm (.004 in.).

Results of these experiments indicated that as tie spacing increased, the longitudinal resistance of the ballast increased. The reason for this increased resistance was the greater volume of ballast in the cribs available to become activated in shear resistance. Obviously some limiting value for tie spacing exists since maximum tie spacing is limited by vertical pressure on the subgrade. MAV has not identified this limiting value. These tests also demonstrated that the maximum tie spacing allowed by the subgrade was to be preferred in specifications for track construction.

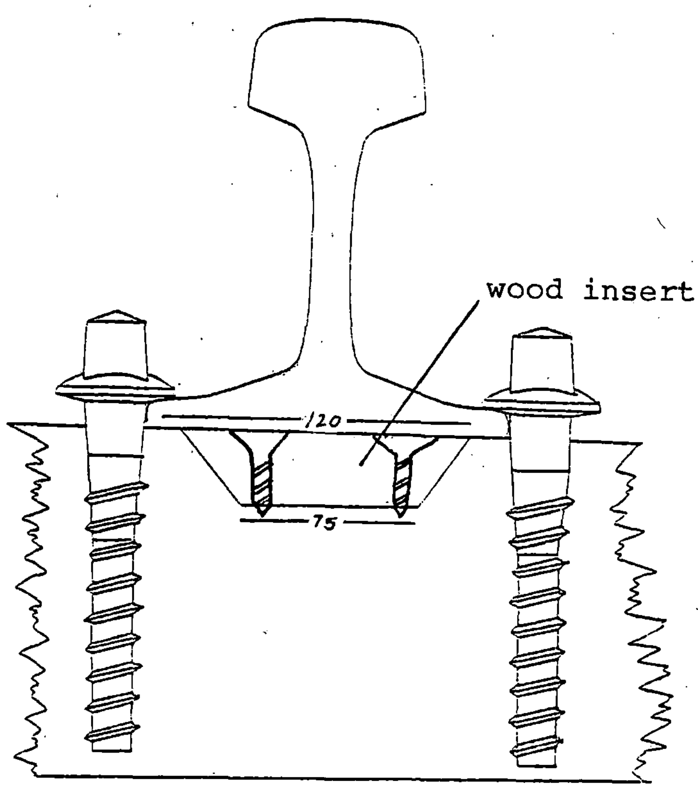
POLY-IMPREGNATED TIE INSERTS-POLAND

The Polish research center has developed and tested special hardwood and poly-impregnated wood inserts designed to extend tie life. Substantial testing was conducted to determine optimum test geometry of these inserts, which finally resulted in a trapezoidal shape. A preliminary design is illustrated in Photograph 6-6. The wood-polymer inserts were placed in the seat areas of a wooden tie and effectively doubled the plate cutting life of a wooden tie under rolling load laboratory conditions. The initial design featured two of these trapezoidal shaped inserts installed under each tie plate in notches cut in the tie. The newest design features a single insert which is slightly wider than the rail base. The principle is based on the concept of converting the crushing loads normally seen by the horizontal wood fibers into longitudinal loads in the fibers. Two ties, one with inserts and one without inserts, have been subjected to several million load repetitions in the track test facility. The tie with the inserts exhibited no indentation, while the tie without the insert suffered tie plate cutting of 1/4 to 1/2 of an inch. Test results have also demonstrated that ties with inserts last twice as long as those without.

Although initial tests were performed with polymer impregnated inserts, further testing has demonstrated that unimpregnated inserts made of hardwood would also double tie life. A concept currently being tested uses non-impregnated hardwood inserts on new soft wood ties. Preliminary results indicate a greatly improved performance against tie plate cutting. The inserts can be bonded into place with an epoxy. However, the Polish researchers have been using screws to fasten the inserts as shown in Figure 6-1 below.

Figure 6-1

Fastening of Hardwood Tie Insert



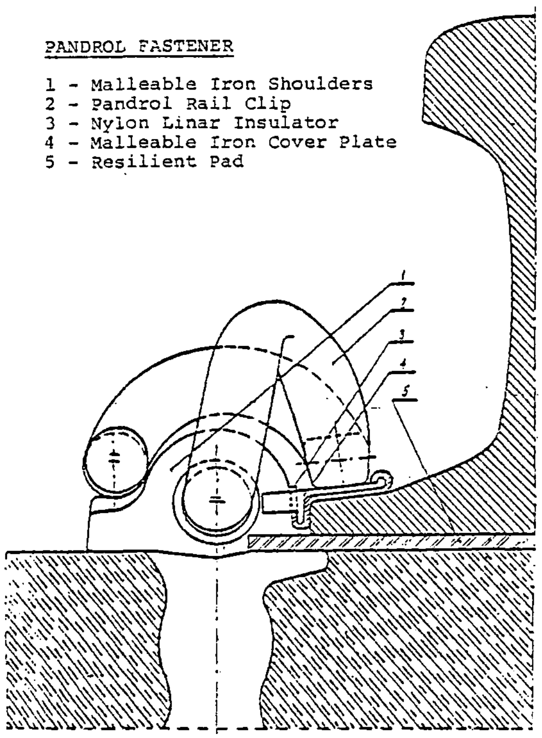
The PKP is also very interested in other methods to extend wood tie life. Timber supply has become a problem and the treatment of green lumber appears to result in a much shorter tie life. Those studying this problem estimate that if timber was allowed to dry naturally for 2 years, service life of the tie could be increased by 5 years. The PKP has tried kiln-drying, but naturally dried wood appears less sensitive and vulnerable to fungus attack.

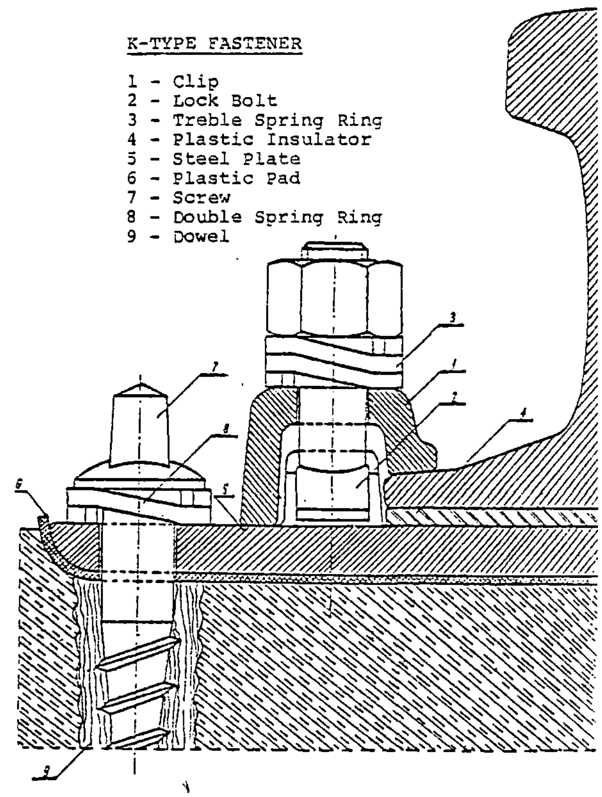
RAIL FASTENER TESTING -- POLAND

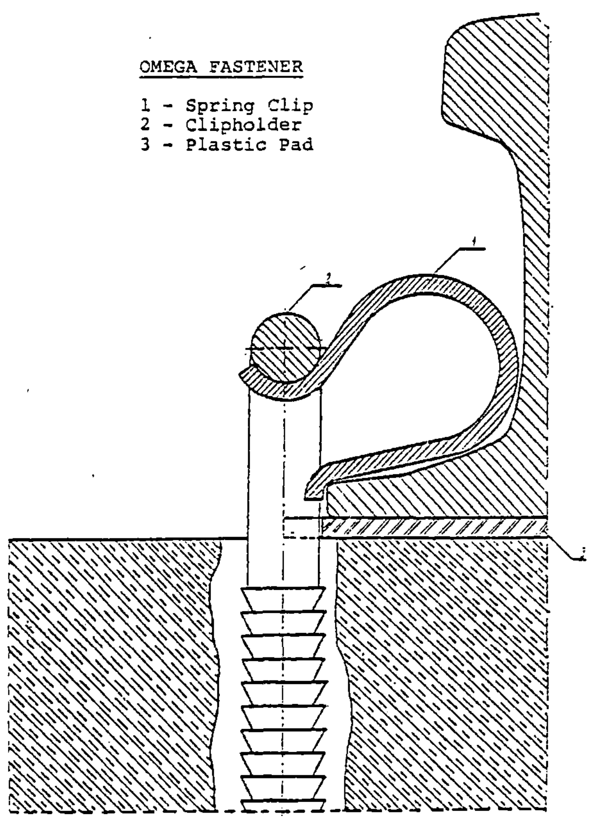
The COBiRTK has placed significant emphasis on fastener development. Figure 6-2 illustrates several of the experimental designs. The omega clip (Figure 6-2) is the most recent design and much interest exists in its testing. Static hold down tests will be performed within the scope of the dynamic testing program. Dynamic loading of the omega clip is applied and static measurements, including hold down tests, are repeated at various load cycles.

Similar tests will be performed with the Pandrol fastener as a part of the US agreement. The Polish representatives exhibited strong concern over the Pandrol system's performance. The results of the Polish tests should provide some indication of the fastening system's relative merits. Follow-up tests will probably be necessary, especially in the Pandrol case, to verify the laboratory findings by field tests.

<u>Figure 6-2</u>
<u>Experimental Fastener Design</u>







SECTION B: UNITED STATES

CONCRETE TIE PROGRAM

Utilization of concrete ties on U.S. railroads is currently limited with the most extensive use on Amtrak's Northeast Corridor, the Florida East Coast, Kansas City Southern and Seaboard Coast Line railroad. Several other freight railroads have only recently installed and evaluated test sections of concrete ties. In contrast, many U.S. transit systems have adopted the use of concrete ties to minimize maintenance costs.

Recent research activities evaluating concrete track performance have indicated that concrete ties probably will display increased service lives and better performance than wood ties. However, the inadequacy of current fastening systems is a problem which substantially impacts the overall service life and maintenance requirements. The lack of accurate cost data, the logistics of concrete tie replacement of wood ties, and the high initial capital requiremeents has impeded the replacement of wood with concrete ties.

In comparison, European countries tend to favor concrete ties, not necessarily because of technical adequacy or better performance, but because of the general shortage of timber on the European continent. The inadequacy of fastener design has stimulated the ongoing fastener design and testing program in Poland as well as in other European countries.

Concrete tie research in the United States has been conducted by both the FRA and UMTA. A major program to develop a standard specification for concrete ties for use on transit systems was conducted by APTA*/UMTA and TSC from 1976 through 1979. Phase I involved development of a specification, economic analysis, and projection of the number of ties which would be used over the subsequent ten year period. This phase was completed in 1978. Phase 2 involved laboratory testing of prototype ties. This phase began in 1977 and was completed in 1979. Phase 3 was to involve field testing of the prototype ties but was cancelled when the transit industry decided to adopt a standard concrete tie which was then under production for use on freight railroads.

* APTA - American Public Transit Association

Several studies conducted by the Portland Cement Association have demonstrated that concrete ties exhibit better life cycle costs than wood ties. A similar study conducted by Battelle in 1978 compared the economics of concrete and wood tie track structures using maintenance cost records from U.S. and foreign railroads.(1) Results of the study showed that average annual savings for track maintenance and component renewal costs was significant and increased with the annual gross tonnage. On 4 degree horizontal curves, the average annual savings were even more pronounced for concrete versus wood tie track (maintained to Class 5 standards). However, average annual costs to repair derailments was significantly higher for concrete ties.

A comparative analysis of concrete and wood ties is also being conducted at FAST to evaluate 50 year life cycle capital maintenance and renewal costs for line segments constructed using the two tie systems. Interim reports were prepared in 1980 addressing 150MGT and 425MGT cumulative loadings.(2)(3)

Results indicate that significant replacements of wood ties were necessary on a 5° curve section before 425MGT loading. However, very few concrete ties required replacement on a concrete section with the same curvature characteristics. No flexural failures in concrete ties occurred because of train loading of concrete tie track. However, the purchase cost of fully equipped concrete ties was 25% - 30% higher than for comparable wood ties. Thus, unless the cost difference was significantly reduced, concrete tie use in mainline track must depend on differences in performance such as added life, prevention of gage widening in curves, and track maintenance cost improvements over wood tie structure.

A concrete tie evaluation program is currently under way on the Northeast Corridor and on four other U.S. railroads to compare FAST experimental results with those obtained in revenue service. Information concerning these tests is not currently available.

---

(1) Economics of Concrete and Wood Tie Track Structures, Interim Report, Prepared for U.S. Department of Transportation, Federal Railroad Administration by Battelle Colombus Laboratories, August, 1978.

(2) Concrete and Wood Tie Track Performance Through 150 Million Gross Tons, Report No. FRA/TTC-80/02, Prepared for The FAST Program, Federal Railroad Administration, March, 1980.

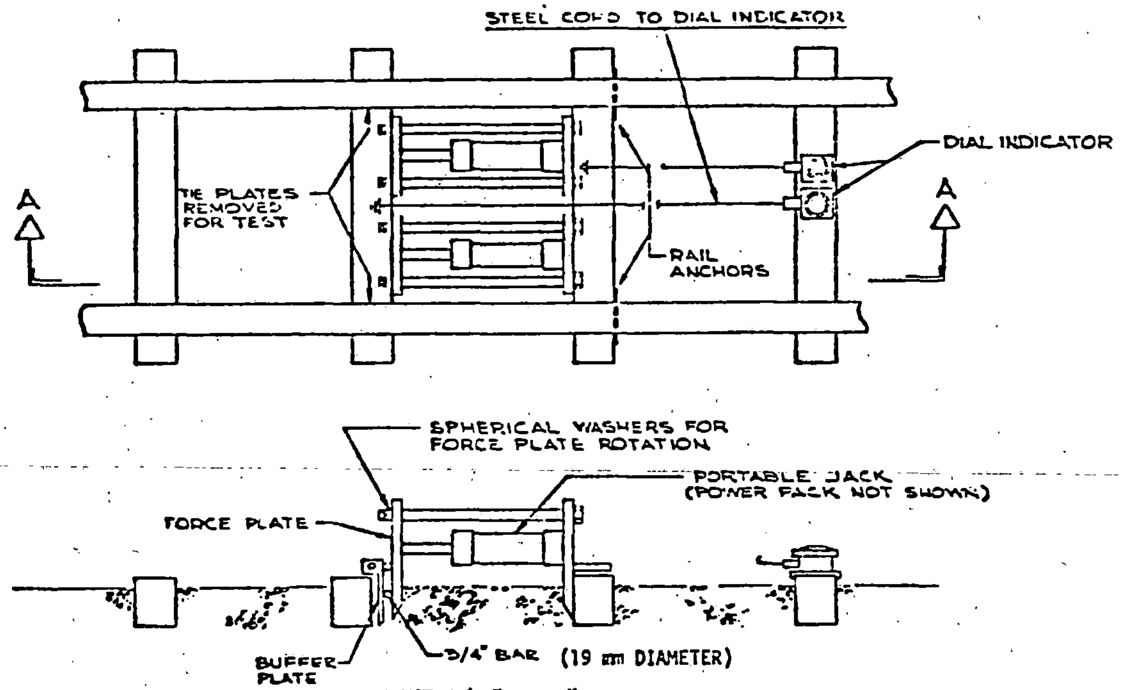
(3) Francis E. Dean, Concrete and Wood Tie Track Performance Through 425 Million Gross Tons, at the Facility for Accelerated Service Testing, Battelle, Columbus, Ohio, August, 1980

LONGITUDINAL
RESISTANCE TESTING

Longitudinal resistance testing in the U.S. has been extremely limited, with no specific research conducted on the effects of tie spacing. Longitudinal resistance tests are useful for evaluating the resistance of the track structure, including the movement of ties, to longitudinal forces transmitted by the rails, such as those from braking and acceleration, as well as temperature induced expansion and contraction. A schematic of a typical test apparatus is shown in Figure 6-3.

Figure 6-3

Longitudinal Tie Resistance Test



VIEW "A-A"

The tie is separated from the rails by removing spikes, tie plates and fasteners, and pushed in the longitudinal direction. Both the longitudinal force and resultant displacement are measured. Usually, only a single tie is tested.

Longitudinal resistance tests were used in experiments to evaluate the effects of tamping and vibratory compaction on ballast and tie stability. These tests were conducted by the State University of New York (SUNY) at Buffalo. Results of the experiments indicated a 30-70% reduction in longitudinal resistance after tamping compared to the longitudinal resistance of undisturbed track.

POLY-IMPREGNATED TIE INSERTS

Railway organizations in the U.S. have not experimented with poly-impregnated tie inserts, but have conducted research on laminated compressed ties and particle board resin ties. The insert installation process practiced in Poland requires additional labor. Therefore, use of these inserts is not of great interest to the U.S. railroads considering the current cost structure for wood ties.

Composite particle board ties produced from the ground wood of old ties and held together with resin were tested at FAST. After 500 MGT of traffic, many ties were found to be structurally weak with the occurrence of both plate cutting and complete failure. Cross grain laminated ties are currently being tested at FAST, but results are not yet available.

The substantially higher cost of such modified wood tie systems focuses attention on the issue of improved performance. To date, the advantage of modified wood ties with regard to the performance-cost tradeoff has not been demonstrated to the U.S. rail industry.

DUAL BLOCK TIE SYSTEMS

United States railroads and related organizations demonstrate the same lack of interest in the French dual block tie systems as Poland and Hungary. Dual-block ties are more expensive to manufacture than mono-block pre-stressed concrete ties. The Massachusetts Bay Transit Authority (MBTA) Red Line and the CTA in Chicago are the only rail lines in the United States which currently uses a dual-block tie system. No problems have been experienced with the tie system on these lines.

Tests of the dual-block tie system were also conducted by the Chessie Rail System at Noble, Illinois; however, no public information is available.

RAIL FASTENER SYSTEMS

Failure of rail fastening systems due to pad slippage or fastener breakage constitute the primary problems experienced with concrete tie systems in both the United States and Europe. Such failures may lead to increased track maintenance and premature failure of concrete ties. Therefore, U.S. research has been oriented towards the fastener systems, since the U.S. rail industry is satisfied with the basic design of the concrete tie. Fasteners are thus the most critical components of the concrete tie system which must be improved if this more expensive system is to achieve acceptance and utilization in the UWS.

Several spring type elastic fasteners are currently being tested and used in combination with various types of pads and insulators to determine whether improved performance can be achieved. The basic problem is to design or perfect a resilient fastening system which will not fail prematurely. AREA and AMTRAK have guidelines for evaluating resilient fasteners.

Laboratory tests are currently being conducted by Battelle on three existing fastening systems to determine problems inherent to these systems, recommend fastener system guidelines for the FRA and UMTA, and develop fasteners with improved in-service performance. The fasteners were subjected to both a longitudinal resistance test and a gage widening test. A 20,000 to 30,000 pound load is applied cyclically to the rails, and fastener strain was measured. Each of the systems tested performed equally well in rail hold down and maintaining gage, but all three failed to achieve a longitudinal resistance of 2400 pounds.(4)

Tests were conducted under accelerated loading conditions at FAST using various combinations of fastening system components.(5) Components included four types of fasteners, and eight types of pads on six types of concrete ties. Tests were conducted on Section 17, Figure 6-4, which included horizontal curves of three and five degree separated by a tangent section.

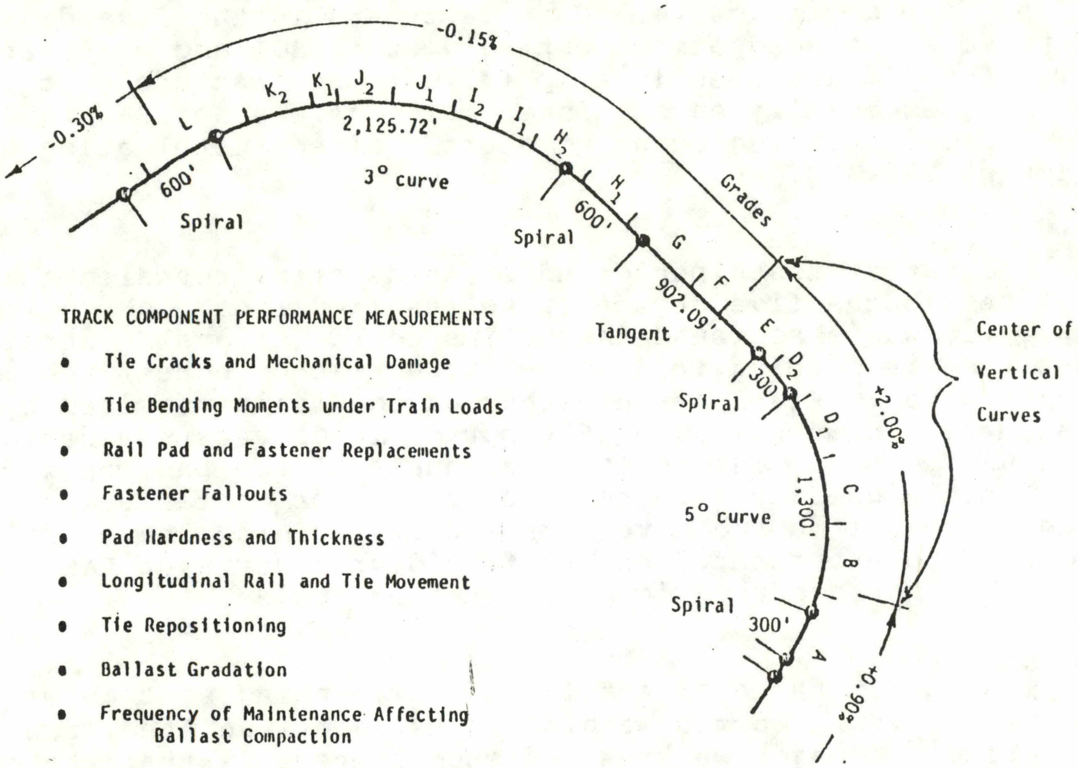
---

(4) Paul Witkiewicz, Transportation System Center, interviewed March 11, 1981.

(5) Francis E. Dean, Concrete and Wood Tie Track Performance.

Figure 6-4

Layout of Concrete Tie Section 17 At FAST



TRACK COMPONENT PERFORMANCE MEASUREMENTS

- Tie Cracks and Mechanical Damage
- Tie Bending Moments under Train Loads
- Rail Pad and Fastener Replacements
- Fastener Fallouts
- Pad Hardness and Thickness
- Longitudinal Rail and Tie Movement
- Tie Repositioning
- Ballast Gradation
- Frequency of Maintenance Affecting Ballast Compaction

The geometrics at the five degree horizontal curve were particularly severe since a two percent grade also occurred at that location. Unfortunately, only one fastener was tested on the curves through 425 MGT, making comparisons difficult. Performance of the fastener systems was measured by the rate of clip fallout and required replacement of pads, clips, and insulators.

Performance of the fastening systems was generally satisfactory on the three degree and tangent sections, but unsatisfactory in the five degree curve. Clip fasteners in the five degree curve were replaced almost entirely at 61 MGT and again at 235 MGT. A rapid increase in clip fallout and fractures occurred at 100 MGT, especially on the inner rail, gage side. A high rate of clip fallout also occurred shortly after installation of new clips at 235 MGT.

Laboratory tests performed on these clips revealed that most failures in the five degree curve resulted from high cycle fatigue. It was also found that clips could be locally strained past the yield point to 6,000 - 10,000 micro-inches/inch during installation. Field measurements of toe loads provided by these fasteners produced 1400 - 1600 pounds loads versus a design load of 2,000 pounds. The relative hardness of the pad was found not to affect significantly the rate of fallout or failure of the clip fasteners on the five degree curve. This rate of fallout and failure experienced on the five degree curve at FAST, however, has not occurred in U.S. revenue service.

Testing of three direct fixation fastening systems will begin in Summer, 1981, on the Washington Metropolitan Area Transit Authority. A major weakness of such systems is that the current design specification was patched together based upon the redesign of individual components which previously failed to perform adequately. Thus an optimal integrated design may not have been achieved.(6)

---

(6) Paul Witkiewitz, Transportation Systems Center, Cambridge, Ma., interviewed March 11, 1981

Pandrol clip fasteners have been used extensively in revenue service on the Northeast Corridor. Problems have been encountered with the stiffness of the pads used. Results of tests conducted on the Pandrol system at FAST also indicated generally that the system did not perform up to expectations.(7)

Unlike Europe, the U.S. has not used or extensively tested rigid K-type fasteners. The K-type fastener is over-designed in vertical stiffness, and requires significant maintenance since hold-down nuts must be re-torqued, and the springs beneath the nuts occasionally break requiring replacement. A test installation was constructed by the Santa Fe Railroad near Olathe, Kansas. The Polish experience indicated that the stiff track system provided by K-type fasteners caused premature rail failure, and induced increased wheel and track wear.(8) For these reasons, several European railroads are gravitating away from the rigid K-type fasteners toward elastic fasteners.

In the U.S., cut spike wood tie fasteners are used almost exclusively. Most European countries use screw-spikes on wood ties and have experienced satisfactory performance. Experiments on screw spikes(9) as well as special fasteners such as the Dutch DE and Pandrol compression clip are being conducted at FAST and in revenue service. The results of these experiments are not currently available.

---

(7) Paul Witkiewicz, Transportation Systems Center, Cambridge, Ma., interviewed March 11, 1981.

(8) Andrew Kish and Andrew Sluz, TSC, Cambridge, Ma., interviewed March 11, 1981.

(9) Andrew Kish and Andrew Sluz.

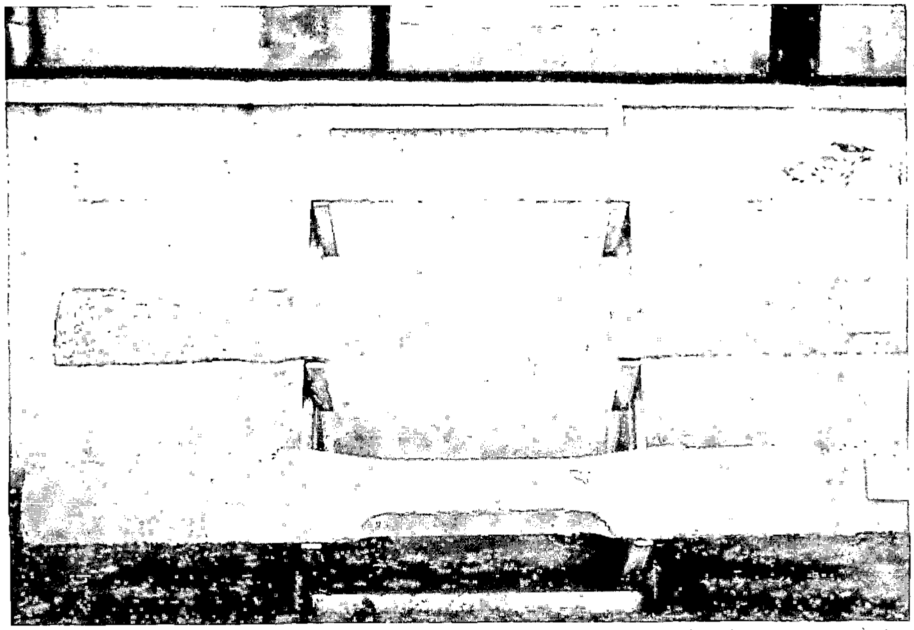


Photo. 6-1. Experimental Ties (Poland).

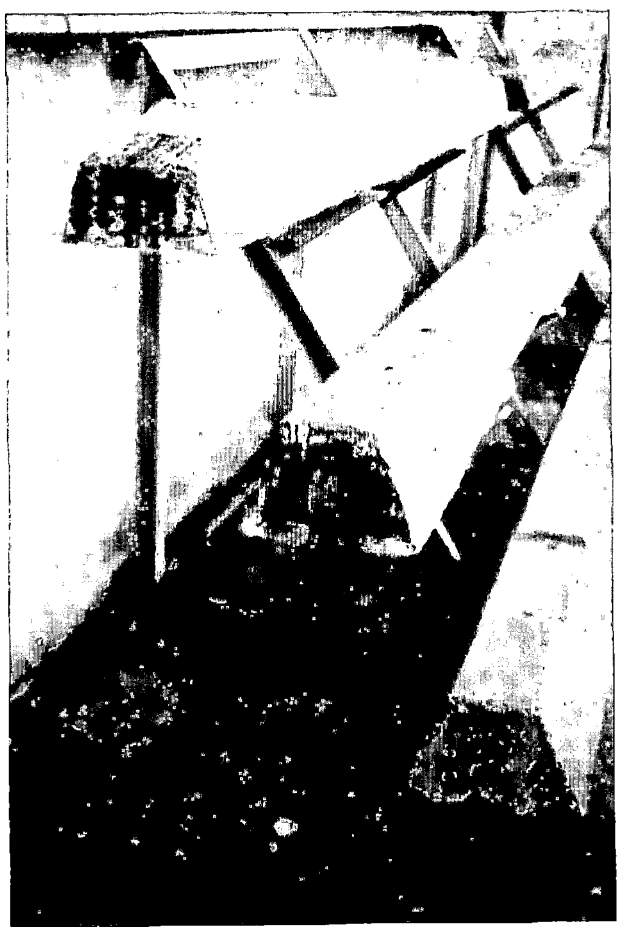


Photo. 6-2. End View of Experimental Ties (Poland)

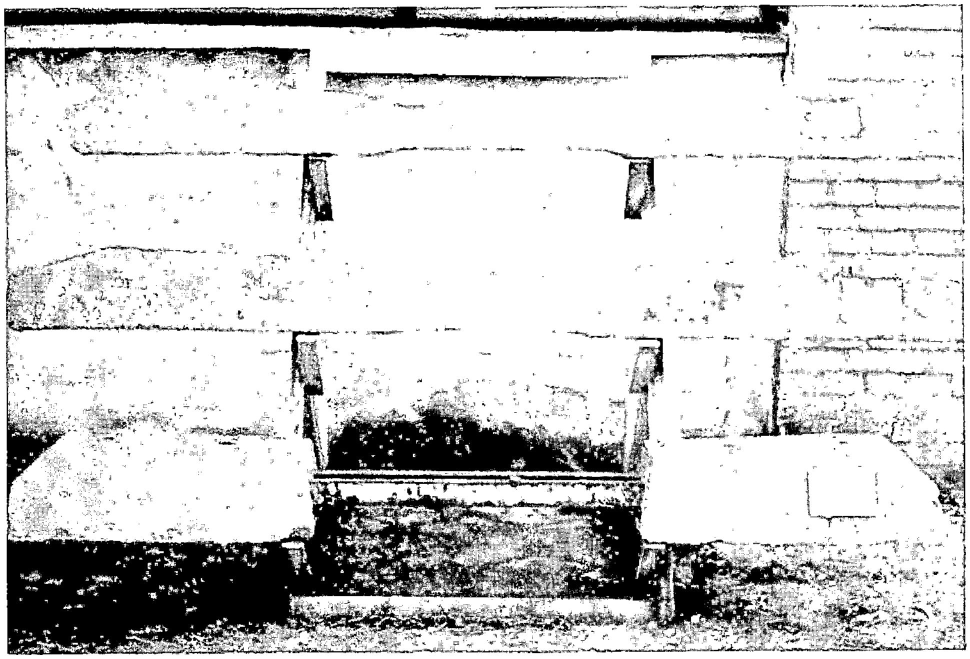


Photo. 6-3. Experimental Ties, Including Dual Block at Bottom (Poland).

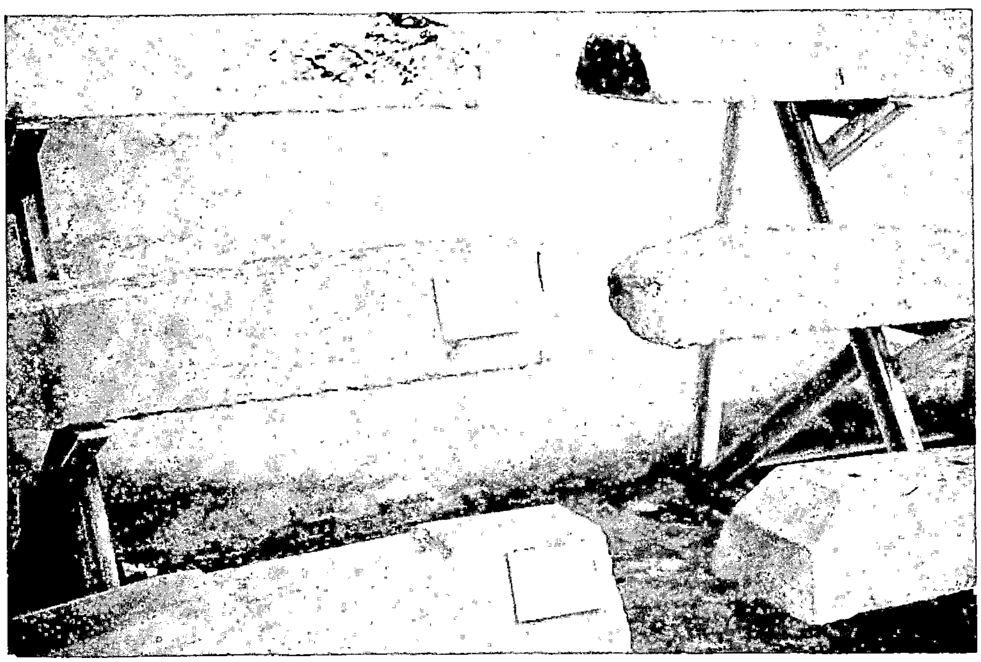


Photo. 6-4. End View of Experimental Ties, Including Dual Block at Bottom Right (Poland)

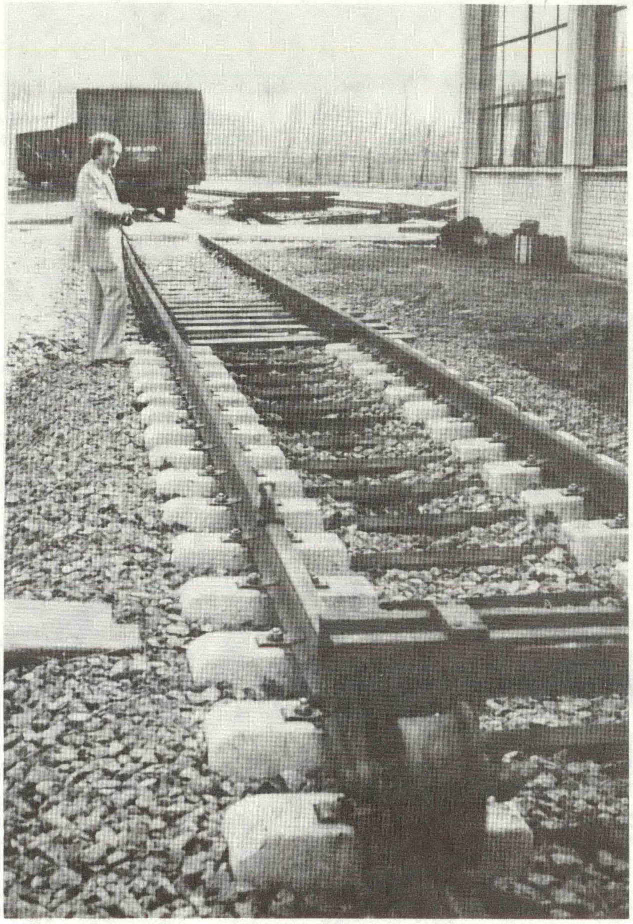


Photo. 6-5. Dual Block Tie System
Experimental Section (Poland)

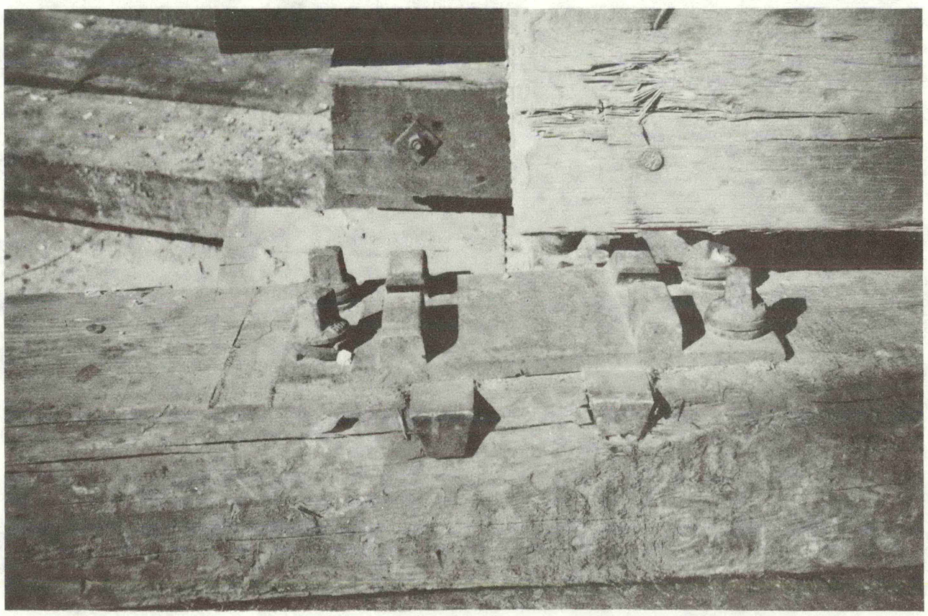


Photo. 6-6. Poly-impregnated Tie Inserts

CHAPTER 7
MISCELLANEOUS RUMANIAN RAILWAY RESEARCH

BRAKE SHOE WEAR AND PERFORMANCE STUDIES

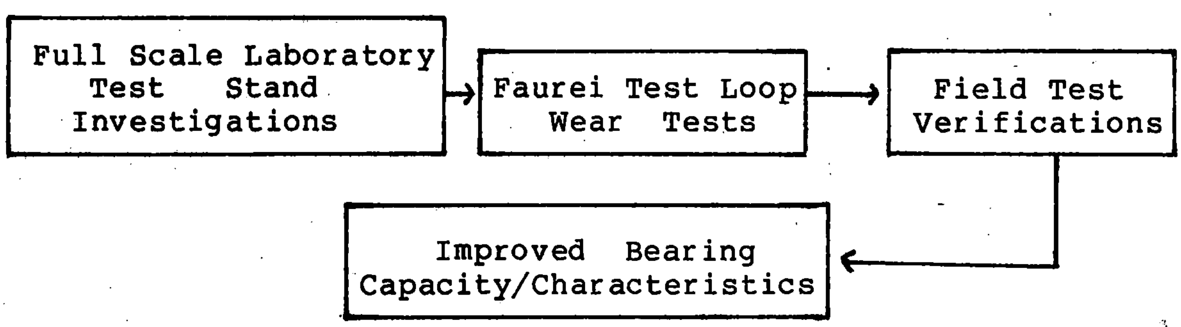
The ICPTT is actively engaged in brake shoe wear and performance studies on a long-term basis. The first step was to determine the performance level of current cast iron brake shoes and wheels with steel rims (UIC specifications BN1 and BN2). Phosphorus brake shoes and the effect on wheel and brake shoe wear were tested. (Phosphorus brake shoes are currently practical for use only on locomotives.) Comparative tests were run on cast iron brake shoes and brake shoes with various contents of phosphorous (1.5 to 3%). The three stages of investigations were:

1. Testing on a laboratory machine designed to simulate brake shoe and wheel operations and interface.
2. Performance testing on rolling stock at the Faurei test track.
3. Field testing in actual operation.

This testing process is diagramed below:

Figure 7-1

Brakeshoe Test Procedures



The testing machine has the capacity to test brakes from 760 to 1,250mm (30.4 to 50 in.) and is designed to simulate brake shoe applications under operating conditions. Comparison with field results indicated that the wear values determined from the testing machine are approximately twice as large as field wear values. Each brake shoe is tested to failure or to a fully worn condition.

The critical parameter under investigation is the effect of varying the phosphorous content in the cast iron brake shoes under two kinds of braking modes: 1) "complete" sudden stopping, and 2) "slow down" gradual brake application over a specified distance. General results of the experiments to date indicate that for sudden stopping:

1. High phosphorous (3%) brake shoes have a 10% greater braking capacity then low phosphorus shoes.

2. Laboratory machine testing shows a 500% increase in brake shoe life with a high phosphorus content and a commensurate 500% increase in wheel wear.

3. High phosphorus brake shoes perform better in emergency stopping.

4. Operational tests in mountainous terrain resulted in high phosphorus shoes lasting 2 1/2 - 3 months versus 1 1/2 months for low phosphorus shoes.

5. Wear increased for both types of phosphorus brakes under "slow down" gradual brake application.

Unfortunately, rim wheel wear increased proportionally negating the other demonstrated advantages. Based on this fact, ICPTT decided that phosphorus brakes were not cost effective. As an alternative, one percent phosphorus brakes are now being investigated.

LOCOMOTIVE TRUCK PERFORMANCE ON CURVES

Rumania has under development a mathematical locomotive curving model with 39 degree of freedom to be used for determining wheel set position on the rails. The model (named DEREA) is quasi-static and linear and is currently suitable for one truck analysis of a six axle locomotive where the wheels are considered to be conical. The links from the locomotive truck to the secondary suspension system are not vertical, which introduces a lateral load on the truck. No creep effect or worn profiles are included in the current form of the model.

BILEVEL PASSENGER CAR DEVELOPMENT

Currently the Rumanians are testing a prototype bilevel passenger car. The car has operated on the test track at 167 km/hr (103.5 mi/hr) although its normal speed is 120 km/hr (74.4 mi/hr). Test speeds are allowed to exceed normal speeds by 20%. car capacity is increased by more than 50% from the normal 80 to 124 (passengers) while weight increases only 20% from 40 to 50 metric tons (44 to 55 tons). Car length remains the same while the car's center of gravity is lower than normal. Brakes are installed on each bogie. See photographs 7-2 and 7-3 at the end of this chapter.

The Rumanians have not released the vibration data but did report that the vertical vibration level was low. The American delegation rode in the test car at speeds in excess of 160 km/hr (99.2 mi/hr) and rated the ride quality as exceptionally good. This quality ride was evident despite the fact that the track was concrete tie track with jointed rail and wooden ties at each joint. Joints at the test track were not staggered as in U.S. practice, but directly opposite each other. This condition is only temporary since CWR is to be installed.

CAR RECOGNITION SYSTEM

The R-41 counter discriminator apparatus is an electronic device which can be used to count on both railway cars or mine cars on electrified and non-electrified lines. The apparatus operates with two paddles mounted on the rail.

TECHNICAL CHARACTERISTICS

Supply	220 V
Consumption	10 W
Gauge	320;200;160 mm
Apparatus Weight	2 kg
Paddle weight	2.5 kg

The device is protected against train heating systems and disturbances caused by the current of electric traction.

The system exhibits several significant advantages over other car recognition systems:

- Recognizes any type of car having between 2 and 26 axles.
- Discriminates the cars independent of the direction of travel and the speed.
- Recognizes cars without identification code board when coupled with a car automatic identification device.
- Has proven highly reliable in service.
- Not disturbed by monorail or other metallic or nonmetallic bodies.

This device is presently in use at the Rumanian test facilities. Tests have shown a practical speed of 100 km/hr (62 mi/hr) for counting axles, since at higher speeds only cars are counted. The system can be used in classification yards because the rail shields the device from interference from adjacent areas. A special design can be added to detect hot boxes.

The Rumanians have patented the recognition system and are currently marketing it. Apparently Siemans Company has signed a contract for the system and the Shank Company of West Germany plans to use the device in conjunction with a car profile determination device to locate oversize cars.

Sales of the device should be aided by a ORE Committee (S-1010) recommendations that the R-41 device be incorporated into a European system of car identification. ORE Committee A-97 has further recommended that the microwave OCI be incorporated by 1985.

R-53 - OPTICAL ACI SCANNING SYSTEM

The Rumanians have developed a new optical ACI scanning system, called R-53, which uses different paths for the incident and reflected beams of light. This device is claimed to have five times the "reflectivity index" of other existing devices. The detectibility of dirty and torn labels is greatly improved. The advantages of R-53 over existing U.S. optical identification systems were studied by ICPTT. A system developed by Sylvania has also been evaluated but the results are not available.

The Rumanians have also developed an impulse data processor system, but it has not been coupled to the optical system for testing.

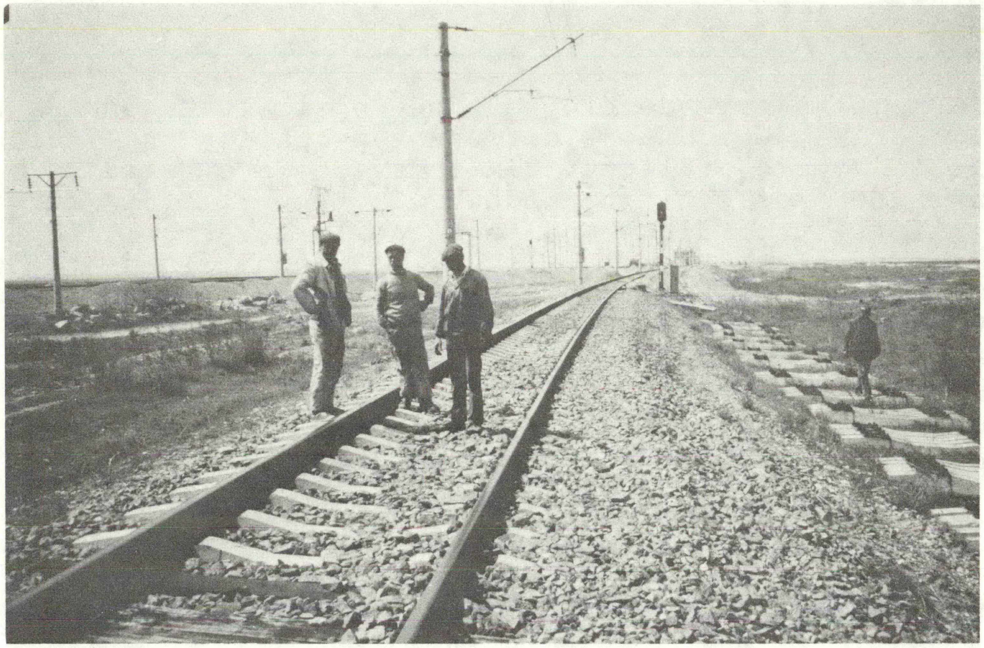


Photo. 7-1. Typical Track Section at Faurei Test Track.

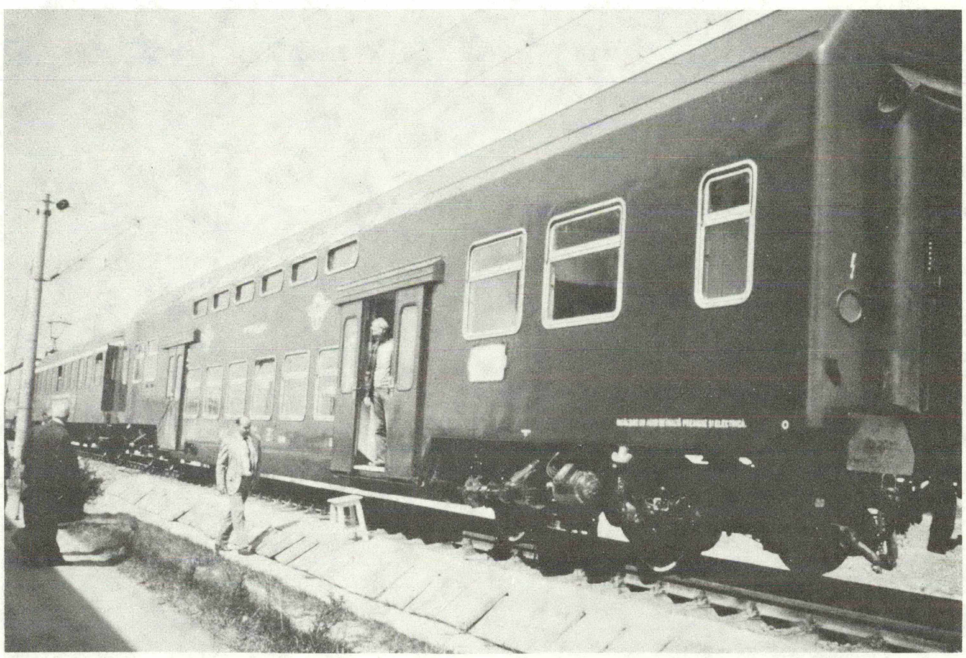


Photo. 7-2. Rumanian Bi-Level Passenger Car.

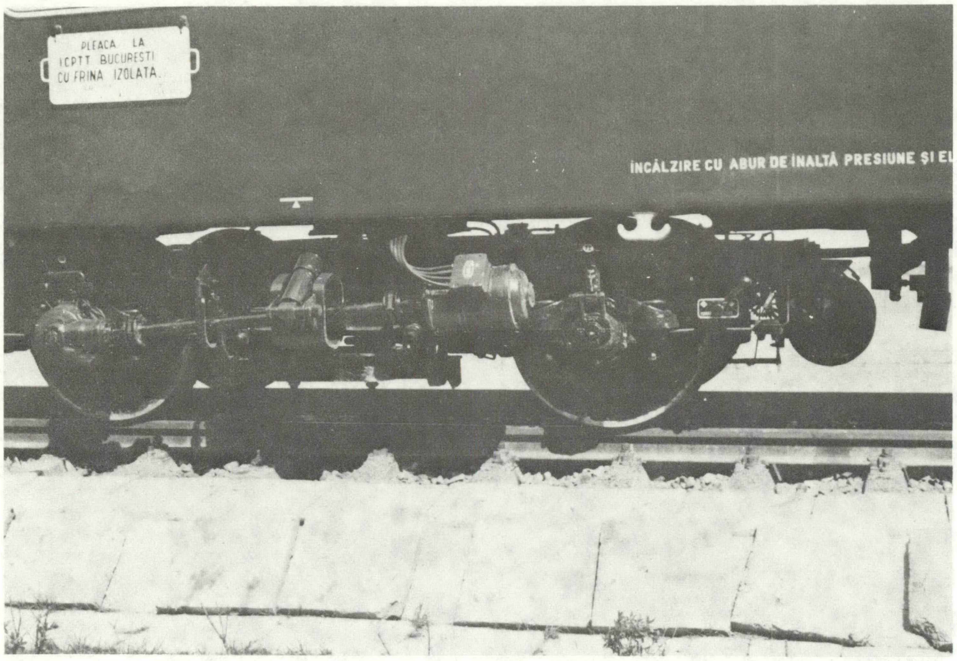


Photo. 7-3. Wheelsets and Braking System on Rumanian Bi-Level Passenger Car.

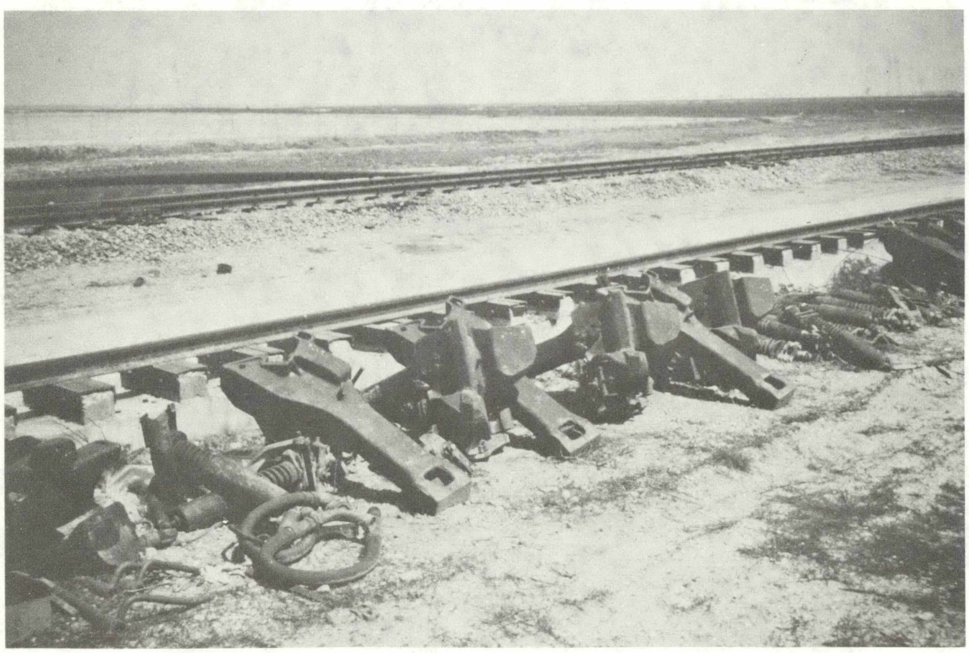


Photo. 7-4. Automatic Coupler Systems Being Tested at Faurei Test Track.

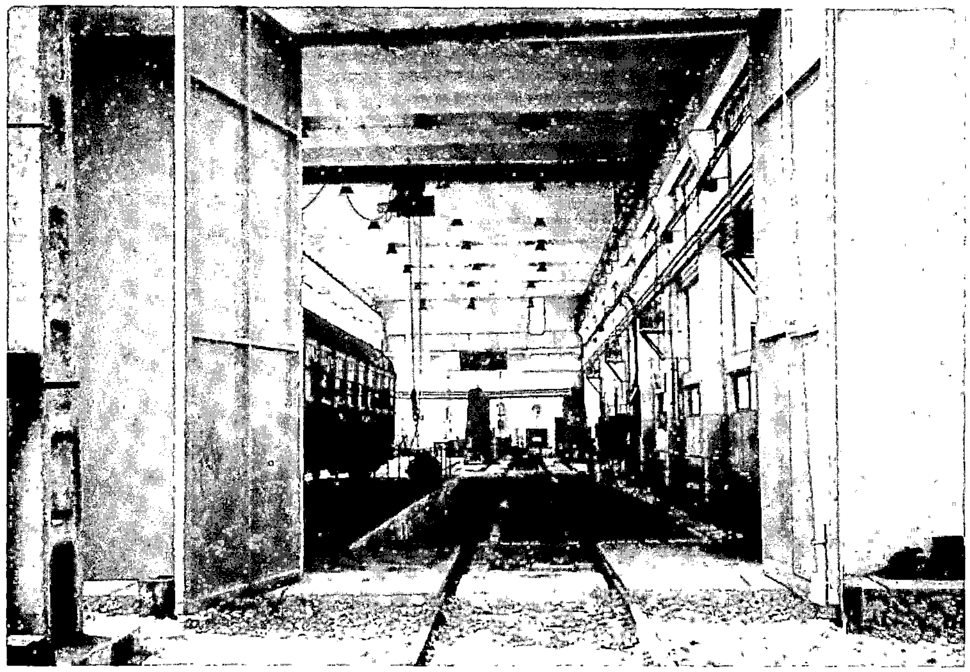


Photo. 7-5. Vehicle Maintenance and Laboratory Test Facility at Faurei Test Track.

CHAPTER 8
POLISH AND U.S. COOPERATIVE AGREEMENT

TIE RENEWAL PROGRAM RESEARCH

The investigation of tie renewal is being conducted under Task 3 of Project 4A (A cooperative U.S./Polish Research Agreement).

The two major project objectives are tie renewal as a function of service in track, and use of ties following renewal. Service will be studied for classical (bolted) S49 and S60 rail and for CWR S49 and S60 rail.

The two failure modes that will be considered in the study will be tie plate cutting due to frost action, abrasion from the tie plate, etc; and tie cracking or splitting. The three destructive forces to be taken into account are mechanical wear, environmental conditions, and bacterial action. The failure criteria will be the track's inability to maintain gage, 40 percent tie plate cutting, spike removal (40 kg or 88 lbs. of force), and broken ties.

A multi-variant analysis will be performed to develop a predictive model to forecast tie failure. Tie life is presented as a function of four variables: P1, lateral force leading to gage widening; P2, ratio of force needed to pull out fasteners and force applied; P3, mean value of tie plate cutting; and P4, the number of ties qualified for replacement in one kilometer of track.

This analysis should determine the total number of ties that could be expected to be replaced in a kilometer of track. Statistical entropy will be utilized to determine what occurrences belong in each group of the tie failure mode. Some groups may have so few occurrences in each cell that they have to be combined, whereas others may occur so often that they must be broken down further. As an example, COBiRTK has been investigating the parameters that affect the load on the rail. The quality of the track, train speed and percent of remaining service life all contribute to the real axle load on the rail. For this project the COBiRTK will attempt to minimize variables by selecting sections of good track quality with S60 rail, over which trains pass at approximately 60 km/hr. (38.2 mph.). Approximate tonnage over each section since construction (or reconstruction) will be approximately 300 MGT metric (330 million gross tons). A sample of 800-1500 ties per section is considered. A detailed description of each section will be provided so that the FRA may evaluate what parameters are being compared.

Other topics of tie research being pursued outside of Task 3 include: tie treatment for extended life, longitudinal rail stress, and U.S. acquisition of additional tie damping measurement (TDM) devices.

RAIL FASTENER TESTING PROGRAM

The COBiRTK has an extensive fastener design and testing program.

Two specific fastener development and design problems are being addressed: 1) design of individual fastener components, and 2) determination of the effect of random manufacturing tolerances on changes in fastener performance over the life of the fastener systems.

Figure 8-1 on the following page presents a block diagram which summarizes the functional steps of Task 2 designed to resolve these problems.

Figure 8-1

Rail Fastener Testing

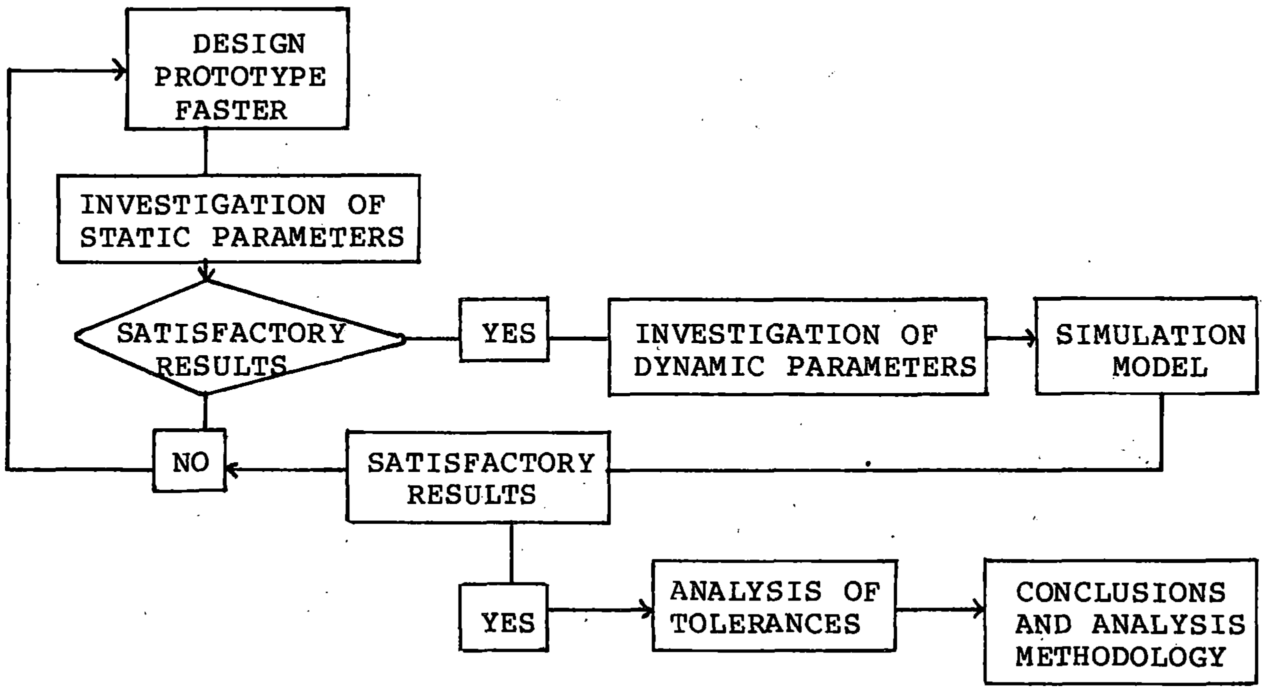


Table 8-1 which follows provides information on the test variables.

The Project 2 plan appears to be very thorough and complete. The total applicability of the results to the U.S. will not be known for some time until it can be determined whether a general model can be developed from the three models (one for each fastener) that are being constructed. However, in the interim extensive data on the Pandrol system will be collected, as well as on fastener evaluation techniques, and construction of an evaluation facility.

The fastener toughness test would be used to determine:

- Likely damage to a tie by the fastener system
- Probable service life of fastener systems
- Fastener component with the shortest service life
- Theoretical variations in characteristics of fastener components.

The program will include testing of K-type, Omega and Pandrol fastener systems as indicated in the prior Table. Photographs of the K-type and Omega fasteners are presented on the following page.

For each component tested, the assumption will be made that the loads transferred from the rail are identical. Each fastener configuration will be submitted to 3 million cycles on the track strength machine. Periodically during each test, elastic properties (e.g. clip hold down force and the elastic characteristic curve for various components) and permanent deformation of each component will be measured as a function of the number of load cycles applied.

The data from these tests will be used as input for new fastener design and also to identify fastener types to be rejected for particular uses.

TABLE 8-1
RAIL FASTENER TEST VARIABLES

ENVIRONMENTAL

Freight Service: High loads, low frequency
53,000 lbs. Vertical (a 100 ton car is approximately 33,000 lbs. static load)
16,000 lbs. Lateral
9-10 Hertz (calculated at 35-40 mph with typical freight car wheel base)

Passenger Service: Low loads, high frequency
23,000 lbs. Vertical
7,000 lbs. Lateral
20-25 Hertz (calculated at approximately 100 mph with a typical passenger car wheel base)

TYPE OF FASTENERS
STATIC TESTS

K-Fastener	Pandrol	Omega
pads	elastic clip	clip
elastic rings	pad	pad
	insulator insert	

Test duration and measurement points: 3,000,000 cycles with elastic property measurements taken at 0K, 300K, 600K, 1,000K, 2,000K and 3,000K cycles.

- Measurement of elastic characteristics (at 0.1 Hertz)
  - -- Hold down force
  - -- Hysteresis loop
- Determination of any permanent set in any of the components

Static load tests -- tests will be conducted on panels of 7 cross ties (constructed with one fastener type per panel) to determine the following results under load:

- Track gage at .55 inches below the rail head
- Lateral rail displacement at each tie
- Vertical rail deflection at upper face of each tie
- Permanent deformation of the pads

Other Tests to be Conducted Include:

- Longitudinal creep
- Rail rollover resistance
- Tie insert resistance

RESULTS

The results of the effort will provide:

- A reliability model
- The ability to evaluate the effect of fastener material changes
- A new fastener design evaluation technique
- The ability to assess a fastener for future investigation
- Improvements to existing designs

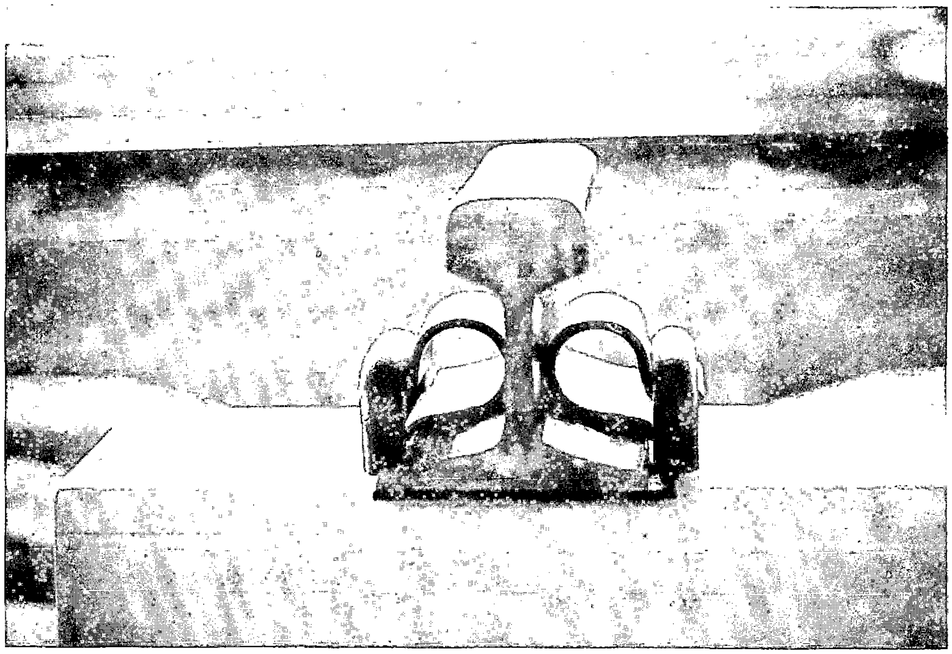


Photo. 8-1. End View of Omega Type Fastening System.

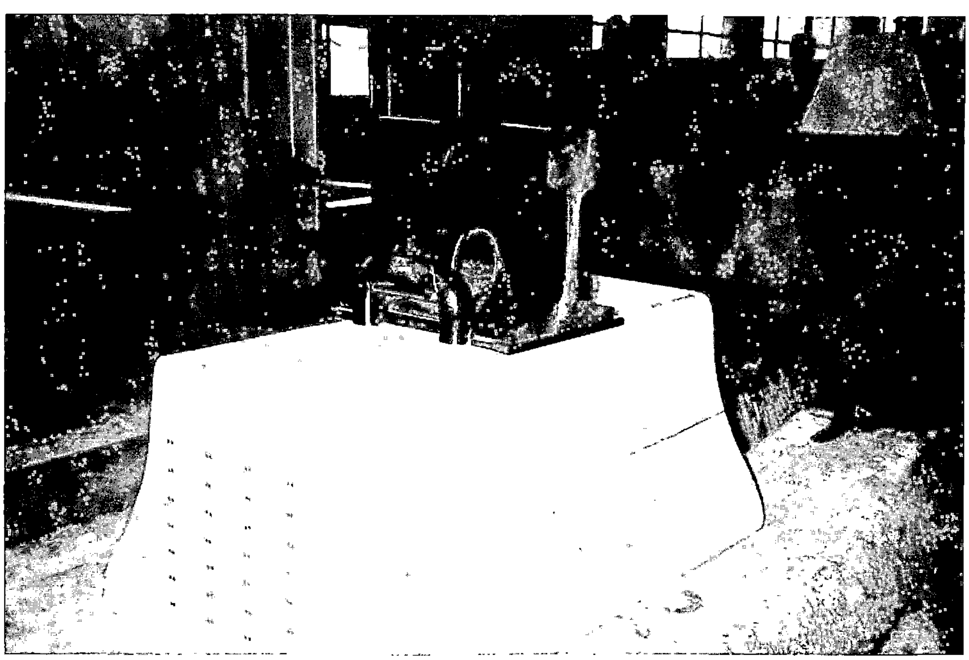


Photo. 8-2. Side View of Omega Type Fastening System.

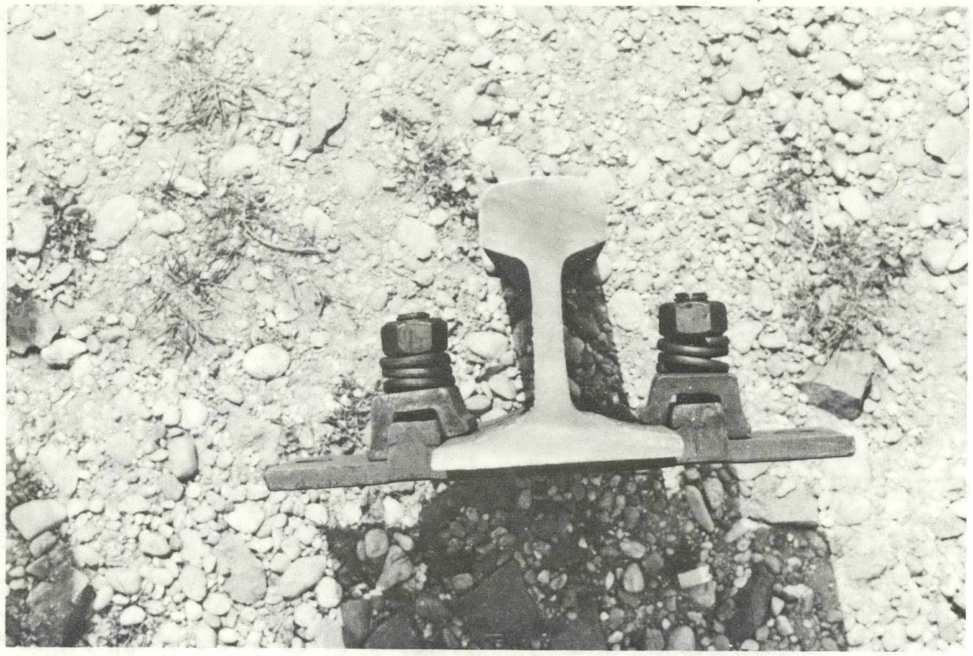


Photo. 8-3. End View of K-Type Fastening System.

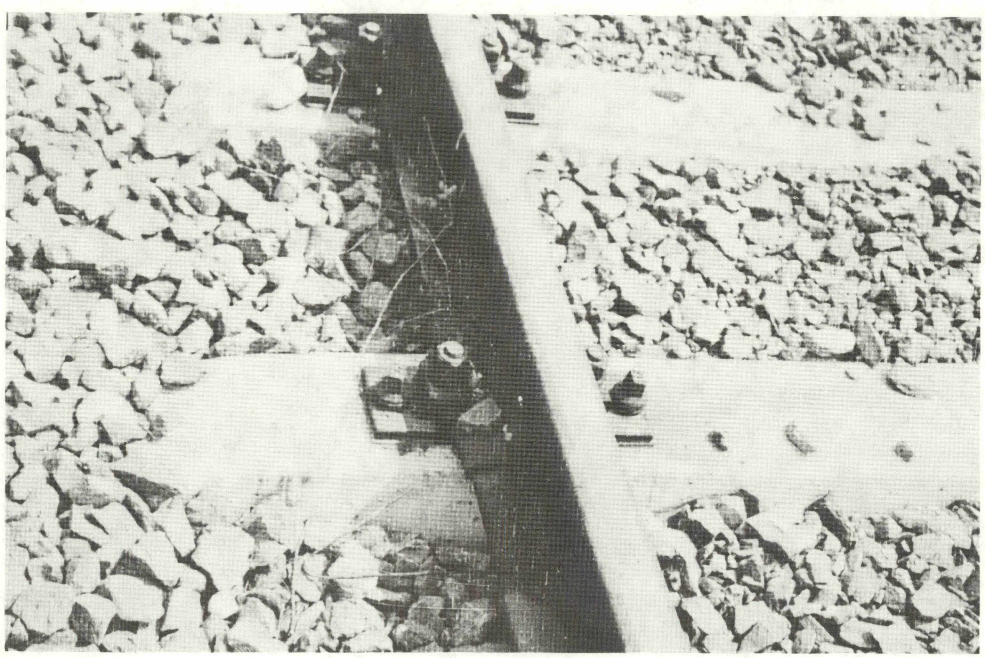


Photo. 8-4. K-Type Fastening System in Service.

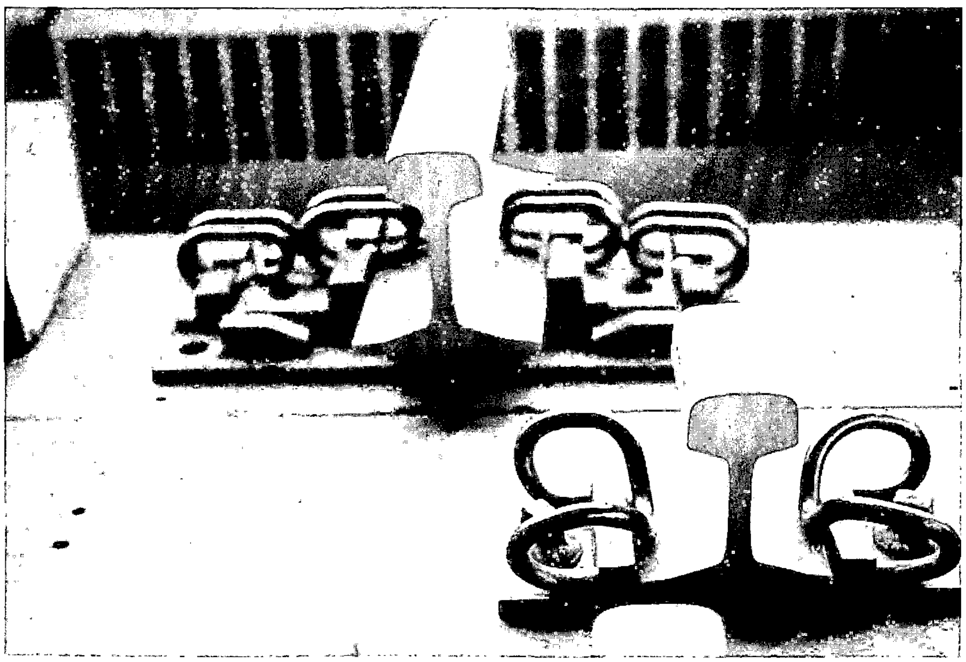


Photo. 8-5. Other Rolled Clip Fastening Systems Tested in Poland.

APPENDIX

SOURCES FOR FIGURES
(United States)

Figure 3-1:
Selig, E.T.: Yoo, T.S.; Panuccio, C.M., Mechanics of Ballast Compaction, Volume 1: Technical Review of Ballast; compaction and Related Topics, FRA/ORD-81/16.1 (USDT, Transportation Systems Center, Cambridge, Massachusetts).

Figure 3-4:
Panuccio, C.M.; Yoo, T.S. and Selig, E.T., Mechanics of Ballast Compaction, Volume 3: Field Test Results for Ballast Physical State Measurements, (USDOT, Transportation Systems Center, Cambridge, Massachusetts), pp. 29,30.

Figure 4-5
Selig, E.T.; Yoo, T.S.; Panuccio, C.M., Mechanics of Ballast Compaction, Volume 2: Field Methods for Ballast Physical State Measurements, (USDOT, Transportation Systems Center, Cambridge, Massachusetts), p.27.

Figure 4-6
Reiner, I.A., Lateral Resistance of Railroad Track, FRA/ORD 77/44, August 1977, Figure 27.

Figure 4-7
Panuccio, C.M.; McMahon, D.R.; Selig, E.T.; Mechanics of Ballast Compaction, Volume 4: Laboratory Investigation of the Effects of Field Compaction Mechanisms, (USDOT, Transportation Systems Center, Cambridge, Massachusetts), p.11.

Figure 4-8
Ibid, p. 13.

Figure 4-9
Concrete and Wood Tie Performance Through 150 Million Gross Tons, Interim Report No. FRA/TTC-80/02, (FAST Transportation Test Center, Pueblo, Colorado) March 1980, p. 25.

Figure 4-10
Dean, Francis E., Concrete and Wood Tie Track Performance Through 425 Million Gross Tons, (Batelle, Columbus, Ohio), August 1980, p. 31.

Figure 5-4
Kish, Andrew, Graphics developed for Test Objectives for the Rail Heating Tests presentation, Transportation System Center, Massachusetts.

SOURCES FOR FIGURES (CONT)
(United States)

Figure 5-5
Ibid

Figure 6-3
Selig, E.T.; Yoo, T.S.; Panuccio, C.M., Mechanics of Ballast Compaction, Volume 1, p. 164.

Figure 6-4
Dean, Francis E., Concrete and Wood Tie Performance, p.6.

INTERVIEWS

Kish, Andrew, Construction and Engineering Branch, Transportation Systems Center. Interviewed on March 11 and 12, 1981 on all report topics.

Lamond, James, Construction and Engineering Branch, Transportation Systems Center. Interviewed March 11 on ballast.

Moody, Howard, Office of Research and Development, Federal Railroad Administration Interviewed March 24, 1981 on Tie Systems and Railroad Fastener Systems.

O'Sullivan, William, Office of Research and Development Federal Railroad Administration. Interviewed March 24, 1981 on Continuously Welded Rail and Lateral Resistance.

Raab, Robert, Chief of Construction and Engineering Branch, Transportation Systems Center. Interviewed March 11, 1981 on Rail Fastener Systems.

Sluz, Andrew, Construction and Engineering Branch, Transportation Systems Center. Interviewed March 11 and 12, 1981 on all report topics.

Witkiewicz, Paul, Construction and Engineering Branch, Transportation Systems Center. Interviewed March 11, 1981 on Rail Fastener Systems and Concrete Ties.

BIBLIOGRAPHY

UNITED STATES

American Railway Engineering Association 1980-1981 Manual for Railway Engineers, AREA, Washington, D.C., 1981.

Concrete and Wood Tie Performance Through 150 Million Gross Tons, Interim Report No. FRA/TTC-80/02, FAST Transportation Test Center, Pueblo, Colorado, March 1980.

Cunney, E.G; May, J.T; Jones, H.N., Effects of Accelerated Ballast Consolidation, FRA/ORD-76/274, U.S. Department of Transportation, Federal Railroad Administration, March 1977.

Dean, Francis E., Concrete and Wood Tie Track Performance Through 425 Million Gross Tons, Batelle, Columbus, Ohio, August 1980.

Dean, Francis E. and Kish, Andrew, Evaluation of Lateral Track Strength Measurements at FAST, June 1980.

Economics of Concrete and Wood Tie Track Structure, Interim Report, U.S. Department of Transportation, Federal Railroad Administration, August 1978.

Goldberg - Zoino and Associates, Inc. Single Lateral Tie Push Tests, Readville, Massachusetts, December 1980.

Hay, W.W.; Peterson, H.C.; Plotkin, D.E.; and Baker, P.T. Lateral Stability of Ballast, Report No. FRA/ORD-77/61, September 1977.

Panuccio, C.M.; Yoo, T.S. and Selig, E.T., Mechanics of Ballast Compaction, Volume 3: Field Test Results for Ballast Physical State Measurements, USDOT, Transportation Systems Center, Cambridge, Massachusetts.

Panuccio, C.M.; McMahon, D.R.; Selig, E.T.; Mechanics of Ballast Compaction, Volume 4: Laboratory Investigation of the Effects of Field Compaction Mechanisms, USDOT, Transportation Systems Center, Cambridge, Massachusetts.

Kish, Andrew, Test Requirement Definition for Track Buckling Tests, USDOT, Transportation Systems Center, Cambridge, Massachusetts, January 1981.

Kish, Andrew, Track Structure Performance -- Comparative Analysis of Specific Systems and Component Performance, FRA/ORD -- 77/29, USDOT, Federal Railroad Administration, June 1977.

Kish, Andrew and Dean, Francis, E., Comparative Performance Evaluation, Wood and Concrete Tie Track (150 MGT), FAST-TN-DR-001, September 1979.

Reiner, I.A., Lateral Resistance of Railroad Track, FRA/ORD-77/44, August 1977.

Selig, E.T.; Yoo, T.S.; Panuccio, C.M., Mechanics of Ballast Compaction, Volume 1: Technical Review of Ballast Compaction and Related Topics, FRA/ORD-81/16.1, USDOT, Transportation Systems Center, Cambridge, Massachusetts.

Selig, E.T.; Yoo, T.S.; Panuccio, C.M., Mechanics of Ballast Compaction, Volume 2: Field Methods for Ballast Physical State Measurements, USDOT, Transportation Systems Center, Cambridge, Massachusetts.

EASTERN EUROPEAN

Much of the published material provided by the Eastern European representatives are research working papers, internal memos or translations. For many of these publications, complete bibliographic information is not available. However, the titles of the articles have been listed below for future reference. Additionally, numerous research references where submitted in the original language and have not been translated into English and therefore have not been included.*

HUNGARY

Results of VIKI research are available in the Hungarian Railroad Scientific Research Institute Yearbooks, edited by Dr. Jozsef Nazy, (1973-1977).

---

*For further information, contact:
Mr. Philip Olekszyk, FRA
Mr. Andrew Sluz, FSC
Dr. Andrew Kish, TSC

POLAND

Project Agreement No. 4a, Task 1: Investigation of the Lateral Resistance of Concrete - Tie Track, Research Institute of the Polish State Railroad (COBiRTK), Warsaw, (December 1979).

The Methods of Strengthening of Wood Sleepers, Kolnex, Foreign Foreign Trade Enterprise of the Railway Rolling Stock Industry Union, Warsaw, Poland.

U.S./Poland Cooperative Agreement (Task 2). Project: "Development of a Method for Laboratory and Simulation Tests of Rail Fastenings to Cross-Ties."

U.S./Poland Cooperative Agreement (Task 3). Project: "Development of Rules for Wood Tie Classification and Criteria and a Forecasting Methodology for Their Renewal."

New Methodology of Rail Fastenings Testing Conducted in the Course of Polish-American Cooperative Agreement.

Preliminary Evaluation of Rail Fastening Test Structures by Adopted Criteria.

A Portable Ride Index /Wz/meter (CoBiRTK), Warsaw, Poland

RUMANIA

Romel/Scorteaner, R-41 Apparatus for Car Counting and Discrimination, Institute for Research and Technology Design in Transportation, Bucarest, Rumania (1979).

Romel/Scorteaner, Emil Spirea, Roder Crestia, R-53, Optical Electronic System for the Identification of a Retro-Reflective Label, Institute for Research and Technology Design in Transport, Bucharest, Rumania (1979).

Eastern European Track Structure Technology and Research (Final Report), 1981
US DOT, FRA, AT Kearney, Inc