Rationale and Technology Used by Amtrak to Select Concrete Ties for Use in Northeast Corridor

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The installation of concrete ties was necessary to achieve the goals of the Northeast Corridor Improvement Program (NECIP). A number of considerations, ranging from diverse operating requirements to specific structural attributes, were instrumental in arriving at this decision. The rationale and technology used by Amtrak during this decision process are discussed in this paper and an update is given on the performance of the concrete tie installation in the Northeast Corridor.

The Railroad Revitalization and Regulatory Reform Act of 1976 authorized the Northeast Corridor Improvement Project (NECIP). NECIP is a broad program of improvements to the railroad facilities, installations, and other fixed-plant properties along National Railroad Passenger Corporation's (Amtrak) Northeast Corridor (NEC) from Boston, Massachusetts, to Washington, D.C.

The Act established as a goal the achievement of regular, dependable service on a 3-hr, 40-min schedule between Boston and New York and a 2 hr, 40 min schedule between New York and Washington, D.C. The schedule at the beginning of NECIP was 3 hr, 56 min and 3 hr, 4 min, respectively (1, p. 1). Substantial track improvements were required to achieve the improved schedule time.

The requirements for track improvement, however, had to take into consideration more than running time. The Northeast Corridor was heavily congested with commuter and freight trains as well as intercity passenger trains, and this traffic was projected to increase steadily in the future.

The heavy freight tonnage dictated certain track criteria, and the frequency of trains meant that minimal time would be available to perform track work without dramatic disruption of service. Amtrak faced not only unique opportunities in railroad construction but also unique barriers to orderly progression of the work.

U.S. railroads have traditionally performed track reconditioning by component replacement. The Canadian National Railways, numerous European railroads, and the Soviet railroad have replaced whole sections of track in mechanized, one-step operations with track-laying systems.

The complete rebuilding method was chosen to minimize construction time. The types of ties to be used were then assessed. Among others, the Canadian National Railways, the Japanese National Railway, numerous European railroads, and, to a limited extent, some U.S. railroads had experience with concrete ties.

RATIONALE

The selection of concrete ties for use in the NEC was influenced by a number of factors. The following sections relate some of the major considerations that led to the decision to install more than 400 track-miles of concrete ties in the NEC.

Operating Requirements

Amtrak's main spine in the NEC consists of two segments: Washington, D.C., to New York City and New Haven, Connecticut, to Boston. The 57-mile segment from New Rochelle, New York, to New Haven is operated by the Consolidated Rail Corporation (Conrail) for the Metropolitan Transit Authority and the Connecticut Department of Transportation (Figure 1). The segment between Washington, D.C., and New York City is an electrified, multitrack system that has as many as six main tracks at congested locations. Amtrak intercity passenger trains currently operate over large stretches of this territory at speeds of up to 110 mph. On completion of NECIP, 120-mph operations will be possible at many locations. Extensive commuter operations, peaking at 108 trains per day in the New York City area (2, p. 8), exist throughout this segment. Freight service in the Washington to New York segment contributes to a total of up to 63.2 million gross tons annually over some double-track sections (3, p. 9). The segment between New Haven and Boston is predominantly a two-track system with lighter freight traffic and commuter operations limited to the Providence, Rhode Island, and Boston areas. Passenger train speeds in this segment are also scheduled to increase to 120 mph when NECIP is complete. In addition to the broad range of service requirements encountered in the NEC, the climate throughout this region is severe.

When Amtrak acquired the NEC in 1976 both of these segments contained numerous slow orders as a result of deferred maintenance by the predecessor railroads (Figure 2). These slow orders totaled 191 track-miles and severely limited operational flexibility. The slow orders had to be removed concur-

Figure 1. Schematic of Northeast Corridor.

Figure 2. Slow order chart.

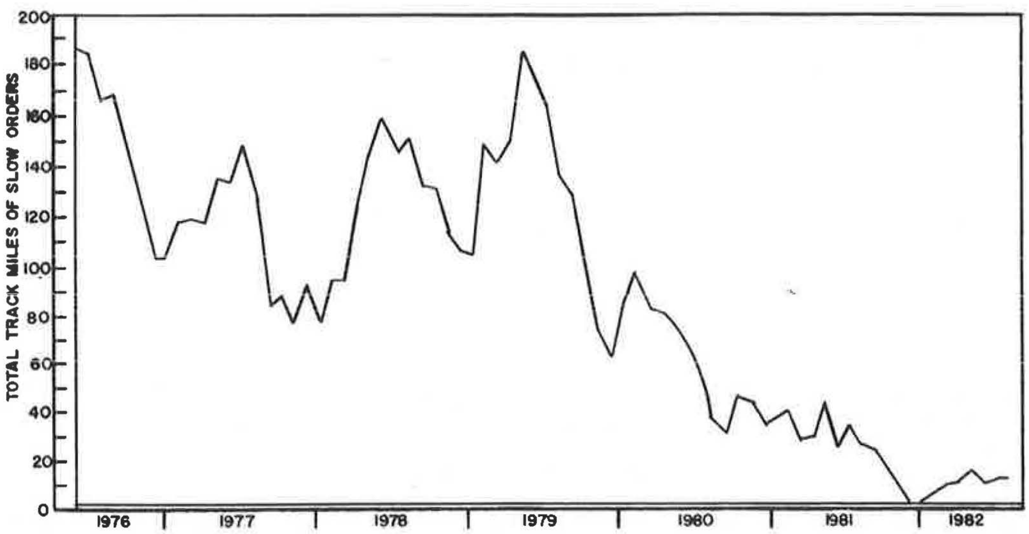
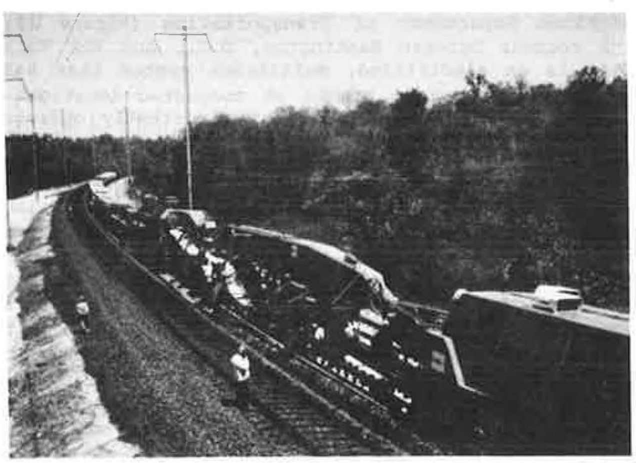


Figure 3. Track-laying machine.



rently with the undertaking of the NECIP high-speed track improvements.

Installation Techniques

In 1976 during the initial planning for implementation of the NECIP track program, Amtrak realized that conventional track rehabilitation methods and track structures would not be sufficient to allow achievement of all congressionally mandated program goals. Included in these goals was the installation of a track structure capable of providing both high-speed passenger service and high-tonnage freight operations safely and economically. At that time the completion date for this installation was set for February 1981. Because of this time limitation and the high traffic density in the NEC, a track-laying system approach was necessary in addition to conventional component-renewal techniques. Investigations of various track-renewal systems, including panel renewal with gantries, led to the selection of a continuous track-renewal system. Continuous total track renewal was expected to provide the highest productivity for each hour of track time in areas designated for high-speed operation.

The system selected was the Canron track-laying machine model P-811 (Figure 3). The adoption of this method of track renewal allowed the consideration of various types of track structures that otherwise would not be feasible. The two primary systems that were evaluated were wood ties with elastic fasteners and concrete ties with elastic fasteners. Either of these systems would have been compatible with the total track-renewal method.

Suitability for High-Speed Operations

Once the decision to use total track renewal was made the focus of the evaluation turned to meeting the requirements for high-speed (up to 120 mph) operation. Ride quality at 120 mph is sensitive to deviations in track geometry. Therefore, the track structure must be such that any permanent deformation or systematic deviations occur uniformly. Studies over a period of years by European and Japanese railroads indicated that concrete ties provided a measurable increase in the ability of the track structure to retain the stringent track geometry needed at high speeds. This was due in large part to the greater weight of the concrete tie, which would help to mitigate the static and dynamic loadings that accelerate track geometry degradation. Testing on various railroads and at the facility for accelerated service testing supported the hypothesis that concrete ties, when compared with wood ties, provided improved track geometry retention (1;3, p. 9). An additional advantage of the concrete tie was the accurate (+1/32 to 3/32 in.) uniform gauge that could be specified and constructed during manufacture. This feature is of primary importance when high speed is desired.

Maintenance Requirements--Wood Versus Concrete

Traffic levels were projected to rise steadily in the future; therefore, close attention was given to maintenance requirements for wood versus concrete tie track. Perhaps the most important requirement that had to be addressed was the service life of the tie. Abundant information was available on the service life of wood ties and a 25-year life was adopted for the NEC (1). The projected life for concrete ties, however, was not well documented. The combination of high-speed and high-tonnage operation presented a scenario unique to the NEC. A performance evaluation of concrete ties in the high-speed operations of Europe and Japan and those installed in high-tonnage operations, such as the Canadian National Railways, Chessie System, Santa Fe System, and Norfolk and Western Railway Company, aided the development of a design that is expected to have a 50-year service life for concrete ties installed in the NEC (1). Concrete ties also showed potential for reducing maintenance reqirements for rail renewal and track surfacing.

Drainage requirements for concrete tie track had historically been more stringent than that for wood ties. A minimum of 12 in. of clean ballast was required under concrete ties. This requirement can be met with the addition of new stone; however, the restricting overhead clearances on the NEC limited the amount of track raising and forced the adoption of an undercutting program at the time of installation. In addition to the policy of undercutting (Figure 4) at the time of installation, ballast cleaning was projected on a cyclical basis thereafter. This is good practice on any high-speed track but mandatory for concrete ties.

Economic Factors

An investigation of the initial investment and life-cycle costs of installing concrete ties as opposed to wood ties was conducted and the results supported the selection of concrete ties. A track-laying system would be used for installation in either case.

Table 1 (1) gives a comparison of the unit cost for a wood tie and elastic fastening system versus the cost for a concrete tie with an elastic fastener. This comparison reveals a 14 percent higher cost per tie for the concrete tie; however, this higher cost per tie is offset by a reduction in the number of ties per mile as a result of the selection of a 24-in. tie spacing. Accordingly, the projected cost of $201,941/mile for concrete tie track (Table 2) was 5 percent lower than the projected cost of $211,891/mile (Table 3) for wood tie track.

The life-cycle cost comparison indicated that a cost savings would be achieved with concrete ties. A comparative cost analysis was conducted to project costs over a 50-year life cycle (1).

The initial material costs, initial installation costs, annual maintenance costs, and the residual value of the track structure components were compared for (a) component renewal of wood ties, (b) total renewal of wood ties, and (c) total renewal of concrete tie alternatives. A computer program was developed that displayed the total initial construction costs and each category of maintenance cost and any residual value, all identified by the year of expected occurrence. The costs were then discounted to a present value by using a discount rate of 10 percent. This analysis showed a cost savings with the use of concrete ties.

Cost sensitivities were estimated for the discount rate, expected tie life, and expected rail life. This analysis gives the following results:

1. As the discount rate increases the life-cycle advantage of concrete ties decreases,

Figure 4. Undercutter.

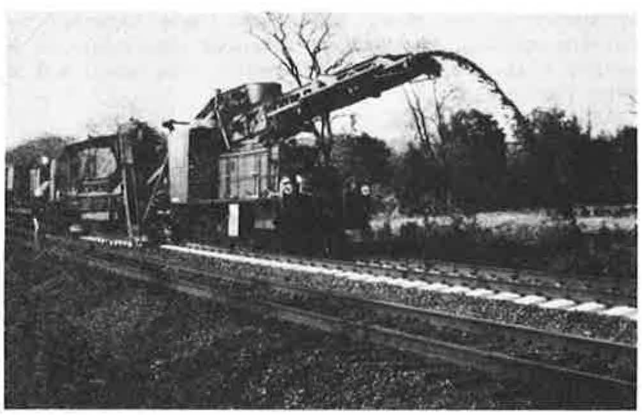


Table 1. Unit cost comparison of wood tie versus concrete tie.

Item	Quantity	Cost per Item ($)	Total ($)
Wood Tie, Elastic Fastening			
Wood tie	1	17.22	17.22
Special plates	2	5.34	10.68
Lock spikes	8	0.18	1.44
Elastic clips	4	1.52	6.08
Total			35.42
Concrete Tie, Elastic Fastening			
Concrete tie including shoulders for elastic clips[a]	1	31.50	31.50
Insulator assembly, nylon	4	0.45	1.80
Tie pads, polyethylene	2	0.50	1.00
Elastic clips	4	1.52	6.08
Total			40.38

Note: All costs are in 1977 dollars.
[a]Area performance specification for monoblock 8 ft 6 in. long.

Table 2. Concrete tie installation costs.

	Year 0 Cost per Track-Mile ($)			
Item	Labor	Material	Equipment	Total
Distributing continuous welded rail	612	4,082	1,329	6,023
Removing other track material	971		72	1,043
Track-laying system[a]	5,660	196,583	7,397	209,640
Tie-sorting plant	1,126	1,211	404	2,741
Rail cleanup	1,074		1,469	2,543
Undercutting and surfacing with machine costs	5,356		10,642	15,998
Distributing ballast	340	1,901	342	2,583
Inspection	287		51	338
Spot surfacing	151		92	243
Salvaging rail and other track material		-28,223		-28,223
Salvaging ties		-10,968		-10,968
Total	15,577	164,586	21,778	201,941

Note: All costs are in 1977 dollars.
[a]Includes rail, ties, and other track material cleanup.

Table 3. Wood tie installation costs.

Item	Year 0 Cost per Track-Mile ($) Labor	Material	Equipment	Total
Distributing continuous welded rail	612	4,082	1,329	6,023
Preplating ties	838		271	1,109
Removing other track material	971		72	1,043
Track-laying system including other track material	4,347	213,234	6,970	224,551
Tie-sorting plant	1,126	1,211	404	2,741
Rail cleanup	1,074		1,469	2,543
Undercutting and surfacing with machine costs	3,764		6,144	9,908
Distributing ballast	340	1,901	342	2,583
Inspection	287		51	338
Spot surfacing	151		92	243
Salvaging rail and other track material		-28,223		-28,223
Salvaging ties		-10,968		-10,968
Total	13,510	181,237	17,144	211,891

Note: All costs are in 1977 dollars.

2. Varying rail life with concrete ties from 25 to 35 years has a negligible affect on life-cycle costs,

3. Varying the life of concrete ties from 40 to 50 years affected life-cycle costs by less than 2 percent.

Table 4 gives the findings of the economic analysis.

TECHNICAL EVOLUTION

Once concrete tie tracks were found to possess certain attributes (e.g., tighter construction tolerances, higher track modulus and stiffness, reduced maintenance possibilities, and economic advantages) desirable for use in the high-speed track upgrading program, the technical evolution of the tie began. The combination of high speeds and high tonnage presented a unique problem for the designer. For this reason, a specification somewhat more specific than that adopted by the American Railway Engineering Association (AREA) had to be developed. The development of the Amtrak-NECIP concrete tie specification generally covered three areas--the design of the tie, the selection of the fastening system, and quality control.

Design of Concrete Ties

Of primary concern during the development of the Amtrak-NECIP specification for concrete ties was the need to design a tie capable of withstanding the severe service requirements of the NEC for at least 50 years. With this requirement in mind, a monoblock, prestressed, reinforced tie was specified. A tie spacing of 24 in. was determined to be adequate for providing the desired track modulus, subgrade pressure, rail support, and economy. In addition, parameters such as overall dimensions, bearing areas of the tie bottom, concrete mix design, and manufacturing tolerances were delineated in the Amtrak-NECIP specification.

Because of Amtrak's service requirements, the flexural capacity of the NEC concrete tie had to be somewhat higher than is normally required for high-speed passenger operations. Therefore, specific static and dynamic bending moments were identified; the results yielded a tie with approximtely 20 percent greater flexural strength than the minimum AREA requirement.

Selection of a Fastening System

The specifications for the fastening system emphasized requirements for a low-maintenance, nonthreaded, elastic fastener. The fastening system had to be capable of providing full lateral, vertical, and longitudinal restraint of the rail and also of absorbing the shock of impact loads imparted by rolling stock. The system selected consisted of a spring clip, cast shoulder insert, tie pad, and a separate insulator.

Quality Control

A stringent quality control and testing program was developed at the production facility to ensure a uniform high-quality product. Three ties were selected at random from each production line (560 ties) for dimensional verification and quality control testing. These tests included rail seat positive moment, center negative moment, and bond development-tendon anchorage tests. In addition six cylinders were taken from each production line for concrete compressive strength tests. Cylinders were broken to ensure a strand-release compressive strength of 4,000 psi and a minimum 28-day strength of 7,000 psi. Only after all quality control testing had been completed successfully and all ties had been inspected visually were the ties accepted and released for shipment.

Table 4. Life-cycle cost comparison.

Structure Basis and Renewal Method	Description	Year 0 Cost ($/mile)	50-Year Life-Cycle ($/mile)[a]
Total renewal-wood ties	Wood ties with elastic fastener; 25-year avg tie life, 25-year avg rail life, new rail and 3,250 ties in year 0, and in year 25, 52 new ties every 12 years, 124 new ties every 16 years, 210 new ties every 20 years	211,891	288,197
Total renewal-concrete ties	Concrete ties with elastic fastener; 50-year avg tie life, new rail and 2,640 ties in year 0, 18 new ties every 24 years, 62 new ties every 36 years, 100 new ties every 44 years	201,941	242,649

Note: All costs are in 1977 dollars.

[a]Discount rate of 10 percent included.

Acceptance

A team of specialists from Amtrak, De Leuw Cather/ Parsons, and FRA was assembled to evaluate the proposals solicited from various concrete tie manufacturers. This evaluation was conducted in two stages. A technical proposal was solicited, and manufacturers that met the technical requirements were requested to furnish pricing proposals. This two-part evaluation procedure led to the selection of a tie manufactured by the Santa Fe-San-Vel Pomery, Incorporated, with a Pandrol-601 fastening system. The ties were manufactured at Littleton, Massachusetts, and installation began at Wood River Junction in Rhode Island in June 1978.

RESULTS

From June 1978 to August 1982 Amtrak installed more than 940,761 concrete ties on 373 miles of track in the NEC. Ties were divided as follows: 215 track-miles between Washington and New York City and 158 track-miles between New Haven and Boston. Service requirements range from the high-tonnage and high-speed requirements found at Aberdeen, Maryland, to the high-frequency passenger service on Amtrak's high line into New York City.

For the most part these ties perform in accordance with the rationale adopted for their selection. Amtrak is benefitting from improved track geometry retention in concrete tie track. It is participating in a program with FRA to develop a method for quantifying requirements for track maintenance based on an overall track quality index. The development of this program, along with accumulation of data from regularly scheduled inspections, should allow a meaningful measure of concrete tie performance to be provided. Preliminary analysis of geometry car data indicates that concrete tie track provides the uniform settlement projected during the selection process. At this point, however, thinking has to be modified on the first cycle for surfacing after installation. Because of the undercutting required for concrete ties, the initial settlement of the track is greater than expected and the current practice is to surface after approximately 6 months under traffic. This practice is primarily a by-product of undercutting track and is not limited to areas that have concrete ties.

As might be expected with an installation of this magnitude and lack of precedence, refinement to the original system is continuing. One example of this process is the work being done to solve a problem with clip fallout. Amtrak has experienced a phenomenon wherein certain stretches of track exhibit a tendency for the clips to work out of the shoulder inserts over a period of time. Field inspections at a number of locations have been conducted to isolate the cause for this situation.

These inspections have revealed a possible connection between rail surface imperfections (e.g., engine burns or corregations) and clip fallout. The possibility that wheel irregularities have contributed to this situation is being scrutinized. Amtrak has attempted to improve clip retention by the combined use of stringent procedures for repair of engine burn and a thorough wheel-inspection program. In addition to the installation of tie pads, Amtrak is currently evaluating various insulator configurations designed to combat clip fallout.

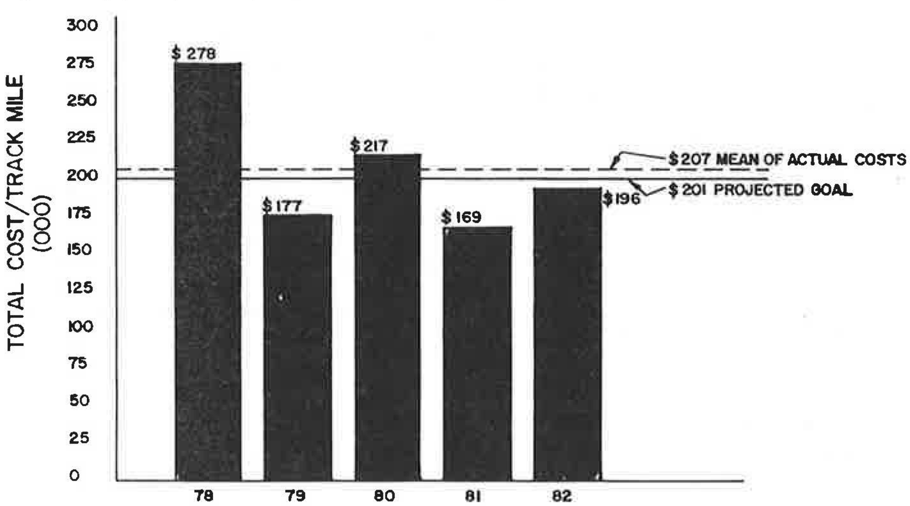
A second phenomenon that is being monitored closely is the appearance of hairline cracks in the rail seat area of some ties. The majority of these cracks is not visible to the naked eye and must be washed with alcohol to be seen. Amtrak has conducted numerous inspections of ties throughout the NEC in an effort to identify the source of the cracking and to monitor the growth of existing cracks. Again, wheel irregularities are thought to be the source of the high-energy-impact loads capable of causing cracking. A softer tie pad was installed during the 1982 program in the hope of mitigating the high loadings imparted on the rail seat area of the tie.

One additional point of interest associated with the evaluation of concrete ties is the comparison of the projected installation costs to the actual installation costs experienced during the past 5 years. The results of this comparison are shown in Figure 5 and include tie exchange, rail replacement, and undercutting. Note that the mean of the actual costs (in 1977 dollars), $207,735, follows closely with the cost per mile of $201,941 projected in 1977. The variance of costs for individual work seasons reflects the learning curve that was encountered with Amtrak's track-laying system and the differing levels of track occupancy provided.

CONCLUSION

Amtrak's experience with concrete ties has, for the most part, been consistent with the rationale used for tie selection. Although the final evaluation of

Figure 5. Equipment, material, and labor costs: concrete ties.



concrete ties will not be made for several years, they appear to be performing as intended. The ties on the NEC have, during the last 4 years, provided good track geometry retention while being subjected to up to 82 million gross tons in addition to 110 mph passenger operations.

Amtrak is continuing the evolutionary development of the specifications and maintenance technology associated with concrete ties with an eye toward additional installations in the future. Funding is currently being sought to complete the installation of concrete ties on two tracks between Washington, D.C. and New York. Also, the satisfactory performance of the concrete tie has led to the exploration of the feasibility of concrete switch ties. Amtrak remains firmly committed to the development of the concrete tie and urges others to write for more information about its experience.

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

Geotechnical Evaluation of Track Structure

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The Illinois Central Gulf Railroad undertook a program of track roadbed stabilization as part of a track rehabilitation project financed by FRA's purchase of preferenced shares under Title 505 of the Railroad Revitalization and Regulatory Reform Act of 1976. The investigation and analytical techniques that evolved from these projects are summarized in this paper. The procedure of data gathering used to identify and classify observed irregularities in track surface geometry is described. Also described is a method of field investigation to prove theories of failure developed by study of the collected data. The laboratory analysis of soil samples recovered from sites selected for remedial measure and the methods employed to achieve enhanced track roadbed strength are also addressed.

Addressed in this paper is a method of geotechnical investigation developed during a program of roadbed rehabilitation performed in three successive stages on the Illinois Central Gulf (ICG) railroad. The program was funded by FRA's purchase of preference shares as provided for in Section 505 of the Railroad Revitalization and Regulatory Reforms Act of 1976. These resurfacing, restoration, rehabilitation, and reconstruction (4-R) stages of the program, which were primarily track superstructure rehabilitation projects, were begun in the fall of 1977 and completed in April 1983.

SYSTEM

The manner in which the 4-R programs were organized provided a means of segmenting the 700 route-miles of track into more manageable lengths. A segment lends itself to logical analysis of the results of remedial expenditures and, preferably, has beginning and ending points pertinent to train operations.

The system also required a method of investigation. The method evolved into a two-part program. The first part is the initial investigation, which results in a report of site selection. The second part is the detailed investigation, which results in a recommendation of remedial work.

Of primary importance to any system is the recognition of a goal. The goals of this effort are (a) to determine the time-dependent response of the plane of the top of the rails to germane force fields and (b) to evaluate the probable increase of the length of a track surface maintenance cycle by installing a designed remedial measure. The system must also recognize that track that can be maintained to the requirements of service and regulation without an extraordinary expenditure of track maintenance resources, as determined by the responsible maintenance officer of the company, is good track and not a fit subject for these procedures.

INITIAL INVESTIGATION

The initial investigation is the crux of the roadbed stabilization effort. It consists of three activities: office investigation, field observation, and site selection. The office investigation consists of the collection of segment history, geometry, topography, and climatological and geologicl data. The field observation consists of an on-track inspection in the company of maintenance officers familiar with the segment. Site selection, the formal results of the initial investigation work, lists and sets the priority order for the lengths of track in a segment that has track surface irregularities and notes the sites to be included in the detailed investigation.

Office Investigation

The purpose of the office investigation is to gain insight into the lay of a segment of track and its environment. This study has two results. The first and most important is to enhance the investigator's knowledge of the segment, and thus increase understanding during the field investigation activity. The second result is to broaden the data available for a segment, and thus enhance site-selection reporting.

Field Observation

Successful gathering of field notes is the key to a successful initial investigation effort. A day of