Development of U.S. Army Railroad Track Maintenance Management System (RAILER)

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ABSTRACT

U.S. Army Facilities Engineers are responsible for the maintenance of more than 3,000 mi of railroad track. The track is dispersed in small lots and is analogous to industrial rather than commercial trackage. At present, there is no standard method for gathering track inventory and condition data and no standard method of determining the track's condition. In this paper an overview of the proposed U.S. Army Railroad Maintenance Management System (RAILER) and track evaluation concepts are presented. RAILER is to consist of subsystems for network definition, data collection including condition survey, data storage and retrieval, network data analysis, and project data analysis. The development of these subsystems is highly dependent on the track condition evaluation procedures that are used. Two major evaluation categories have been identified: track structural condition and track operational condition. Recommended procedures for performing the evaluation are presented.

U.S. Army Facilities Engineers are responsible for the maintenance of more than 3,000 mi of railroad track. The track is dispersed in small lots and is analogous to industrial rather than commercial trackage. Because the track does not compete well for maintenance funding, much of the maintenance and repair it needs has been deferred. If this trend continues, some of the track may deteriorate to a point where it could no longer support its mobilization mission. At present, there is no standard method for gathering track inventory and condition data and no standard method of determining the track's condition.

An intensive search was performed (1) to define maintenance problems and available maintenance management systems. The U.S. Army Major Command (MACOM) engineers, Strategic Mobility personnel, and track maintenance personnel were interviewed to obtain input about Army track maintenance problems. Twenty-seven large operating railroad firms, 14 firms operating short-line railroad tracks, the Federal Railroad Administration, and private railroad consultants were surveyed to determine what system, if any, they used for managing their track maintenance operations.

The search showed that there is no complete track maintenance management system that could be readily adapted to Army use; it also showed that the most efficient way of providing a track maintenance management system is to design one specifically tailored to the Army system of operation.

The U.S. Army Construction Engineering Research Laboratory (USA-CERL) was tasked with the development of such a system. USA-CERL has successfully developed an Army maintenance management system for pavements (PAVER) (2,3). It was decided that the generic concepts of maintenance management developed for PAVER be adopted, but that special attention be given to the technological differences between pavements and railroads.

In this paper an overview of the proposed U.S. Army RAILER and track evaluation concepts and recommended procedures is presented.

OVERVIEW OF THE RAILER SYSTEM

The basic subsystems of any facility maintenance management system consist of network definition, data collection including condition survey, data storage and retrieval, network data analysis, and project data analysis. The relationship among these subsystems is shown in Figure 1. The development of each of these subsystems for a given facility should be technologically based and cannot be blindly adapted from another facility's management system. The following is a brief description of each subsystem as envisioned for the RAILER system.

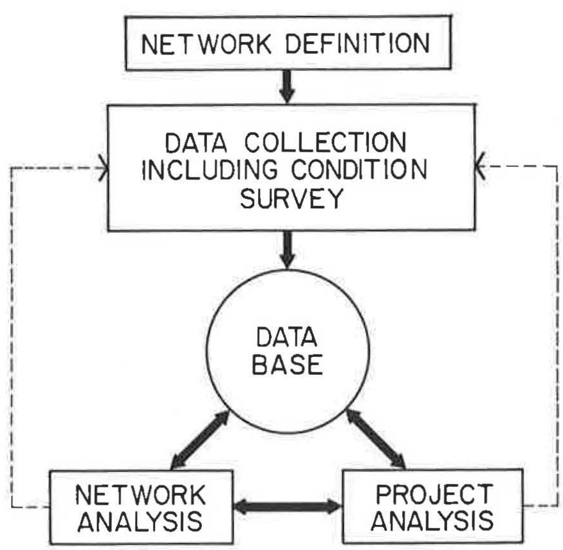

FIGURE 1 Generic facility maintenance management system.

Network Definition

Before anything can be managed, what is to be managed must be defined; railroad tracks are no exception. A track network could be defined in terms of mileposts, switch locations, grade crossings, and structures such as bridges. The network should be divided into sections that are uniform in construction and condition and that are subjected to similar traffic loadings. These sections represent the smallest management units in terms of major rehabilitation needs.

Data Collection

Data collection includes physical inventory of the track structure as well as the condition of each of its components. Data should also be gathered on the traffic that uses the track, including load intensity and number of repetitions. The details of the data collection and condition survey are determined on the basis of the needs of the condition evaluation and analysis techniques developed for both the project- and the network-level analysis. Exceeding these needs will not be cost-effective and could lead to failure of the entire management system.

Data Base

A data base can be manual (file cabinet) or automated (computer). In light of cost, expediency, and convenience, a computer system is much preferred. An inefficient or ill-designed data base will undoubtedly result in an inefficient overall system. The objective of the data base is to provide expedient and friendly data storage and retrieval. In the last 2 years, many "Data Base Manager" computer software packages have become available for microcomputers with features that were only available on large-frame computers before. Some of these packages offer excellent support for screen-formatted data entry, report generation using conversational language, and the ability to interface engineering analysis programs with the data base.

Network Analysis

The objectives of network analysis include budget planning, budget optimization, project identification and priority listing, and network inspection scheduling. To avoid duplication of efforts, it is best to coordinate the network inspection with the agency railroad track maintenance standards inspection. The development of the network analysis programs is a difficult task that requires the cooperation and involvement of the system's ultimate users.

Project Analysis

The primary objective of project-level analysis is to determine the best track rehabilitation alternative. This requires more detailed condition data than are needed for network analysis. One of the major factors in selecting the best rehabilitation alternative is life-cycle costing. Emphasis should be placed not only on initial rehabilitation cost but also on future maintenance costs associated with the alternative. An economic analysis procedure that can be used has been developed as part of the PAVER system (2,3). Guidelines for providing track information inputs to the analysis procedure still need to be developed.

The development of these subsystems is highly dependent on the track condition evaluation procedures used. This subject is addressed in the following section.

RAILROAD TRACK CONDITION EVALUATION CONCEPTS AND RECOMMENDED PROCEDURES

The railroad track and its support system have four main components: the rail and ties, which make up the basic track structure; and the ballast and subgrade, which make up the foundation. In addition to providing direct support for train traffic loads, each component, from the rail on down, distributes these wheel loads over an increasingly large area, thus minimizing pressure on the subgrade. For the track and foundation (track system) to withstand the loads imposed by train traffic, each component must have sufficient structural integrity to carry out its dual role of load support and load distribution.

In addition to providing structural support, the track system must also maintain track geometry: proper position and alignment of the two rails. A deterioration of either track strength or track geometry can make track unsuitable for service.

At present, there is no standardized method for evaluating track condition as a whole--a method that considers both track strength and operational condition. Definitions of major track condition categories and how to evaluate them follow.

- Structural Condition. This is a measure of the load-carrying capacity of the track structure. It takes into account both the magnitude of the wheel loads and the number of load repetitions the track system can handle before failure occurs. Structural condition is evaluated using a track modeling technique and knowledge of the strength of the individual components of the track system, including rail, ties, ballast, and subgrade.
- Operational Condition. This is a measure of maintenance and rehabilitation needs as well as of the safety of the track system. Operational condition is evaluated on the basis of the condition of the individual components of the track structure as well as on the geometric condition of the track.
- Evaluation

1. Rail condition
   a. Internal defects (such as cracks)
   b. External defects (such as wear)
2. Tie condition
   a. Number of defective ties
   b. Severity of defects
   c. Arrangement of defective ties
3. Ballast and subgrade
   a. Degree of fouling and degradation
   b. Drainage condition
4. Track geometry condition
   a. Gauge
   b. Crosslevel
   c. Profile
   d. Alignment

To achieve the objectives of this work, three subcontracts were awarded to three recognized consultants in the area of railroad engineering to perform preliminary studies and provide necessary background in the following three areas:

1. Tie condition evaluation (4),
2. Track geometry condition evaluation (4), and
3. Ballast and subgrade evaluation as well as overall track strength condition evaluation (4).

Meetings were also held with the U.S. Army Pavement and Railroad Maintenance Committee, which includes

Army railroad Major Command engineers. During these meetings, various track condition evaluation concepts were presented and critiqued. The recommendations presented in this paper are based on the consultants' reports, the author's views, and input from the Army Committee. Two major evaluation categories have been identified: track structural condition and track operational condition. Recommendations for evaluating each of these categories are presented in the following sections.

Structural Condition Evaluation

Two evaluation procedures are recommended. One procedure is to be approximate, but simple to use by Facilities Engineers without need for sophisticated testing or analysis. The other procedure is to provide in-depth analysis as a basis for determining cost-effective maintenance and repair alternatives. Both procedures are based, in principle, on mechanistic analysis of track behavior and on relating that behavior to track performance. The inputs for the approximate procedure, however, do not have to be based on direct measurements of material properties.

The overall structural evaluation of the track is a function of its components, including subgrade, ballast, tie, and rail, as well as the load to which the track is subjected. The effect of each track component on track structural condition indicators was studied. The study was performed in cooperation with Marshall Thompson of the University of Illinois, using the ILLI-TRACK computer system (5).

Typical results obtained using ILLI-TRACK are given in Table 1. By using subgrade strength, ballast thickness, tie spacing, rail size, and load as inputs to ILLI-TRACK, the following track structural condition indicators can be determined:

1. Tie reaction in kips [ballast bearing pressure can be computed as tie reaction divided by tie width multiplied by effective length (24 in.)],
2. Tie deflection,
3. Subgrade stress ratio (stress/strength), and
4. Rail bending stress.

TABLE 1 ILLI-TRACK Response Summary (4)

Ballast Thickness (in.)	Subgrade[a]	Maximum Tie Reaction (kips)	Tie Δ (mils)	Subgrade Stress (psi) $\sigma 1$	$\sigma 3$	σD	Relative Subgrade σ^b (%)
12	Medium	18.5	153	26.7	16.9	9.8	43
18	Medium	20.7	138	24.3	15.4	8.9	39
24	Medium	22.4	133	22.1	14.2	7.9	34
12	Soft	16.6	299	23.6	16.6	7.0	54
18	Soft	19.3	266	21.7	15.3	6.4	49
24	Soft	21.5	248	20.0	14.2	5.8	45
12	Very soft	15.4	493	–[c]	–	–	100
18	Very soft	17.4	479	17.1	13.0	4.1	66
24	Very soft	20.2	438	15.6	11.9	3.7	60
6	Medium	16.7	159	30.0	18.8	11.2	49
6	Soft	15.1	319	26.0	18.4	7.6	59
6	Very soft	18.2	553	34.2	28.0	6.2	100

[a] Subgrade strengths: medium – q_u = 23 psi; soft – q_u = 13 psi; very soft – q_u = 6.2 psi.
[b] Relative subgrade stress = 100 (subgrade stress/subgrade strength) = 100 (σ_D/q_u).
[c] Extensive subgrade and ballast failure. Stress data are not valid.

Each of these indicators can be used to determine the adequacy or inadequacy of the track to carry a specific load for a given number of repetitions.

For the approximate procedure, it is recommended that a parameter study be performed using ILLI-TRACK (or a similar mechanistic model) from which a nomograph, such as that shown in Figure 2, can be constructed. For the approximate procedure, a methodology needs to be developed for which all the inputs can be obtained by the Facilities Engineer's staff without the need for sophisticated testing or analysis. If track strength is determined to be inadequate or questionable, the detailed structural evaluation can be requested.

For the in-depth evaluation procedure, similar nomographs could be developed, but the input would require more direct measurements and the output should be in terms of allowable specific load value and associated number of repetitions. An alternate method for the in-depth evaluation is the direct use of the selected mechanistic model on a project-by-project basis.

A limited parameter study was performed using

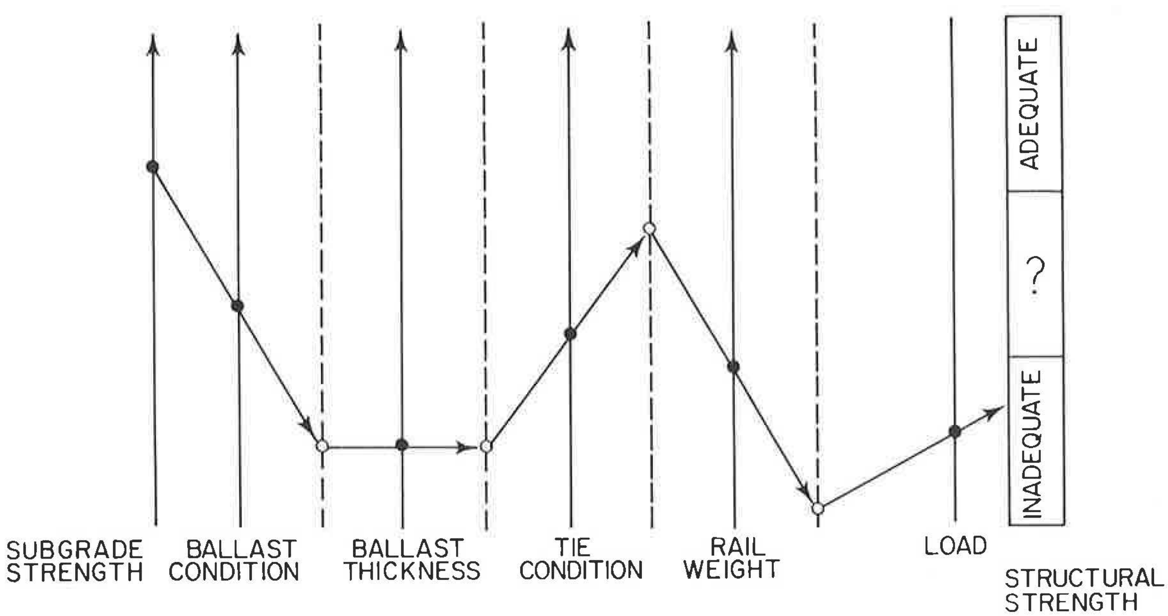

FIGURE 2 Conceptual nomograph recommended for U.S. Army railroad track structural evaluation.

TABLE 2 ILLI-TRACK Comparisons (5)

Rail Size	Tie Spacing (in.)	Maximum Tie Reaction (kips)	Tie Δ (mils)	Subgrade Stress (psi) $\sigma 1$	$\sigma 3$	σD	Relative Subgrade σ^a (%)	Rail Bending Stress (ksi)
132	20	16.6	299	23.6	16.6	7.0	54	19.3
132	40	30.3	456	25.8	16.4	9.4	72	22.1
90	20	19.5	310	24.4	16.5	7.9	61	28.9
90	40	31.7	459	26.4	16.3	10.1	78	32.8
60	20	26.0	331	26.3	16.8	9.5	73	43.0

Note: Ballast thickness = 12 in.; soft subgrade; and tie size = 9 in. wide by 7 in. thick.

[a] Subgrade strength: soft – q_u = 13 psi; relative subgrade stress = 100 (subgrade stress/subgrade strength) = 100 (σ_D/q_u).

ILLI-TRACK to illustrate the relative effect of rail size and tie spacing on the structural strength indicators. The results of the study are given in Table 2 and Figures 3-6. It should be noted that a tie spacing of 40 in. was used to simulate a case in which every other tie is bad, although further parameter studies should consider various arrangements of bad ties. However, from this limited study, the importance of both tie condition and rail size cannot be overemphasized. The study was performed assuming a soft subgrade. The significance of the subgrade class is clearly demonstrated in Table 1.

Operational Condition Evaluation

In many cases the operational failure of a track system may be caused by the gradual deterioration of the system components, localized defects, or improper track geometry. These conditions are often correctable, before failure, with an effective maintenance management system. They represent the operational condition of the track.

The operational condition of a track segment can be determined by measuring and inspecting

1. Rail condition,
2. Tie condition,
3. Ballast drainage condition,
4. Subgrade drainage condition, and
5. Track geometry.

Rail Condition

Rail condition is determined by inspecting both internal and external defects.

Internal defects must be detected with special equipment. These defects are potentially hazardous because they cannot be seen, and there are often no external indications of their presence. If not detected, an internal defect can grow until a rail break occurs.

External defects include rail head wear (both top and side), corrosion, cracks, and various surface defects. Sometimes these occur in combination with internal defects.

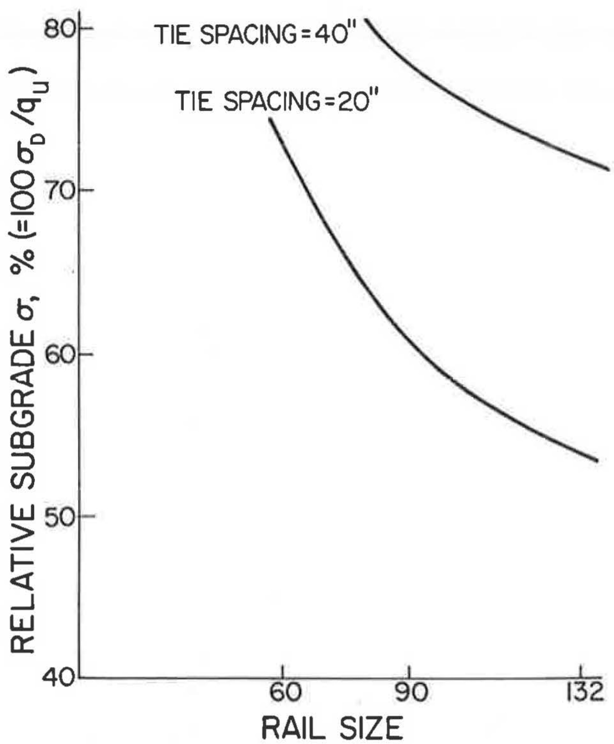

FIGURE 3 Effect of tie spacing and rail size on relative subgrade stress.

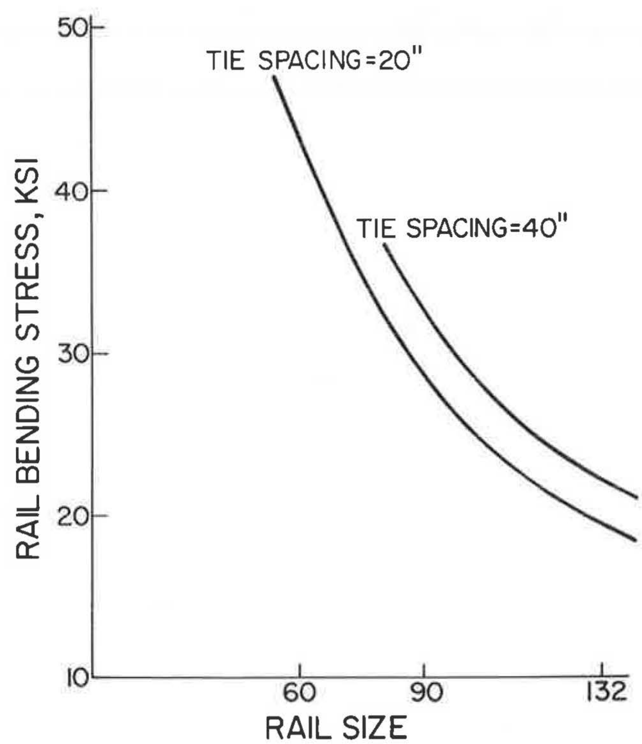

FIGURE 4 Effect of tie spacing and rail size on rail bonding stress.

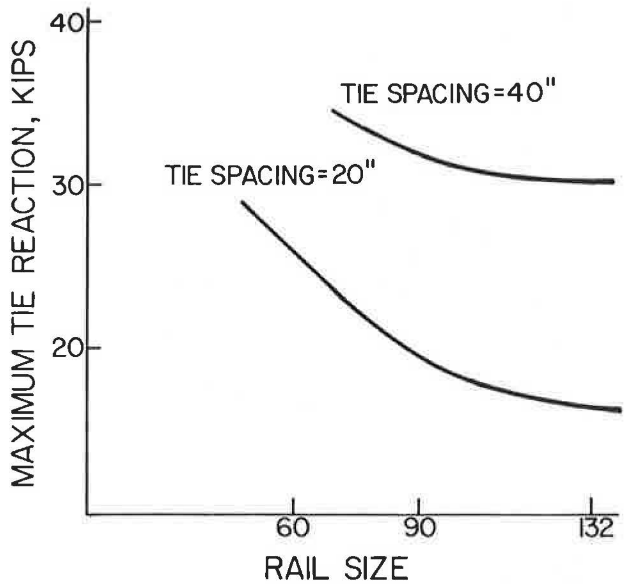

FIGURE 5 Effect of tie spacing and rail size on maximum tie reaction.

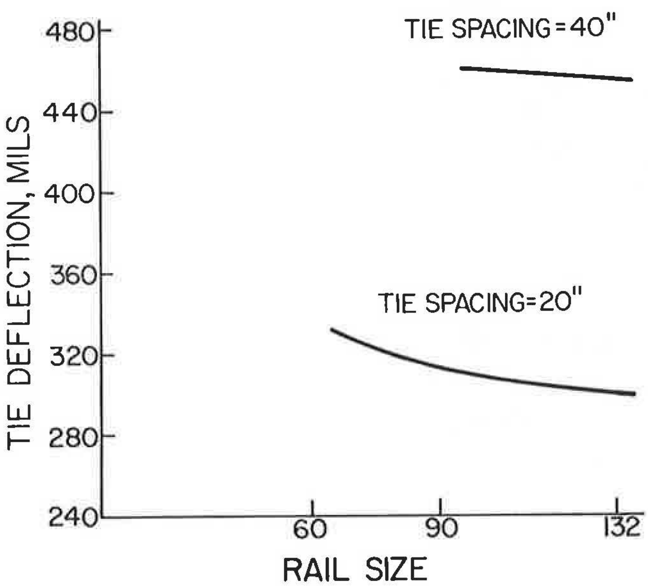

FIGURE 6 Effect of tie spacing and rail size on tie deflection.

In most cases, rail defects are corrected by replacing the defective section.

Tie Condition

Tie condition may be determined by combining a visual inspection procedure with calculations to produce a tie condition index. This index would indicate the overall condition of ties in a given track segment.

Tie defects may cause the loss of both vertical and lateral rail support, which leads to poor track geometry and loss of track load-carrying capacity. The need for tie replacement in a given track segment is determined by the number of defective ties, the arrangement of defective ties (i.e., the presence of consecutive defective ties), and the severity of the defects. Figure 7 shows typical tie defects.

Ballast Drainage Condition

The ballast section holds the track in vertical and horizontal alignment. To properly perform this function, ballast must drain well and not suffer significant particle degradation.

Visual inspection can be used to detect drainage problems and ballast deterioration. When such conditions exist, remedial action is required.

Subgrade Drainage Condition

Like the ballast section, the subgrade provides vertical track support. To do this, the subgrade must have sufficient strength and be properly drained. Visual inspection can be used to detect drainage problems and signs of subgrade failure.

Track Geometry

Track geometry is usually described by four parameters: gauge, crosslevel, alignment, and profile (Figure 8). For military railroads (or any other low-speed trackage), the most important geometric parameters are gauge and crosslevel. Ultimately, all track system components hold the rails in proper position; therefore, a track geometry defect usually indicates the failure of one or more of these components.

Track geometry measurements can be made with simple devices on unloaded track. However, without full-scale loading, the results may not accurately reflect what the position of the rails would be when subjected to actual train traffic. This is especially the case for track that is of light construction, is rarely used, has had minimal maintenance over the years, or has structural defects. A significant portion of Army track falls into at least one of these categories. Therefore, it was recommended that track geometry measurements be taken with engine- or car-mounted devices.

Geometry-measuring devices that mount on the engine or car are currently available. They allow measurements to be made and recorded continuously along the track under full-scale loads. In addition, this equipment is easily installed and removed.

SUMMARY

The concepts developed for the U.S. Army Railroad Track Maintenance Management System (RAILER) have been presented. RAILER will consist of subsystems for network definition, data collection including condition survey, data storage and retrieval, network data analysis, and project data analysis. Two major track evaluation categories have been identified: track structural condition and track operational condition. Current work efforts include the development of these elements.

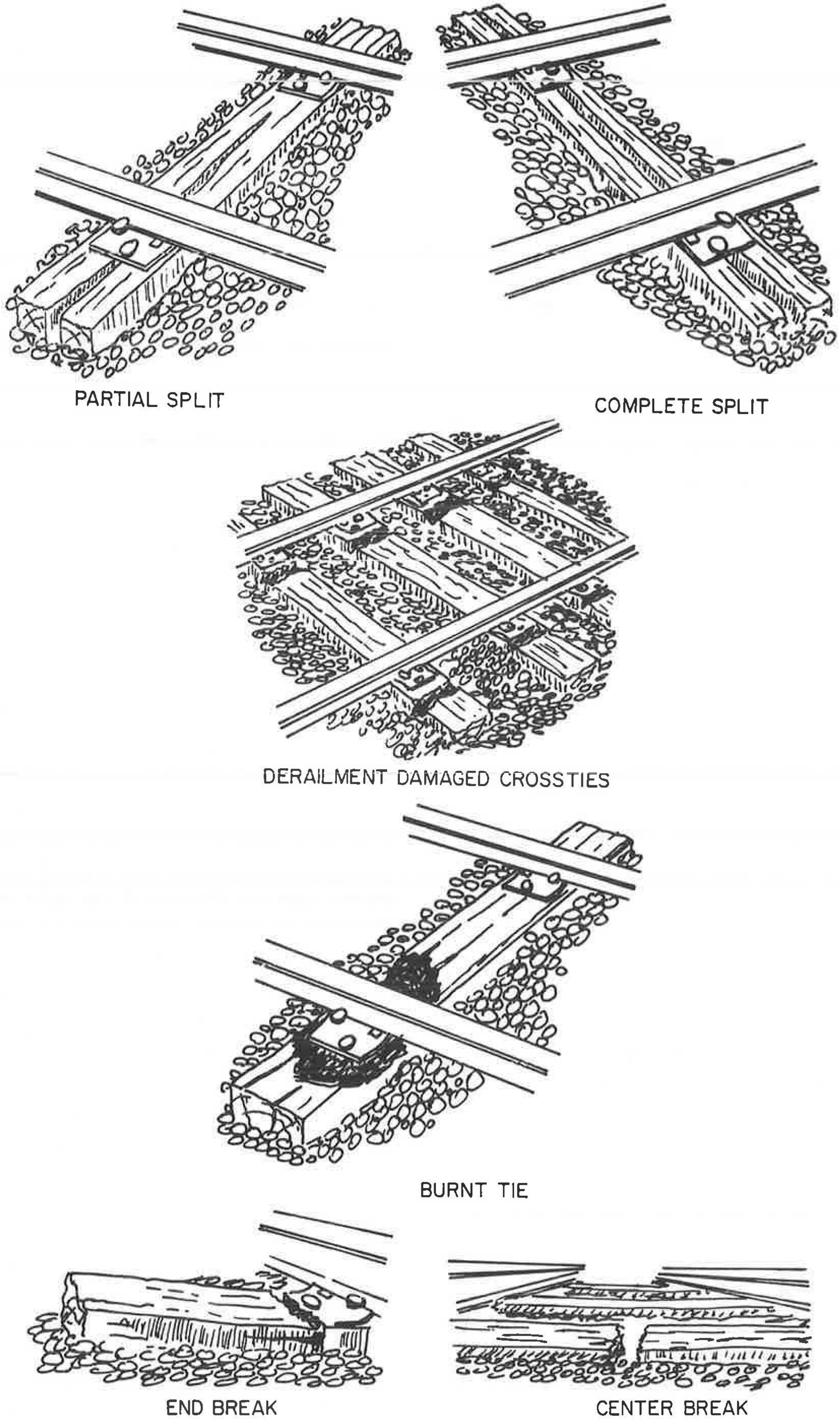

FIGURE 7 Typical bad ties.

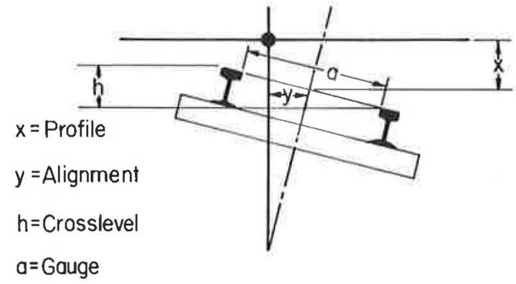

FIGURE 8 Track geometry measurements *(4)*.

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Use of Reinforced Earth® for Retained Embankments in Railroad Applications

VICTOR ELIAS and PHILIP D. EGAN

ABSTRACT

Since its introduction in the United States in 1969, Reinforced Earth® technology has been used in a variety of civil engineering projects, especially in the field of highway construction. In the last 5 years several Reinforced Earth structures have been built to provide direct support for railroad tracks, including retained fills, bridge abutments, and a foundation slab. Although they offer the economies normally associated with Reinforced Earth construction, these structures have also been designed for the vibratory loads and higher live loads associated with railroads. Design methods have been developed, on the basis of both research and experience, to produce structural designs that are responsive to these loading requirements. The behavior and failure mechanism of Reinforced Earth structures are discussed in this paper. The normal design procedure is described, followed by a detailed discussion of the dynamic effects of rail loading. Substantial research and field measurement of these effects have led to modification of the normal design procedure for the case of railroad-supporting structures. Three completed projects the design of which incorporates the results of this research are described. The economic impact of these modified design procedures has been found to be minimal.