ownership. Some transportation planners have advocated, as a solution to the problem of nonequal treatment of transportation modes by government, a system in which railroad rights-of-way would be publicly owned, as are highways, but the private sector would own and operate the trains in a manner analogous to the trucking or barge companies. Considered only as a political question, this proposal has some significant appeal. But, when the subject is considered from the systems perspective and the secondary technological effects are evaluated, some rather serious questions arise. For example, Would a private company choose a GG-1 locomotive in preference to an R-1 to operate over trackage it did not own and need not maintain? The private railroads have made errors with respect to track-and-train system compatibility, but these errors have probably not been as numerous or as serious as they would have been without the incentives that common ownership and responsibility provide.

Combinations of public and private ownership and enterprise have considerable appeal today. Their advocates tell us that they combine the private enterprise incentive with public responsibility—but in this case, I am afraid that the limitation to system thinking imposed by the separation of track responsibility from equipment responsibility is too high a price.

Railroads are excellent examples of industrial systems. They include a variety of mutually dependent organizational and technical subgroups that make up a unified whole. In fact, many railroads historically included the word system in their corporate title. Track, the fundamental subgroup of a railroad system, is a system itself. But, systems thinking can lead us into trouble in such a complex environment as railroading by setting the limits of the system under consideration either too narrow to include all the essentials or so broad as to be incomprehensible, and either can lead to disastrous consequences. The really successful system engineer is the one who knows, guesses, intuitively understands, and sets the appropriate limits to the system analysis required by the specific problem. In this respect, track systems are no different from any other kind—they still require qualitative, personal judgment.

Problems and Needs in Tie and Fastener Research

Thomas B. Hutcheson, Seaboard Coast Line Railroad Company

The advantages of the timber crosstie—relatively low cost; traditional ready availability; toughness, resilience, and strength; allowance for a flexible system of support; relatively long useful life; and availability of a relatively inexpensive fastening system—are compared with its disadvantages—increasing cost; decreasing availability; economic relation to competing demands for timber; suitability for increased train lengths, equipment configurations, and wheel loads; and availability of satisfactory substitutes. Similarly, the advantages of the crosstie fastening system used in North America—relatively low cost, ease of application, satisfactory service for many years, and flexibility of tie loading—are compared with its disadvantages—selective loading of individual ties and mechanical wear in the tie plate and spike holes. Areas for research suggested by the disadvantages are enumerated.

Since the early nineteenth century, after brief experiments with longitudinal support in various forms involving the use of timber, stones, and other materials, American railroads have used the timber crosstie to transmit wheel loads through the rails to the subgrade. At first this was done directly, but then as loads and speeds increased, selected materials were applied as ballast and subballast to assist in maintaining the line and the surface of the track and to facilitate drainage.

During this period, extending for more than 140 years, the solid timber crosstie has served North American railroads well. It represents a considerable improvement over the longitudinal support system used on the earliest roads. The discrete support of the rail and loading of the ballast and subsoil provides a flexible means of load distribution that is highly desirable.

An interesting discussion of the development of stress analysis in rails and ties using this loading system is given by Kerr (1).

As loads have increased, the physical aspects of the crosstie and its use have undergone changes, generally of minor and apparent natures. The length has varied, first with the gauge of the track, and then with the load. Current North American practice uses tie lengths of 2.59 to 2.74 m (8.5 to 9 ft). The size of the tie has been standardized for many years at 17.8 by 22.9 cm (7 by 9 in) for the largest recommended size. Tie spacing, center to center, has varied from about 1.83 m (6 ft) in the earliest practice to the 48.3 to 50.8 cm (19 to 20 in) commonly used in current heavy-duty main tracks.

During this period of time, at least on the North American continent, the timber crosstie has withstood competition from other materials and methods of support. Among its advantages are that

1. It is relatively inexpensive;
2. It was for many years generally in adequate supply, and the raw materials were widely distributed over the continent;
3. It offers excellent physical characteristics of toughness, resilience, and strength in the most favored species;
4. It provides a desirable discretely flexible system of support that allows inexpensive correction of deviations in line and surface;
5. When properly treated with readily available preservatives, it has a relatively long useful life, and
6. The current North American fastening system, involving the cut spike, a steel tie plate, and base anchors is relatively inexpensive and easily applied.

On the other hand, there are new factors that make it desirable to reexamine the function and role of the timber crosstie in terms of changed conditions of service and load, some accumulated over time and some of rather recent vintage. Some of these factors are that

1. The cost of timber crossties has increased at a sharper rate than both forest products generally and other railroad materials and supplies during the 5-year period from 1971 to 1975,
2. Timber of the size and species required for solid timber crossties has a long growing cycle and is increasingly scarce,
3. Competition for suitable crosstie timber fluctuates widely with housing starts and economic factors related to other timber uses, such as pallets and dunnage, whose economies are related to operations rather than to material cost,
4. Current train lengths, equipment configurations, and wheel loads have increased the dynamic forces and actions of trains and produced much higher vertical, lateral, and longitudinal forces, which brings into question not only tie and fastening strength, but also size, length, and shape, and
5. New technologies have produced methods and materials that may provide a satisfactory substitute for a solid timber tie.

The continued availability of an adequate supply of timber for solid timber crossties is an important problem. Increasingly, over the past 10 years, the availability of timber has been questioned, even though tie installations have been at considerably less than the estimated requirements. In the 10-year period from 1966 to 1975, average tie insertions in the United States have been at an annual level of 37/km (60/mile) of maintained track; whereas a conservative estimate of annual requirements is approximately 62/km (100/mile) of maintained track. In addition, during this period, railroads have of necessity purchased less desirable species, including mixed hardwoods that are difficult to satisfactorily dry and treat, and some softwoods that will not satisfactorily withstand current axle loads. Tie insertions on class 1 railroads over the past 10 years have averaged 17 800 000 ties annually, but the requirements, estimated on a basis of an annual replacement of 67 ties/km of maintained track are 28 870 000; i.e., there is a shortfall of 11 070 000 ties on the basis of the 1975 kilometers of track using crossties.

These supply problems suggest the following areas for research:

1. Study of forest growth rates to determine the expected future availability of timber of suitable species and dimensions to produce satisfactory crossties for current service conditions;
2. Study of methods for producing ties of adequate dimensions and shapes by using available timber and lamination, doweling, chipping, fabrication, and other means;
3. Study of refabrication of released ties by chipping and recasting, using resins or other binders;
4. Study of methods for extending the life of ties by improvement in treating methods, materials, coatings, and otherwise inhibiting fungus attack;
5. Study of methods of reducing mechanical wear on conventional ties by improved fastening methods;
6. Study of the cost and demand factors that affect the movement of timber of suitable size and acceptable species to the crosstie market; and
7. Study of the economic factors that create the large swings of demand in the crosstie market, to assess the cost to the tie industry and railroads of an unstable market.

The increase in the cost of ties and the need to purchase undesirable species to secure adequate replacements indicate a need to locate a satisfactory substitute for the timber tie. Also, the current train lengths, axle loads, and dynamic forces transferred to the track structure suggest that increased track moduli may be desirable for current and prospective service, and these facts suggest the need for increased research into the development of a suitable substitute for the timber tie.

Work in this area thus far has produced mixed results under North American conditions. Although the concrete crosstie has gained general acceptance in the United Kingdom and is widely used throughout Europe, its use in North America has generally been restricted to test installations. There are a number of reasons why this is so. Some of these are that

1. The 10-year replacement rate of 37 ties/km of maintained track (an average of about 17 800 000 ties/year), which is determined by economic rather than need considerations, has been met by available timber-tie production in recent years;
2. Timber demand in the construction and furniture industries and other normally higher priced markets has been lower in recent years;
3. Track maintenance practices in Europe call for complete track replacement, but cyclic tie replacement is the current practice in North America;
4. Accounting practices dictated by the Interstate Commerce Commission favor cyclic maintenance as opposed to complete replacement maintenance;
5. The lighter European axle loads and shorter train consists do not load the track as severely as is done in North America;
6. European methods of tie and rail fastenings have traditionally used more expensive and responsive fastenings than have American methods; and
7. Early American tests of concrete ties experienced severe fastening and load problems due, in large part, to attempts to compete with the wooden tie by using inadequate fastening systems and wider spacing, which resulted in failure in the fastening, the tie itself, and the ballast and subgrade section.

Thus, the concrete tie has had only limited use in North America, and at the same time, for largely economic reasons, timber-tie replacements have lagged significantly behind the actual requirement. Also, for reasons dictated by current economic conditions, there has been only limited research and service testing of concrete ties, and research and testing of reconstituted ties and laminated or other composite ties are in their early stages.

Other matters requiring evaluation and research under North American conditions are

1. The size and length of ties required to meet current conditions of vertical and lateral loads;
2. The economic and load relation between tie spacing and ballast-section depth and width;
3. The effect of tie shape on the lateral stability of track;
4. The determination of an optimum replacement philosophy and maintenance practice, including the impact of current accounting procedures on life-cycle cost factors;
5. The development of life-cycle cost-accounting procedures, including disposal costs;
6. Methods of extending the life of timber ties by reducing mechanical wear and improving resistance to fungus attack; and
7. Acceptable substitutes for conventional timber ties.

Work is under way in many of these areas, but continued effort will be required to bring about acceptable changes and improvements.

The crosstie fastening system used in North America has remained basically unchanged over many years. The conventional cut spike, steel tie plate, and base-applied rail-anchor system is relatively inexpensive, easy to apply in the field and, until recent years when dynamic loads, speeds, and axle loads increased significantly, has given satisfactory service. To keep pace with change, tie plates have become longer, heavier, and wider. The spiking practice has been changed by increasing the size of the spikes and the number used, and recently, plate hold-down spikes having a more positive locking feature have been introduced. The number of base rail anchors applied has increased with train lengths, and the generally accepted current practice is for every other tie to be box anchored. Disadvantages of this system are that (a) the base-anchoring system loads individual ties selectively (as opposed to uniform longitudinal loading of all ties) and (b) the spike-held tie plates allow serious mechanical wear in the tie plate seat and spike holes. Its major advantage is that it provides a more flexible system of individual tie loading, which limits pumping action.

The European system of track fastening is much more positive than is the North American system. Heavier plates are used, and these are more or less rigidly anchored to the tie with bolts or lag screws. The rail is anchored through the plate system with a heavy clamping or spring force, which controls longitudinal movement of the rail and inhibits rail overturn. Rail cant is provided through the tie plate in both fastening systems.

Early limited use of the European system under the North American loads of the time resulted in loss of surface and line, principally because of pumping. Thus, the more flexible fastening system has continued to be used. However, recent problems related to mechanical wear in ties, rail cant, rail overturning, loss of gauge, track movement or buckling, and other problems of lateral, vertical, and longitudinal stability suggest that the system of tie plate, base rail anchor, and cut spike is operating at the upper limits of its ability to withstand current train load forces.

This suggests the following areas for research:

1. The effect of alternative fastening systems on the lateral, vertical, and longitudinal stability of the track system;
2. The engineering and economic aspects of rigid versus flexible fastening systems, including the effect on the ballast section under North American loading conditions;
3. The determination of the optimum rail cant to reduce both rail damage and timber-tie mechanical wear; and
4. The determination of the level of restraint required or desirable to prevent rail overturn and the means to provide such restraint.

While the timber tie and its unique fastening system developed for North American use has served well, changed conditions now indicate that a critical review, involving economic and engineering research, is desirable to determine a direction for the future. This review should include investigation of the economic philosophy of track maintenance to determine whether the North American practice of individual component renewal and adjustment results in a lower life-cycle cost than does the European system of complete rebuilding of the entire track system near the end of its economical service life. It should also include a critical examination of the fastening system to determine whether current and future force levels can be satisfactorily met with the flexible spike, tie plate, and base anchor fastening system or whether the life-cycle costs will be lower if a more positive restraint system, such as is commonly found in British and European practice, is used.

REFERENCE

1. A. D. Kerr. On the Stress Analysis of Rails and Ties. Proc., AREA, Bull. 659, Vol. 78, Oct. 1976.

Track-Structure Analysis: Methodology and Verification

Amir N. Hanna, Transportation Development Section, Portland Cement Association

Track behavior under traffic and environmental conditions can be predicted by using appropriate methods of analysis. Well-developed concepts and procedures in the structural engineering field are used to illustrate methods of track analysis. These procedures are based on assumptions that often require verification by laboratory or field tests. In this paper, some of the approaches to the analysis of track structure and the methods for laboratory and field tests are discussed.

The purpose of a track structure is to support and guide railway vehicles. In performing this function, the track is subjected to repeated loads, which it must withstand to provide a safe and acceptable ride to the passengers and a nondamaging environment for the movement of goods.

To evaluate the performance and safety of a track and to plan for its maintenance, it is necessary to understand its behavior under traffic and environmental conditions. This can be accomplished by using a systematic procedure such as that illustrated in Figure 1, which consists primarily of a method of analysis that uses two sets of input data. These data are

1. Factors external to the track that contribute to its performance and behavior, i.e., (a) rolling stock characteristics, such as axle loads, arrangement of axles, and diameter of wheels; (b) operating conditions, such as volume and type of traffic and operating speed; (c) environmental conditions, such as frost action and tem-