Track Evaluation and Ballast Performance Specifications

M. J. KLASSEN, A. W. CLIFTON, AND B. R. WATTERS

A variety of laboratory tests has traditionally been used in the selection of a material and gradation for ballast. The results of the laboratory tests are commonly used to reject or accept material for use as ballast and rarely imply benefits or costs of selecting alternative materials or gradations. In this paper are presented the results of a track sampling and evaluation program to determine the performance of ballast, subballast, and the subgrade on Canadian Pacific (CP) Rail. A simple method was developed to determine if a significant portion of maintenance of the track structure is attributable to the subballast and subgrade. The concept of ballast life is presented with a relationship between ballast quality and grading. CP Rail specifications for the selection of a ballast material and the processing of ballast are also presented.

The economics of selecting a track ballast is a function of production, transportation, and placement costs and maintenance costs during the period the ballast is in the track. A state-of-the-art review by the Association of American Railroads (AAR) Technical Center (*1*) in 1979 indicated that there were economic incentives for selecting superior quality ballast materials, although there was a variety of opinions on the appropriate standards and tests for ballast.

Field observations at the Facility for Accelerated Service Testing (FAST) (*2*) indicated that track maintenance is required as a result of a combination of deflections of the ballast, subballast, and subgrade. Fouling of ballast is considered a combination of ballast degradation and contamination from outside sources, both above and below the ballast.

A track ballast sampling and evaluation program was undertaken on Canadian Pacific (CP) Rail during 1979 and 1980 to evaluate the performance of ballast, subballast, and subgrade at selected locations. A CP Rail specification for ballast (see Appendix, pp. 59-63 in this Record), which considers the economic factors of ballast production, ballast life, and ballast and subgrade maintenance, was developed.

Research by Raymond et al. (*3*) developed a track-class ballast ranking and recommended a radical change in ballast grading to an extremely broadly graded ballast for heavy tonnage main lines. A secondary consideration of the ballast evaluation program was to determine if the Raymond track-class ballast rankings and ballast gradation should be adopted for the CP Rail main line.

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MAINTENANCE AND BALLAST REPLACEMENT

Ballast on CP Rail historically was selected on the basis of geologic engineering properties of the rock and its past performance as ballast. Primary consideration was given to materials in proximity or within reasonable train haul of the required location.

Surfacing is planned according to historical maintenance schedules and deterioration of track surface. As the condition of the ballast deteriorates, the track surface becomes difficult to maintain and maintenance costs increase. Reballasting is scheduled to be completed when the old ballast has deteriorated.

A literature review of ballast performance in 1985 (*4*) found general disagreement about properties that are important to ballast life. The consensus of the Ballast and Subgrade Working Group of the AAR (*5*) is that decisions on ballast and subgrade maintenance are subjective in nature and usually made by local personnel.

A proposed model for subgrade performance (*6*) is shown in Figure 1. Permanent settlement decreases with tonnage for a good subgrade but increases with tonnage for a poor subgrade. Track maintenance for a poor subgrade, and possibly the threshold condition, will be controlled by the permanent settlement of the subgrade. Track maintenance on a good subgrade will be controlled by the ballast.

A conceptual ballast performance model on good subgrade (*6*) is shown in Figure 2. The model has been modified to illustrate ballast life and portrays repetitive surfacing cycles with an increasing maintenance frequency as the ballast condition deteriorates. When track roughness increases to an unacceptable level, ballast replacement is required. A similar model for maintenance costs is shown in Figure 3. Curves for a particular ballast indicate the individual performance of the properties of the ballast, which affect the life of the ballast and maintenance frequency.

TRACK EVALUATION PROGRAM

The purpose of the CP Rail track evaluation program was to

1. Develop an understanding of the performance of ballast, subballast, and subgrade by evaluating existing track structures;
2. Determine the significance of ballast—the importance of ballast material quality, grading, and stability—and the predominant properties of ballast;

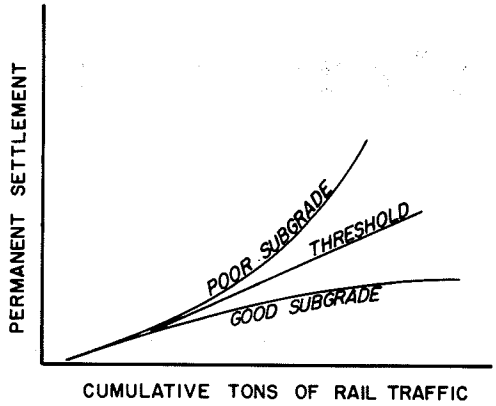

FIGURE 1 Subgrade performance model.

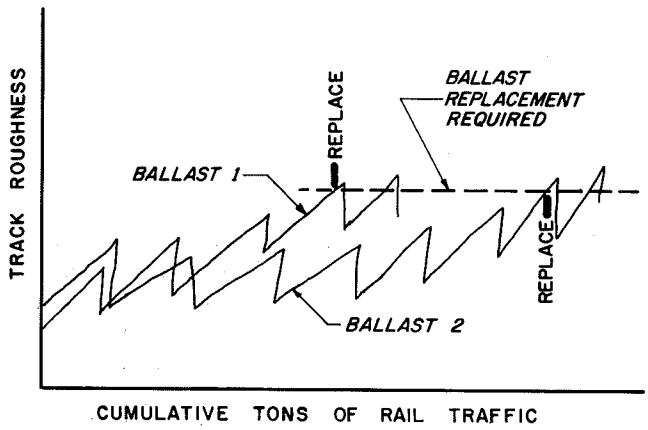

FIGURE 2 Ballast performance model, track quality.

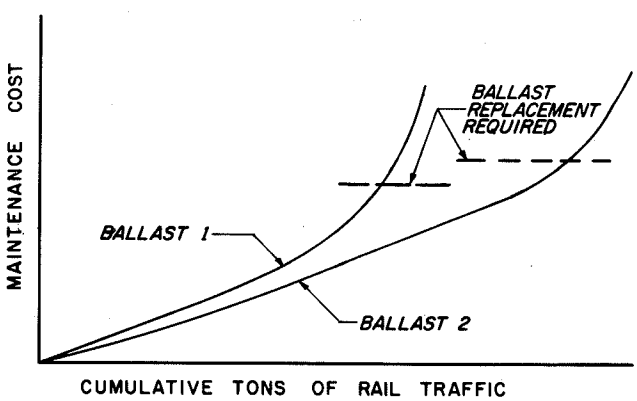

FIGURE 3 Ballast performance model, maintenance cost.

3. Develop an understanding of subballast and subgrade conditions and performance; and
4. Develop a CP Rail specification for ballast, evaluation of ballast sources, and processing of ballast.

Track sections were evaluated by hand excavating the ballast between two ties to the subgrade. The rails were raised to allow a tie adjacent to the excavation to be removed. Samples were carefully collected and identified on a ballast sample location diagram similar to that shown in Figure 4. Technical information for each location was cataloged on an inspection form (Figure 5). The samples were subjected to laboratory testing (see paper by Clifton et al. in this Record)

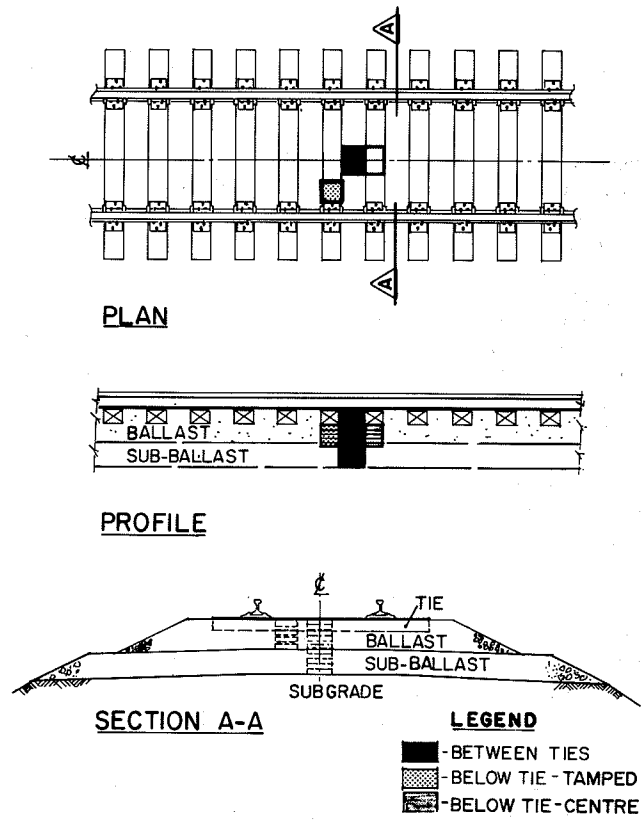

FIGURE 4 Ballast sample location.

GENERAL INFORMATION
SUBDIVISION _____ MILEAGE _____ DATE _____
BALLAST SOURCE _____ YEAR BALLASTED _____
BALLAST GRADATION _____ BALLASTING METHOD _____

DESCRIPTION OF BALLAST
MATERIAL _____
FOULING _____
SEGREGATION _____
CEMENTING _____
MOISTURE _____

DESCRIPTION OF SUB-BALLAST
MATERIAL _____
CEMENTING _____
MOISTURE _____

DESCRIPTION OF SUBGRADE
MATERIAL _____
STRENGTH _____
MOISTURE _____

TRACK PERFORMANCE
_____
_____

FIGURE 5 Inspection form.

and petrographic examination (see paper by Watters et al. in this Record) to develop an understanding of performance of ballast in track.

An excavation in broadly graded Kimberley Float ballast at Mile 65.0, Mountain Subdivision, is shown in Figure 6. The ballast had been in service for 5 years with 52 million gross tons (MGT) of rail traffic annually. The tamped ballast on the left side of the photograph was dense with significant fines filling the voids. Below the center of the tie, in the center of the photograph, the ballast was looser with less fines in the voids. Subsequent excavation showed neither mixing of the pit run subballast and the ballast nor permanent deflection of the ballast-subballast contact.

An excavation in broadly graded Walhachin ballast at Mile 37.2, Shuswap Subdivision, is shown in Figure 7. The ballast had been in service for 8 years with 52 MGT of rail traffic annually. The photograph shows dense ballast in the tamped area below the tie with sufficient fines in the voids to hold water below the tie. The voids in the visible ballast between the ties appeared to be filled with fines when compared with the clean ballast below the center of the tie. Subsequent excavation showed neither mixing of the pit run subballast and the ballast nor permanent deflection of the ballast-subballast contact.

An excavation in uniformly graded Kimberley Float ballast at Mile 52.2, Mountain Subdivision, is shown in Figure 8. The ballast had been in service for 17 years with 52 MGT rail traffic annually. The location was adjacent to a siding switch at a sawmill, and the fines in the ballast showed signs of contamination from woodchips. Subsequent excavation showed neither mixing of the pit run subballast and the ballast nor permanent deflection of the ballast-subballast contact.

An excavation in uniformly graded Uhtoff ballast at Mile 13.2, Mactier Subdivision, is shown in Figure 9. The ballast had been in service for 29 years with 16 MGT of rail traffic annually. The fines below the tie had filled the voids and were holding water. The visible ballast between the ties also appeared to have the voids filled with fines. The visible contact between the ballast and the pit run subballast showed neither signs of mixing of the ballast and pit run subballast nor signs of permanent deflections of the ballast-subballast contact.

Old, strong, fouled ballast was examined at Mile 110.4, Ignace Subdivision, as shown in Figure 10. The clear color differentiation between the old subballasts and the darker fouled ballast indicated neither mixing nor permanent deflections of the ballast-subballast contact.

FIGURE 6 Mile 65.0, Mountain Subdivision.

FIGURE 8 Mile 52.2, Mountain Subdivision.

FIGURE 7 Mile 37.2, Shuswap Subdivision.

FIGURE 9 Mile 13.2, Mactier Subdivision.

A clear contact between the newer ballast and the older darker fouled ballast was observed at Mile 13.8, Kaministiquia Subdivision, as shown in Figure 11. No mixing of the materials was apparent, although the convex shape of the visible contact below the tie indicated that subgrade deflections were occurring. Subsequent excavation identified a layer of peat moss 2 ft below the base of the tie.

Good performance of crushed gravel ballast is shown in Figure 12. The track ties were stable. The out-of-phase maintenance cycle is 2 to 3 years with annual rail traffic of 10 MGT.

Poor performance of ballast is shown in Figure 13. The track ties were moving in the ballast. Out-of-phase maintenance is required annually with 3 MGT annual rail traffic.

FIGURE 10 Mile 110.4, Ignace Subdivision.

FIGURE 11 Mile 13.8, Kaministiquia Subdivision.

DEVELOPMENT OF A GRADATION SPECIFICATION

Field Studies

The ballast field study consisted of the evaluation of 54 track locations; 259 samples of ballast and subballast were collected. The ballast at Mile 65, Mountain Subdivision, and Mile 37.2, Shuswap Subdivision, has been categorized as broadly graded ballast. The initial gradation at these sites was between the 2-in. and the No. 4 sieve. The ballast at Mile 52.2, Mountain Subdivision, and Mile 13.2, Mactier Subdivision, has been categorized as uniformly graded ballast with the initial gradation between the 2-in. and the 3/4-in. sieve. The ballast from Walhachin and Uhtoff quarries was produced to a tight specification. Ballast from Kimberley met a less stringent specification; processing consisted of removing the oversized and undersized material.

The broadly graded ballast sample gradations are shown in Figures 14-17, and the uniformly graded ballast sample gradations are shown in Figures 18-21.

The fines content (percentage passing the No. 4 sieve) increased with depth between the ties for both the broadly

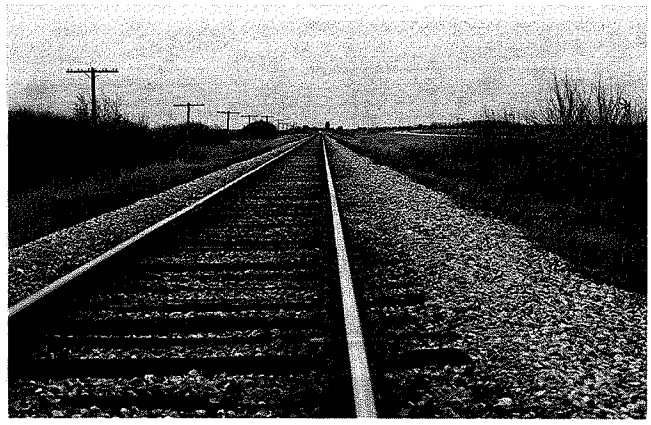

FIGURE 12 Good performance of ballast.

FIGURE 13 Poor performance of ballast.

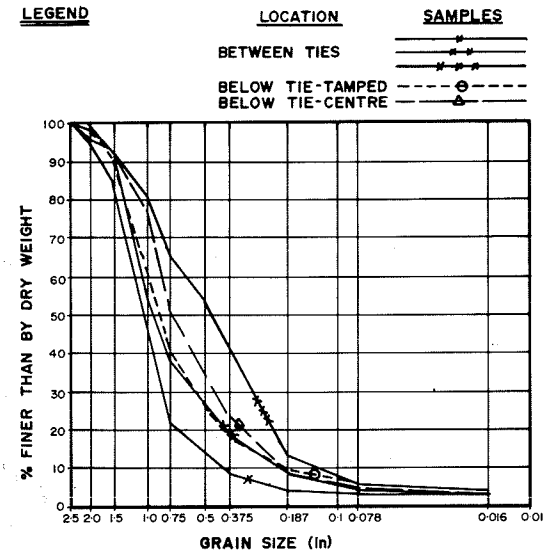

FIGURE 14 Sample gradations: Mile 65.0, Mountain Subdivision.

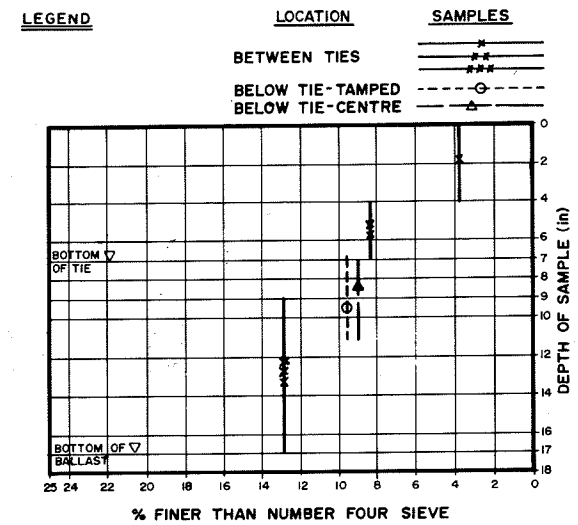

FIGURE 15 Percentage of fines in samples from Mile 65.0, Mountain Subdivision.

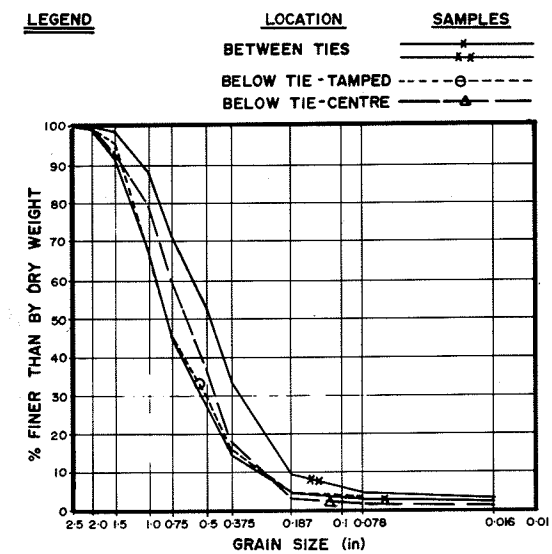

FIGURE 16 Sample gradations: Mile 37.2, Shuswap Subdivision.

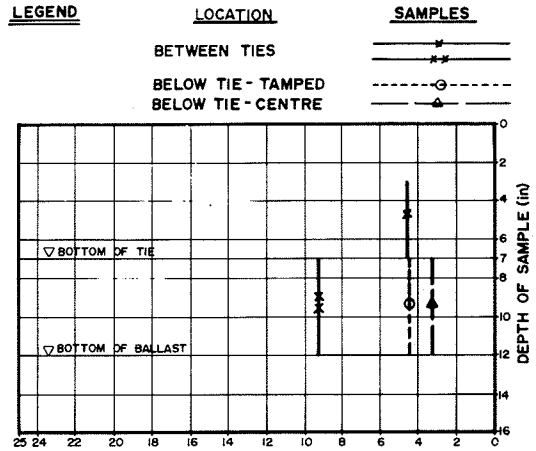

FIGURE 17 Percentage of fines in samples from Mile 37.2, Shuswap Subdivision.

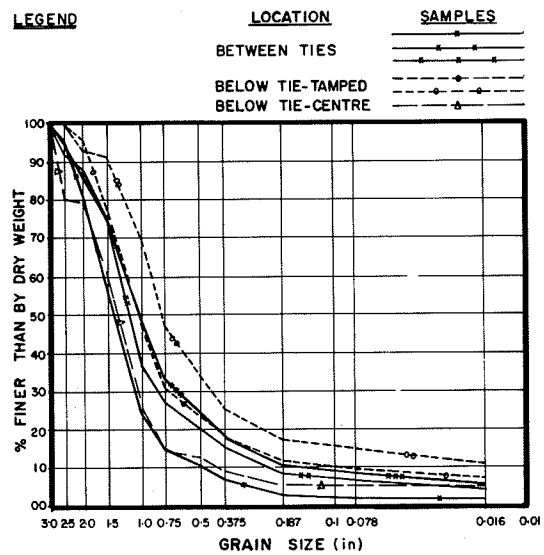

FIGURE 18 Sample gradations: Mile 52.2, Mountain Subdivision.

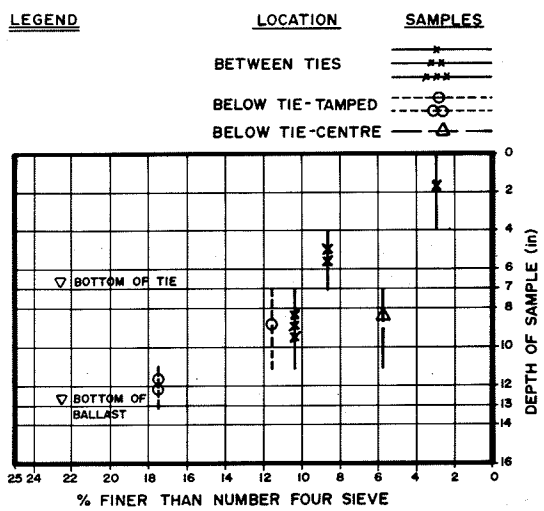

FIGURE 19 Percentage of fines in samples from Mile 52.2, Mountain Subdivision.

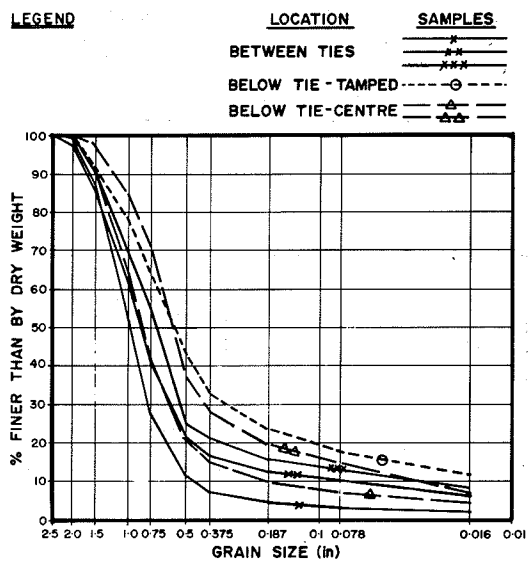

FIGURE 20 Sample gradations: Mile 13.2, Mactier Subdivision.

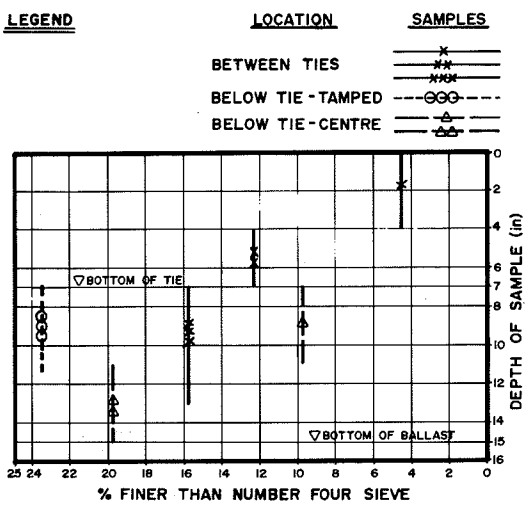

FIGURE 21 Percentage of fines in samples from Mile 13.2, Mactier Subdivision.

graded and the uniformly graded ballasts. The fines content below the center of the tie and in the tamped area varied widely, consistent with the scatter inherent in sampling a coarse granular material. In general, a higher fines content represented a higher degree of fouling.

The primary difference between the broadly graded ballast and the uniformly graded ballast is the percentage of fines that can be in the voids without impeding drainage. From 10 to 15 percent fines were required to impede drainage in the broadly graded ballast whereas 20 to 25 percent fines impede the drainage of a uniformly graded ballast.

The remainder of the sites evaluated during the ballast evaluation program were correlated with the performance of the uniformly and broadly graded ballast.

Laboratory Studies

A laboratory investigation was undertaken (see paper by Clifton et al. in this Record) to develop an understanding of the interrelationship among void ratios, gradation, and index characteristics of various ballast materials. Various uniform and broadly graded specifications were used in the study. The theoretical comparison of voids in each gradation was developed using the theoretical zero voids relationship.

Two quarried rock materials and two crushed gravels were compacted in molds, grouted with epoxy resin, and cut into thick sections. These thick sections allowed a visual evaluation of the interlocking of particles and void characteristics. Figures 22-26 show the thick sections of Kimberley Float ballast.

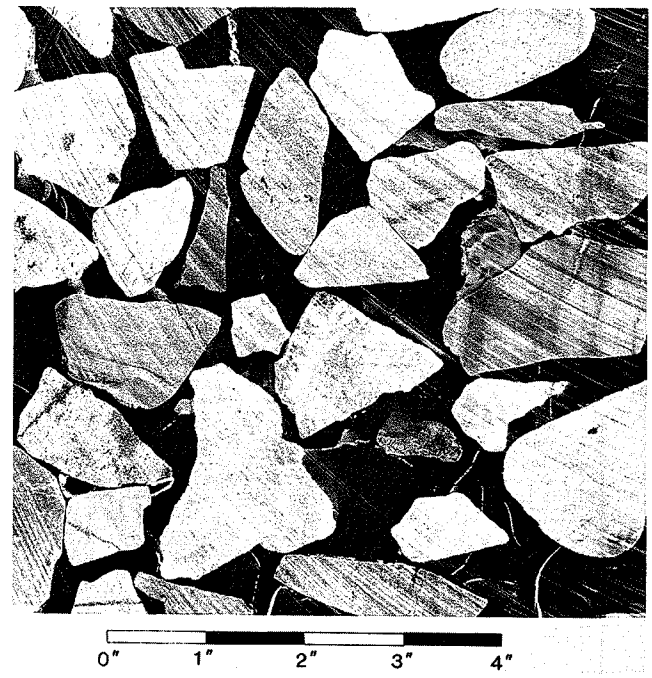

FIGURE 22 Ballast gradation, AREA 3.

FIGURE 23 Ballast gradation, AREA 24.

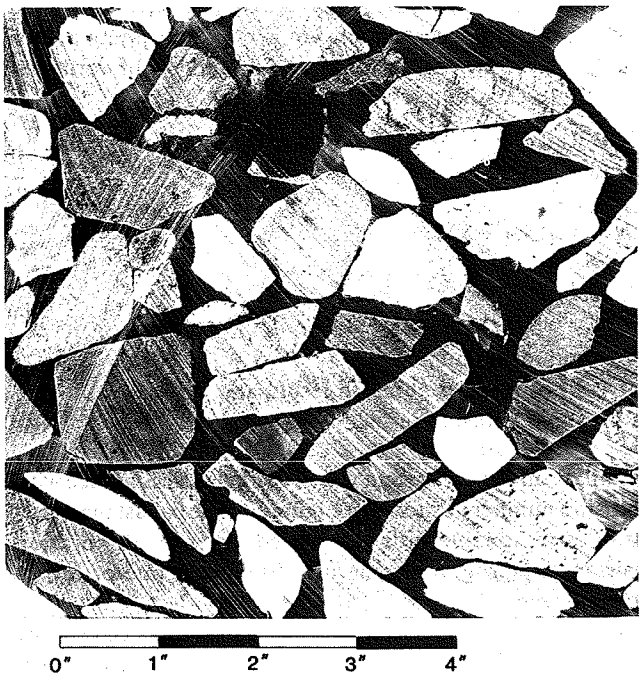

FIGURE 24 Ballast gradation, AREA 4.

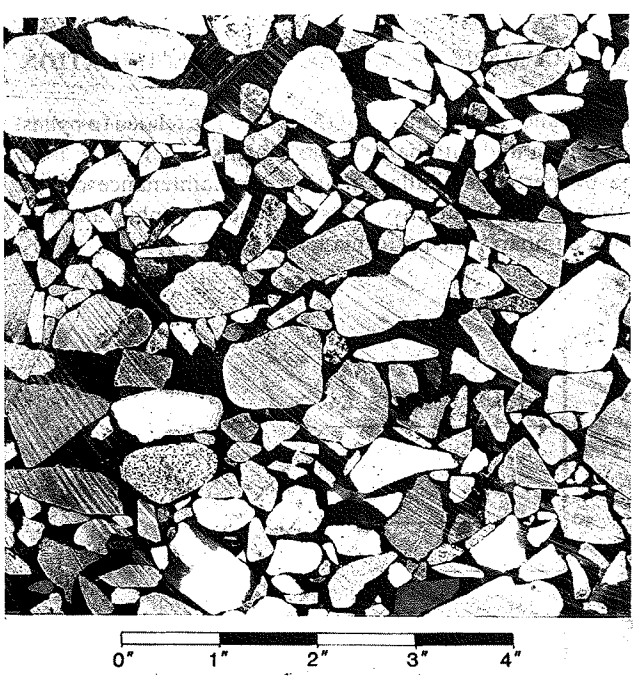

FIGURE 25 Ballast gradation, CP 2.

The study indicated that

1. Uniformly graded ballast has larger average void sizes that allow movement of fines;
2. Broadly graded ballast has a lower volume of voids and lower average void size; voids are not continuous and would obstruct movement of fines; and
3. Broadly graded ballast segregates and does not have uniform void size and spacing.

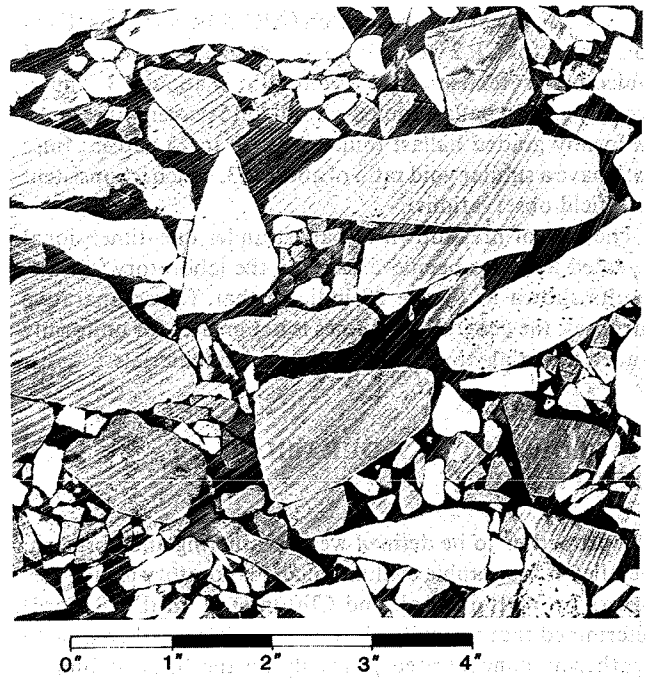

FIGURE 26 Ballast gradation, Raymond 1.

Measured void ratios are plotted against the area between the ballast gradation and the zero voids curve in Figure 27. The void ratio curve for each ballast is a function of material type and gradation.

The difference between materials is illustrated by the density attainable in a mold with the same compactive effort. The laboratory tests indicate a difference in interlocking characteristics of the material. This can be related to maintenance and stability of ballast.

Actual density in the field, where track tampers and possibly ballast compactors are used and train loading is experienced, is not the same as that obtainable in the laboratory. The average slope in Figure 27 illustrates the relationship between void ratios and gradation for a given compactive effort.

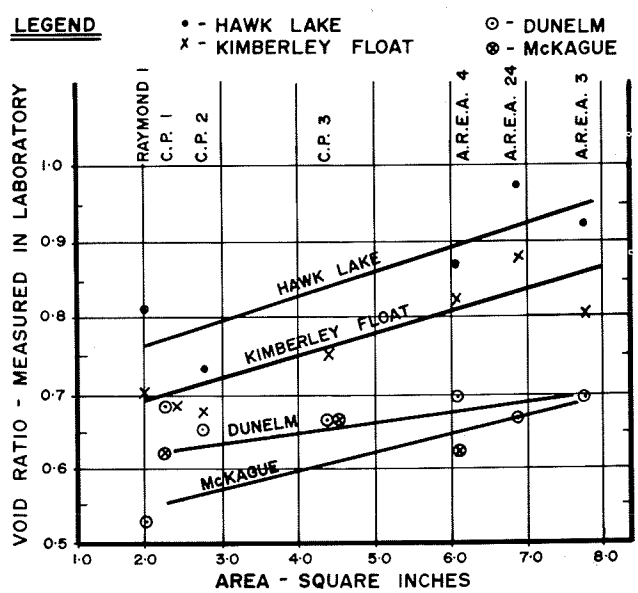

FIGURE 27 Laboratory void ratio.

Field void ratios of 0.5 are common (*7*) for American Railway Engineering Association (AREA) gradations. Field void ratios for CP 2 would be expected to be around 0.4, and fouled ballast tends to have a void ratio of about 0.3. Thus a broadly graded ballast fouled with 10 to 15 percent fines and a uniformly graded ballast fouled with 20 to 25 percent fines both have a similar void ratio of about 0.3, which is consistent with field observations.

The rate of breakdown of ballast under one-dimensional repeated load has been evaluated in the laboratory (*8*). The results shown in Figure 28 indicate that, for comparative purposes, the generation of fines is not greater for uniformly graded materials than for broadly graded materials.

DEVELOPMENT OF A DURABILITY SPECIFICATION

The properties to be defined were weathering and abrasion. Detailed petrographic evaluation and laboratory testing (see papers by Watters et al. and Clifton et al. in this Record) determined that virtually all rock materials weathered, with weathering concentrated primarily on the fines. A limited number of rock types are extremely sensitive to weathering and are not considered suitable for ballast.

The volume of fines generated by abrasion of ballast is a function of the total tonnage of rail traffic. Each of the ballast sections evaluated was extrapolated to a total tonnage in MGT of rail traffic for either a uniform or a broadly graded ballast with 7 in. of ballast below the tie. The extrapolation was based on comparison of the volume of fines present in the ballast with the total storage volume available.

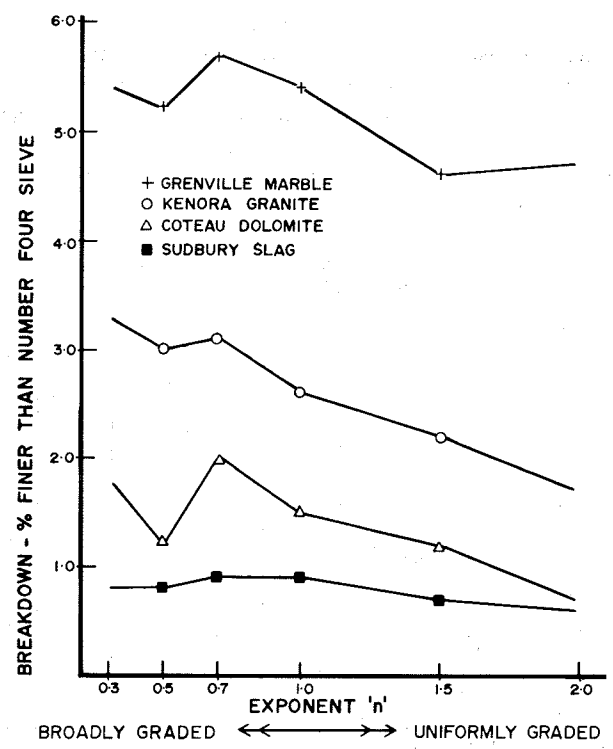

FIGURE 28 Breakdown variation with gradation (Raymond).

A complex relationship proposed by Raymond et al. (*3*) is shown in Figure 29 to correlate track classification with ballast rankings. The relationship is not appropriate and is not usable in practice because of the number of variables required to classify track ballast.

CP Rail developed the concept of the abrasion number as follows:

$$AN = LAA + 5MA$$

where

AN = abrasion number,
LAA = Los Angeles abrasion result, and
MA = mill abrasion result.

Ballast on the CP system was classified in accordance with abrasion number as shown in Figure 30. The ballast materials attain a reasonable order that is consistent with abrasion resistance, petrographic characteristics, and rate of breakdown in track.

The abrasion number was plotted against total tonnage for the estimated life of the ballast sections evaluated. The best-fit relationship, plotted to a natural log scale, is shown in Figure 31 for the two ballast gradations considered.

DEVELOPMENT OF A FRACTURE SPECIFICATION

Maintenance requirements of the ballast are related to ballast breakdown and interparticle movements under cyclic load. The properties of ballast that affect maintenance can be evaluated by laboratory tests and petrographic analysis, which compares the performance of ballast.

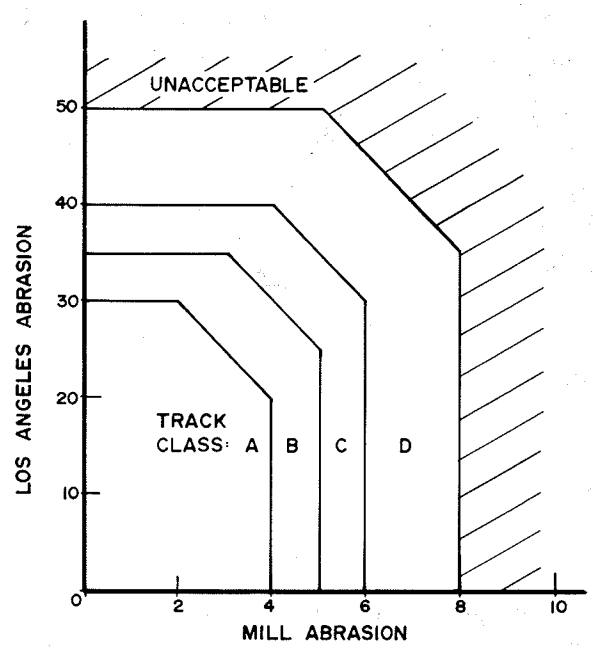

FIGURE 29 Track ballast rankings.

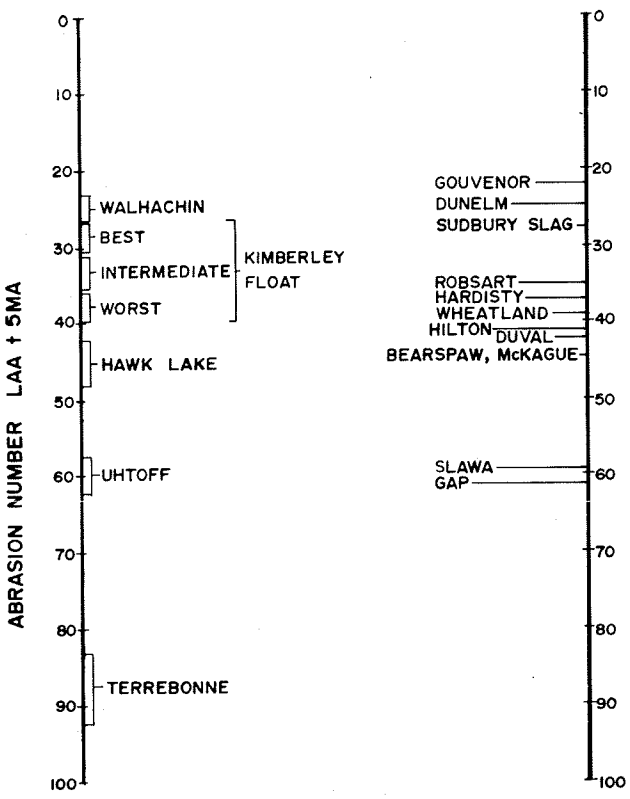

FIGURE 30 Abrasion number for various CP Rail ballast sources.

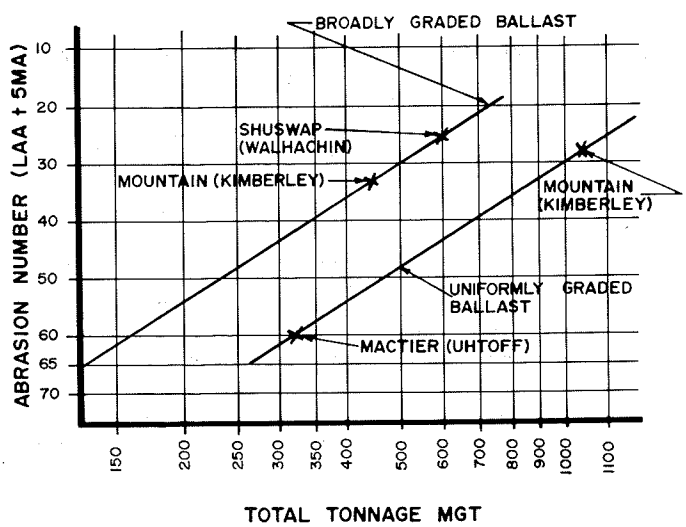

FIGURE 31 Ballast life.

Ballast breakdown and related change in gradation occur over the life of the ballast. Ballasts designed for 20 to 30 years have a similar maintenance cycle because of ballast breakdown. The interlocking characteristics of the ballast material are therefore a primary consideration when comparing maintenance of ballast material. One parameter used to evaluate the ballast surface characteristics is the fractured face test (see paper by Clifton et al. in this Record).

CP ballast tracks were classified as either acceptable or not, in accordance with historic maintenance requirements. These ballasts were subjected to laboratory testing procedures to determine the number of fractured faces (see paper by Clifton et al. in this Record). Figures 32-34 show that ballast performance could not be differentiated unless three or more fractured faces were considered.

CP RAIL SPECIFICATIONS

The three criteria developed to evaluate ballast materials are weathering, abrasion, and stability. These factors are assessed by petrographic examination and laboratory tests, as documented in the CP Rail Specification for Ballast (Appendix, pp. 59-63 in this Record).

The stability of ballast is ascertained by comparison with existing ballasts. Ballast materials that may weather significantly are rejected.

Laboratory tests provide empirical numbers that have been related to ballast performance in track. Petrography provides additional information and a rational basis for interpreting laboratory test results. It allows for a more complete assessment and understanding of the performance of ballast.

BALLAST MANAGEMENT INFORMATION SYSTEMS

The information presented herein was used to prepare CP Rail Specifications for Ballast (Appendix, pp. 59-63 in this Record). Procedures are now in place to document subgrade, subballast, and ballast conditions; estimate the life of the ballast in the track; and correlate track conditions with maintenance costs and track recording car results.

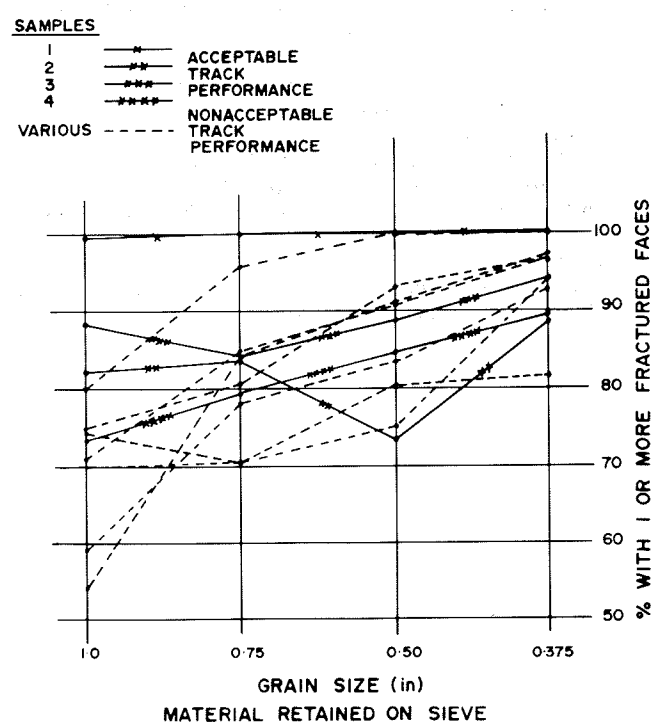

FIGURE 32 One or more fractured faces.

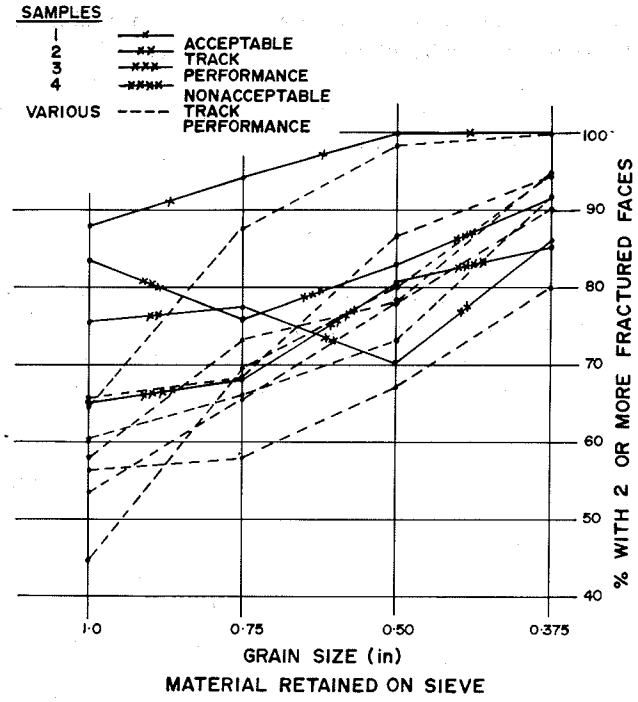

FIGURE 33 Two or more fractured faces.

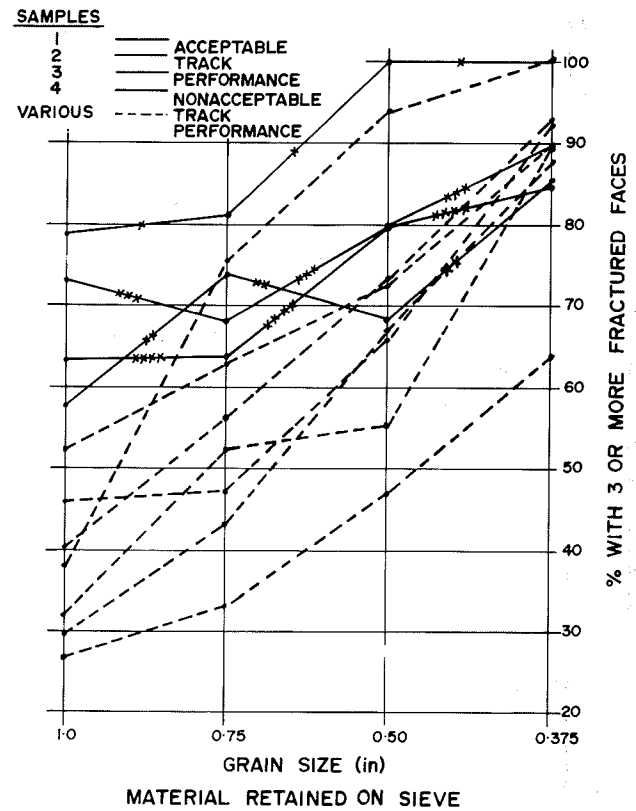

FIGURE 34 Three or more fractured faces.

The economics of alternative ballast sources and gradations can be considered, which will allow system planning of work programs for as long as a 20- to 30-year period.

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