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Sampling, Reconstituting, and Gradation Testing of Railroad Ballast

Citation

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ABSTRACT

Ballast characterization is important for predicting ballast performance and serviceability in track. This paper investigates ballast sampling methods and sizes, reconstitution, splitting, and gradation testing for appropriate characterization of in-track ballast. This paper will review various ASTM test methods and determine how these procedures should be applied to railroad ballast sampling and testing. For example, ASTM D75/75M, *Standard Practice for Sampling Aggregates*, and ASTM C136/136M, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*, require sampling ballast with a maximum particle diameter of 75 mm (3 in.) and about 16 to 17 three-quarters full 5-gal buckets to meet the requirements. These methods are important because of the difficulty of obtaining representative in-field ballast samples. Undisturbed ballast samples are not feasible because of the nature of unbonded granular particles, so sampling emphasis must be placed on best methods to collect and reconstitute field ballast conditions in the laboratory. Another aspect that will be discussed is how to deal with local variations in ballast fouling and degradation that can result in significant differences in ballast characteristics. For example, the ballast underneath the tie (i.e., the ballast of interest) will likely be more degraded and fouled than shoulder

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or crib ballast, but this is also the most difficult location to obtain without track disturbance.

Keywords

ballast, rockfill, ballast sampling, sieve analysis

Introduction

Railroad ballast is a uniformly graded aggregate that provides support to track superstructure (i.e., crossties and rails). As a result, it is the uppermost support and damping system for the static and dynamic loads applied to the track by passing traffic. Understanding the gradation, compressibility, shear strength, and stiffness of ballast is important for assessing track support and load distribution among adjacent ties during train loading because the ballast layer plays a significant role in track displacement and settlement [1].

To address these issues, the main objective of this study is to provide recommendations for the appropriate ballast sampling techniques, sample and specimen masses, and sample splitting techniques. Most of these ballast testing topics are discussed in relevant ASTM test methods and are presented here. However, two of these topics are not specifically addressed in applicable ASTM test methods. These are obtaining a field sample of ballast that is representative of field track conditions and how to reconstitute the field sample in the laboratory to obtain a representative test specimen for gradation and shear testing. For example, no prior study was found in which the field sampling procedure collected a sufficient mass or weight of ballast to be in accordance with current ASTM test methods. This is important because the National Stone, Sand, and Gravel Association [2] states, "…A sample which is too small is of no value and represents wasted effort." If laboratories use identical sampling, remixing, splitting, and testing procedures, the test results should be more comparable and eliminate biases due to sampling, remixing, splitting, and testing procedures in the ballast properties.

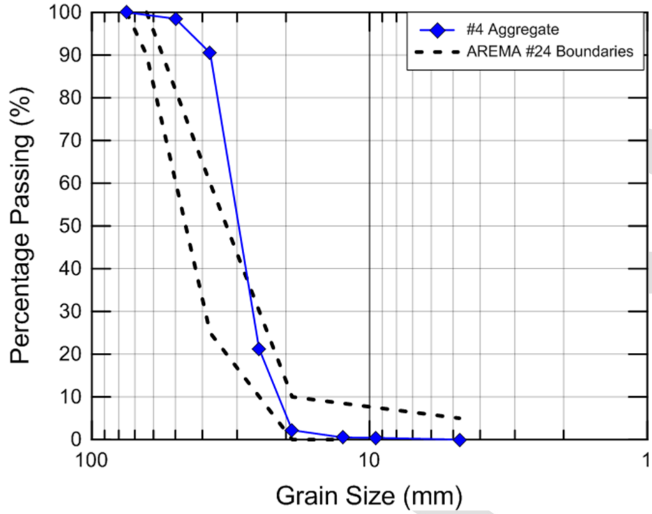
This paper covers the following main topics: ballast gradations tested herein and typical gradations and appropriate sampling, remixing, sample splitting, and gradation testing procedures.

Ballast Tested

This section describes the ballast material used herein to establish the minimum sample and specimen masses required for ASTM test methods for gradation and shear strength testing. Clean granite ballast tested herein was obtained from the Vulcan Materials Co. quarry near Atlanta, GA. The product name for the material tested is "#4 Aggregate Material" and is termed "railroad ballast" by the producer. This material is referred to as "#4 Aggregate" herein.

Fig. 1 shows the grain size distribution of the #4 Aggregate, which has a specific gravity of 2.63 when tested in accordance with ASTM C127, *Standard Test Method*

FIG. 1 Grain size distribution of clean granite ballast tested herein (#4 Aggregate) and AREMA No. 24.



for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate [3]. The granite aggregate size distribution is a little finer than American Railway Engineering and Maintenance-of-Way Association (AREMA) No. 24 ballast gradation but is considered to be representative of main line ballast.

Gradation Tests

This section discusses appropriate sample locations, masses, and test procedures for laboratory ballast gradation (i.e., particle size) analyses that should be used to assess the gradation of clean and fouled ballast. This is important because ballast gradation has been shown to affect testing results [4], so ensuring the sample size is representative and large enough to simulate field ballast (quarry, stockpile, or track section) is important for obtaining meaningful results. For example, obtaining one or two buckets of ballast, as illustrated in **Fig. 2**, is usually not an adequate sample mass to properly represent the ballast and therefore is inadequate for measuring the gradation of the quarry or stockpiled material. Additionally, improper transport and remixing of the ballast buckets can lead to unrepresentative material gradations, especially in fouled ballast because vibration during transport will cause the fine particles to segregate from the larger ballast particles.

Three ASTM procedures are discussed here to provide recommendations for (1) sample mass required to properly measure the field ballast gradation: ASTM D75/D75M, *Standard Practice for Sampling Aggregates* [5], and ASTM C136/136M, *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates* [6];

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FIG. 2 Typical ballast stockpile sampling and filling buckets with stockpiled ballast (photos courtesy of Samuel C. Douglas).

(2) method for splitting or reducing the sample mass to gradation testing size: ASTM C702/C702M, *Standard Practice for Reducing Samples of Aggregate to Testing Size* [7]; and (3) procedure for performing sieve analysis of ballast: ASTM C136/136M.

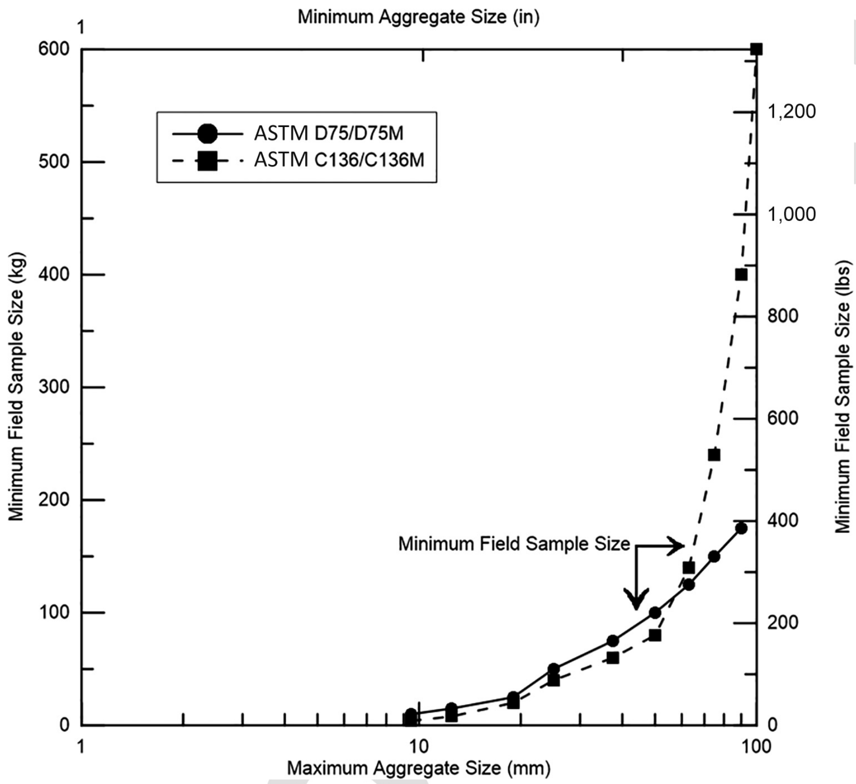
The large ballast particle sizes make ballast sampling a laborious process, and extracting large amounts of ballast from service track is often unrealistic. The ASTM methods are the procedural standards for aggregate and therefore should be applied to ballast testing. Innovative methods to replace sampling may be necessary and are discussed in subsequent sections.

ASTM D75/D75M, *STANDARD PRACTICE FOR SAMPLING AGGREGATES*

Guidelines for securing ballast samples and required sample masses for ballast are presented in ASTM D75/D75M and ASTM C136/C136M, so both of these requirements should be reviewed and followed. ASTM D75/D75M provides recommendations for proper ballast sampling to reduce particle segregation and therefore bias in laboratory test results. Flowing aggregate streams or conveyor belts are recommended, and Section 5.3.1 of ASTM D75/D75M does not recommend sampling coarse aggregate from stockpiles or rail cars especially when determining aggregate properties that are dependent upon gradation, such as shear strength, because of particle segregation. This makes typical or common ballast stockpile sampling, such as that shown in **Fig. 2a**, less desirable than an aggregate stream. However, if stockpile samples must be used, Section 5.3.3.2 of ASTM D75/D75M recommends a sampling procedure to reduce particle segregation involving sampling various locations of the stockpile and combining the samples. This is also referred to as the "mini-stockpile method."

Both Section 5.4.2 of ASTM D75/D75M and Section 7.4 of ASTM C136/C136M [6] provide suggested sample masses for routine grading and quality analyses, which are summarized in **Fig. 3**. Unfortunately, ASTM C136/C136M, discussed here, can require a greater sample mass than ASTM D75/D75M, so engineers must

FIG. 3 ASTM D75/D75M and ASTM C136/C136M required aggregate sample masses.



consider the requirements of both ASTM D75/D75M and ASTM C136/C136M before ballast sampling to ensure the appropriate sample mass is obtained. ASTM C136/C136M covers the test method for determining particle size distribution of coarse aggregates by sieving and requires: (1) the greater of the sample masses required under ASTM D75/D75M and ASTM C136/C136M or (2) four times the sample mass under ASTM C136/C136M. If additional testing (e.g., shear strength) is to be performed, additional sample mass should be obtained so the proper amount can be extracted for the other testing.

For example, using the Dmax of 56 mm (2.2 in.) from **Fig. 1** for the #4 Aggregate tested herein, ASTM D75/D75M requires a sample mass between 100 kg and 125 kg (220 lb and 275 lb), while ASTM C136/C136M requires a sample mass of between 80 kg and 140 kg (176 lb and 309 lb). Of course, the larger of these sample masses, that is, 140 kg (309 lb), should be obtained in the field for gradation testing, and an additional sample should be obtained for other testing. Using the volume of a 18.9-L (5-gal) bucket as about 0.02 m^3 (0.65 ft^3), this means four to five full buckets—or realistically five to six three-quarters full buckets—of ballast are required for a 140-kg (309-lb) sample based on a unit weight of 17.3 kN/m^3 (110 pcf).

However, for values of Dmax greater than or equal to 75 mm (3 in.), the sample size required for ASTM C136/C136M is greater than that required under ASTM D75/D75M. For example, using Dmax of 90 mm (3.5 in.), the samples sizes required under ASTM D75/D75M and ASTM C136/C136M are 175 kg (385 lb) and 400 kg (880 lb), respectively. To meet the requirement of ASTM C136/C136M, that is, 400 kg (880 lb), 16 to 17 three-quarters full 18.9-L (5-gal) buckets based on a unit weight of 17.3 kN/m^3 (110 pcf) are required.

ASTM C702/C702M, *STANDARD PRACTICE FOR SPLITTING OR REDUCING AGGREGATE SAMPLE SIZE*

ASTM C702/C702M [7] presents two methods for splitting or reducing large samples of aggregate to the appropriate specimen size for gradation testing to minimize variations in measured characteristics among tests. This is important because the following section shows that a test specimen with a mass of about 34.8 kg (80 lb) must be obtained or split from the original sample mass of 100 kg to 125 kg (220 lb to 275 lb) for gradation testing of the #4 Aggregate gradation shown in **Fig. 1**.

Under Section 5.2 of ASTM C702/C702M, the two methods presented for splitting or reducing large samples of coarse aggregate are: (1) using a mechanical splitter in accordance with Method A of ASTM C702/C702M, which is the preferred method and (2) quartering the sample on a hard, clean, and level floor in accordance with Method B of ASTM C702/C702M. Under clean and careful conditions, the mechanical splitter appears to provide the best method of obtaining a representative sample for all particle sizes, particularly the fouling material.

Assuming a representative ballast sample can be obtained in the field with sample masses that comply with ASTM D75/D75M and ASTM C136/C136M, the key to obtaining good test results is the remixing and splitting of the field sample. However, it is difficult to standardize the laboratory remixing and splitting processes especially when fouled ballast is involved. If laboratories use the same remixing, splitting, and testing procedures, the test results should be more comparable, which should eliminate the bias from different remixing, splitting, and testing procedures. Because many labs do not have a mechanical splitter, it is recommended that quartering the fouled ballast sample on a hard, clean, and level floor be used and that the fouling material that is collected at the bottom of the buckets be equally dispersed in the four quadrants.

SIEVE ANALYSIS OF BALLAST

ASTM C136 [6] covers the test method for determining the particle size distribution of fine and coarse aggregates by sieving, which is the common technique for obtaining the gradation of railroad ballast. Using Dmax of 56 mm (2.2 in.) for #4 Aggregate in **Fig. 1** and the sample masses in **Fig. 3**, a sample mass of between 100 kg and 125 kg (220 lb and 275 lb) must be obtained to create the necessary gradation test specimen. This 100 kg to 125 kg (220 lb to 275 lb) sample then must be "quartered" using Method B in ASTM C702 to obtain a specimen size of between 25 kg and 31 kg (55 lb and 70 lb) for a sieve analysis.

SHEAR STRENGTH TESTING OF BALLAST

Obtaining undisturbed samples of in situ ballast for shear strength testing is not feasible because of the large individual particles (i.e., no cohesion), and if it was possible, the large particles would hinder trimming of a specimen to fit neatly in a laboratory shear device. Because the use of buckets remains the most common means to sample ballast, the fine fouling material will separate from the ballast particles and collect at the bottom of the buckets during sampling and transport. This sampling procedure is acceptable for gradation testing, but the bucket samples have to be combined and the fouling material returned to its original position in the ballast to obtain meaningful shear strengths. Even if the ballast sample can be reconstituted such that the fouling material is returned to its original position, obtaining a representative sample of the fouling material is also a large problem because of variations in fouling.

Alternative Methods

Because of local variations in ballast fouling and degradation, obtaining a representative sample of the ballast directly under a tie for shear strength testing is difficult and will disturb the track. Therefore, it is imperative to find alternative methods of determining gradation or shear strength without physically removing the ballast.

One option is to better understand the effect and sensitivity of gradation and fouling on ballast shear strength to allow prediction of behavior at other fouling levels and consistencies. This can be accomplished from better understanding and defining fouled ballast parameters and indices [8,9]. For, example, fouling index (FI = P4 + P200) is a common index that determines the proportional weight of the fouling material to the entire sample (P4 = percent weight passing No. 4 sieve) with an additional component to further emphasize the negative effects of silt- and clay-sized particles (P200 = percent weight passing No. 200 sieve). Although laboratory tests have investigated the influence of fouling on ballast settlement [10], much is yet to be learned. This includes the influence of degree of fouling, type of fouling, effect of moisture, and length of track fouled on track behavior [9].

Additional options for measuring ballast engineering properties include using noninvasive techniques for measuring modulus and estimating shear strength instead of trying to obtain and reconstitute a representative fouled ballast sample for laboratory shear strength testing. An example of such a noninvasive technique is seismic surface wave testing, which is described in Sussmann et al. [11].

Summary and Recommendations

In an effort to standardize railroad ballast sampling and testing, this paper summarizes the appropriate sample and specimen sizes, sample splitting, stress conditions, test equipment, and field moisture conditions that should be used for laboratory railroad ballast gradation and shear strength testing using various ASTM test methods. The following summarizes the main recommendations for ballast sampling and testing presented herein:

- Sampling quarry ballast ideally should occur from flowing aggregate streams or conveyor belts, but if sampling occurs from a stockpile, the "mini-stockpile method" sampling procedure from ASTM D75/D75M, Section 5.3.3.2, should be used.
- The mass or weight of a representative ballast sample should follow the larger requirements of ASTM D75/D75M and ASTM C136/C136M, which are summarized in **Fig. 3**. For example, if the maximum aggregate size (Dmax) is 56 mm (2.2 in), a sample mass between 100 kg and 125 kg (220 lb and 275 lb) should be used. As a result, obtaining a representative ballast sample for track degradation or fouling analysis is usually a challenge because of the large sample mass.
- Assuming a representative ballast sample and mass can be obtained, the next important steps in ballast gradation and shear testing are remixing and sample splitting of the required sample mass to obtain representative test specimens and to facilitate comparison of test results. Because many labs do not have a mechanical splitter, it is recommended that quartering the ballast sample on a hard, clean, and level floor take place and the fouling material that is collected at the bottom of the buckets be equally dispersed in the four quadrants.
- Due to the difficulties of sampling and reconstituting ballast, relations between track performance and fouling indices or moduli are desirable. Initial work has been performed in this area, but the end goal of estimating track performance using noninvasive techniques is necessary.

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