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Geotechnical and Structures Laboratory

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Engineer Research and Development Center

Unbonded Aggregate Surface Roads

Reed B. Freeman, Dale A. Goss, Patrick S. McCaffrey,
Joe G. Tom, Toy S. Poole, Landris T. Lee, and Perry A. Taylor

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Final report

Prepared for U.S. Army Engineer District, Vicksburg
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Abstract: Engineers at the Vicksburg District (MVK) of the U.S. Army Engineer Division, Mississippi Valley (MVD), are responsible for the design and construction of levees all along the Mississippi River and its tributaries within the District's boundaries. The local Levee Boards are responsible for maintaining approximately 990 miles (1.6 million meters) of unpaved roads, and the District is responsible for maintaining approximately 390 miles (627,000 m) of unpaved roads that reside on top of the levees. Over the years, the MVK has developed its own specifications to meet these needs. Historically, MVK has relied upon sources of sand clay-gravel that could provide consistent products. However, these sources are becoming depleted, so the products have recently become inconsistent. As a result, the MVK has expanded its specifications to facilitate bid submittals by producers of crushed aggregates.

The purpose of the investigation reported herein was to improve the MVK, MVD, specifications by characterizing various aggregate types in the laboratory, along with collecting performance data under traffic. Because of MVK's recent struggles in finding consistent aggregate sources, both natural and crushed sources of aggregate were included in this study. Trafficking and performance monitoring were accomplished under controlled test track conditions. A review of specifications used by other agencies was also conducted in order to take advantage of their knowledge.

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Conversion Factors, Non-SI to SI Units of Measure

Non-SI units of measure used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
pounds (mass)	0.45359231	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter

Preface

The investigation described in this report was sponsored by the U.S. Army Engineer District, Vicksburg (MVK), of Mississippi Valley Division (MVD). The technical monitor for this study was Dale A. Goss (MVK).

The publication was prepared by personnel of the U.S. Army Engineer Research and Development Center (ERDC), Geotechnical and Structures Laboratory (GSL), Vicksburg, MS. The findings and recommendations presented in this report are based on tests and analyses conducted at ERDC. The study was conducted under the general supervision of Dr. David W. Pittman, Director, and Dr. William P. Grogan, Deputy Director, GSL. Direct supervision was provided by Dr. Albert J. Bush III, Chief, Engineering Systems and Materials Division (ESMD), and Don R. Alexander, Chief, Airfields and Pavements Branch (APB). The principal investigator for the project and primary author of this report was Dr. Reed B. Freeman, APB. Other staff members actively engaged in preparation of the report were Dale A. Goss, MVK; Patrick S. McCaffrey, APB; Joe G. Tom and Dr. Toy S. Poole, Concrete and Materials Branch (CMB); and Landris T. Lee and Perry A. Taylor, Geotechnical and Earthquake Engineering Branch (GEEB), GSL. Technical assistance was provided by Timothy L. Conrad, Carl D. Gaston, and Leroy Hardin of the ERDC Directorate of Public Works.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Engineers at the Vicksburg District (MVK) of the U.S. Army Corps of Engineers' (USACE) Mississippi Valley Division (MVD) are responsible for the design and construction of levees all along the Mississippi River and its tributaries within the District's boundaries. The local Levee Boards are responsible for maintaining approximately 990 miles of unpaved roads, and MVK is responsible for maintaining approximately 390 miles of unpaved roads that reside on top of the levees. Over the years, the MVK has developed its own specifications to meet these needs, as will be presented in this chapter. Historically, MVK has relied upon sources of sand clay-gravel that could provide consistent products. However, these sources are becoming depleted, so the products have recently become inconsistent. As a result, the MVK has expanded its specifications to facilitate bid submittals by producers of crushed aggregates.

The purpose of this investigation was to improve the MVK, MVD, specifications by characterizing various aggregate types in the laboratory, along with collecting performance data under traffic. Because of MVK's recent struggles in finding consistent aggregate sources, both natural and crushed sources of aggregate were included in this study. Trafficking and performance monitoring were accomplished under controlled test track conditions. A review of specifications used by other agencies was also conducted in order to take advantage of their knowledge.

Materials Guidance for Unbonded Aggregate Roads

U.S. Army Corps of Engineers

The USACE has two primary published documents for providing guidance on selecting materials for unbonded aggregate roads, including a Unified Facilities Guide Specification, UFGS-02731, "Aggregate Surface Course" (UFGS 2004), and a road design manual, TM 5-822-12, "Design of Aggregate Surfaced Roads and Airfields" (Department of the Army (DA) 1990). Neither document includes any requirement for aggregate angularity. The guide specification states that "Aggregates shall consist of clean, sound, durable particles of natural gravel, crushed gravel, crushed stone, sand, slag, soil, or other approved materials processed and blended or naturally combined" (UFGS 2004). As is typical for construction aggregates, they are required to be free from lumps and balls of clay, organic matter, objectionable coatings, and other foreign materials.

These documents provide four options for aggregate gradations (Table 1), but the guide specification states that other gradations may be used if they have been shown to perform successfully. In general, the design manual recommends grading for maximum density and minimum volume of voids in order to enhance optimum moisture retention while resisting excessive water intrusion. Such a material will also exhibit cohesive strength as well as intergranular shear strength (DA 1990). "The wearing surface contains fines to provide stability in the aggregate surface. The presence of fines helps the layer's compaction characteristics and helps to provide a relatively smooth riding surface (DA 1990)." The gradations in Table 1 become finer as one proceeds from grading No. 1 to grading No. 4. Figures 1 through 4 compare these gradation limits to theoretical maximum density curves, referred to as 0.45 power curves. These curves are produced according to the following equation (Krebs and Walker 1971). Maximum density for aggregates has been achieved frequently when the power, n, is 0.45 to 0.5 (Barksdale 1991).

$$P = 100 \cdot \left(\frac{d}{D}\right)^{n}$$

where

P = percent finer for a sieve size

d = sieve size in question

D = maximum size of aggregate

n = a power coefficient

Gradation No. 1 surrounds the 0.45 power curve for 1 in. maximum size aggregate (Figure 1). Grading No. 2 falls between the 0.45 power curves for 1 in. and 3/8 in. maximum sizes (Figure 2). Gradation No. 3 and No. 4 are relatively fine and assume distributions that are more uniform (as opposed to well graded) than the 0.45 power curves (Figures 3 and 4).

Table 1
USACE Gradation Requirements for Surface Aggregate

Sieve Size	No. 1	No. 2	No. 3	No. 4
25.0 mm (1 in.)	100	100	100	100
9.5 mm (3/8 in.)	50 – 85	60 – 100	---	---
4.75 mm (No. 4)	35 – 65	50 – 85	55 – 100	70 – 100
2.00 mm (No. 10)	25 – 50	40 – 70	40 – 100	55 – 100
0.425 mm (No. 40)	15 – 30	24 – 45	20 – 50	30 – 70
0.075 mm (No. 200)	8 – 15	8 – 15	8 – 15	8 – 15

While the guide specification (UFGS 2004) does not differentiate between non-frost and frost areas, the design manual (DA 1990) advises that gradations No. 3 and No. 4 may be unstable in freeze-thaw environments. “The percentage of fines should be restricted in all the layers to facilitate drainage and reduce the loss of stability and strength during thaw periods (DA 1990).” The design manual also advises that the percent by mass finer than 0.02 mm not exceed 3 percent, irrespective of climate (DA 1990). This particle size coincides with that used in the Massachusetts Institute of Technology soil classification system to separate medium-sized silt particles from coarse-sized silt particles (Taylor 1948).

The USACE specifies the following physical requirements for the coarse fraction of material (retained on No. 4 sieve). The guide specification allows for waiving the requirement for wear resistance if local experience indicates that the material will perform satisfactorily (UFGS 2004).

a. Los Angeles (LA) abrasion (ASTM C 131) ≤50 percent after 500 revolutions.

b. Flat and/or elongated particles (ASTM D 4791) ≤20 percent (a flat particle has width to thickness ratio greater than 3; an elongated particle has length to width ratio greater than 3).

The USACE specifies the following requirements for the fraction passing the No. 40 sieve (DA 1990 and UFGS 2004).

a. Liquid limit (ASTM D 4318) ≤ 35.

b. Plasticity index (ASTM D 4318) = 4 to 9.

The design manual (DA 1990) suggests that if the minus No. 40 fraction does not meet plasticity requirements, modification by adding chemicals might be required. Chloride products can, in some cases, enhance moisture retention, and lime can be used to reduce excessive plasticity.

Both the guide specification and the design manual require that the surface aggregate layer be compacted to 100 percent of the laboratory-determined modified Proctor (ASTM D 1557) density.

Vicksburg District, Mississippi Valley Division, U.S. Army Corps of Engineers

During its many years of experience building unbonded aggregate roads on river levees, the Vicksburg District has developed its own material specifications to meet these needs (MVK 2004). The individual Levee Boards are responsible for maintaining the levees and the unbonded aggregate surfaced levee crowns so that normal maintenance can be performed along with flood-fighting activities. Their specifications differentiate between the following three materials: sand clay gravel, crushed stone, and crushed stone with binder. The term “gravel” in the first material implies natural, uncrushed aggregate. Gradation requirements are shown in Table 2. Relative to the crushed aggregates, the sand clay gravel is permitted to contain larger particles and a greater percentage of fines (minus No. 200 sieve). For each gradation, the MVK requires that the aggregate be (MVK 2004)

> well graded between the limits shown. All points on the individual grading curves obtained from representative samples of material shall lie between the boundary limits as defined by smooth curves drawn through the tabulated gradation limits. The individual gradation curves within these limits shall not exhibit abrupt changes in slope denoting either skip grading or scalping of certain sizes or other irregularities which would be detrimental to the proper functioning of the material.

The MVK aggregate gradations are compared to 0.45 power curves in Figures 5 through 7. The MVK gradations all follow the well-graded shape of the power curves.

Table 2
MVK Gradation Requirements for Surface Aggregate

Sieve Size	Sand Clay Gravel	Crushed Stone	Crushed Stone with Binder
50.0 mm (2 in.)	100	---	---
37.5 mm (1-1/2 in.)	95 – 100	100	100
25.0 mm (1 in.)	75 – 100	---	---
19.0 mm (3/4 in.)	---	50 – 95	50 – 100
12.5 mm (1/2 in.)	45 – 90	42 – 85	42 – 85
4.75 mm (No. 4)	30 – 65	25 – 65	25 – 65
2.00 mm (No. 10)	20 – 50	---	20 – 50
0.425 mm (No. 40)	10 – 30	10 – 32	10 – 32
0.075 mm (No. 200)	5 – 15	3 – 12	3 – 12

The MVK specification has the following physical requirements for the coarse fraction (retained on No. 4 sieve) of all three materials.

a. LA abrasion (American Association of State and Highway Transportation Officials (AASHTO) T 96)) ≤40 percent after 500 revolutions.

b. Magnesium sulfate soundness loss (AASHTO T 104) ≤15 percent after 5 cycles.

The MVK specification does not include a requirement for flat and/or elongated particles nor for fractured faces.

For the sand clay gravel, fraction passing the No. 40 sieve, the MVK requires the following properties.

a. Liquid limit (AASHTO T 89) ≤ 30.

b. Plasticity index (AASHTO T 90) = 5 to 15.

c. The fraction of material passing the No. 200 sieve shall be less than one-half of the fraction passing the No. 40 sieve.

The crushed stone materials have no requirements on the fine fraction. However, the fraction passing the No. 40 sieve in the crushed stone with binder materials must conform to the following.

a. Liquid limit (AASHTO T 89) ≤ 30.

b. Plasticity index (AASHTO T 90) = 4 to 9.

Thus, the allowable plasticity indices for crushed stone with binder are lower than those for sand clay gravel.

Field Inspections of Aggregate-Surfaced Levee Roads

In June 2004, representatives of both the MVK and the USACE Engineer Research and Development Center (ERDC) visited two levees in order document some examples of material properties and road performance. The levees included Sicily Island Items 1C and 1D Levee near Dunbarton, LA, and the West Bank Mississippi River Levee near Tallulah, LA. The Sicily Island road was inspected at two locations (Sites 1 and 2); both sites were surfaced with crushed sandstone. The West Bank road included one location (Site 1) surfaced with crushed limestone and one location (Site 2) surfaced with sand clay gravel. Field inspections included visual assessments, transverse profile measurements, and measurements of moisture content, density, and strength (using a dynamic cone penetrometer).

All sites were well-worn, with coarse particles concentrated between and outside of the wheelpaths, leaving a finer grained soil within wheelpaths (see Photo 1). The thickness of loose aggregate at centerline was found to be 1 to 2 in. (25 to 50 mm) at Sicily Island, 5 in. (125 mm) at West Bank Site 1, and 1 in. (25 mm) at West Bank Site 2. The road at Sicily Island was evenly crowned when comparing the two sides of the road (river and land). Cross-slopes ranged from 6 to 11 percent with maximum straight-edge rut depth of approximately 2 in. (50 mm). The road at West Bank Levee, Site 1, had an excessive cross-slope of 16 percent on the land side with a slope of 6 percent on the river side. Maximum rut depth was approximately 2.5 in. (65 mm). The road at West Bank Levee, Site 2, had a higher cross-slope of 11 percent on the river side, relative to the land side cross-slope of 7 percent. Maximum rut depth was approximately 2.5 in. (65 mm).

Moisture contents and densities were similar at the four test sites. Moisture contents for the surface aggregates ranged from approximately 4 to 8 percent (see Table 3). Dry densities ranged from approximately 123 to 133 lb/ft^3 (1,970 to 2,130 kg/m^3). Relative to centerlines, wheelpaths generally had lower moisture contents and higher dry densities. One exception occurred with the results at the

West Bank Levee, Site 2. The river side wheelpath at this site had a lower dry density and a higher moisture content than centerline (see Table 3). However, this wheelpath was judged to be capable of holding water as a consequence of its surface profile (see Photo 2). The land side wheelpath at this same location was found to have a lower moisture content and a higher dry density than centerline, similar to the other test sites.

Table 3
Nuclear Density Gage Results

Test Site	Surface Material	Test Location	Dry Unit Weight, lb/ft^3 (kg/m^3)	Moisture Content, %
Sicily Island, Site 1	Sandstone	Wheelpath	131.5 (2105)	5.5
		Centerline	128.4 (2055)	6.9
Sicily Island, Site 2	Sandstone	Wheelpath	130.5 (2090)	5.4
		Centerline	124.8 (2000)	7.8
West Bank, Site 1	Limestone	Wheelpath	130.6 (2090)	4.7
		Centerline	129.0 (2065)	6.3
West Bank, Site 2	Sand Clay Gravel	Wheelpath (River Side)	122.6 (1965)	7.9
		Centerline	130.4 (2090)	5.9
		Wheelpath (Land Side)	132.9 (2130)	4.0

The strength of soil beneath the aggregate surface layers at the four sites was generally similar, with California bearing ratio (CBR) between 4 and 10 percent (see Table 4). One notable exception was the soil beneath sandstone at Sicily Island, Site 1. At this location, there was a particularly weak soil layer directly beneath the surface aggregate, possibly caused by the accumulation of moisture. At centerline, the weak soil layer was 7 in. thick and had a CBR of approximately 2 percent.

Table 4
Summary of Results for Dynamic Cone Penetrometer Tests

Test Site	Test Location	CBR of Underlying Soil, %	CBR of Aggregate Surface Layer %	Depth at Which CBR Falls to 10% or Less, in. (mm)
Sicily Island, Site 1	Wheelpath	5 to 10	60 to 80	6 (150)
	Centerline	2 to 10	10 to 20	6 (150)
Sicily Island, Site 2	Wheelpath	5 to 10	40 to 50	12 (305)
	Centerline	4 to 10	50 to 60	11 (280)
West Bank, Site 1	Wheelpath	5 to 8	80 to 100	10 (255)
	Centerline	5 to 10	100	17 (430)
West Bank, Site 2	Wheelpath	5 to 10	40 to 50	11 (280)
	Centerline	5 to 10	50 to 60	11 (280)

Among the aggregate surface layers, limestone provided the highest CBR: 80 to 100 percent. This relatively high CBR was even found at the road centerline, albeit beneath 5 in. of loose material. The sand clay gravel provided CBRs in the range of 40 to 60 percent. The sandstone at Sicily Island was found to have highly variable CBRs: 40 to 60 percent at Site 2, 60 to 80 percent in the wheelpath at Site 1, and 10 to 20 percent in the centerline at Site 1.

The thicknesses of pavement layers can sometimes be ascertained from DCP data, using changes in CBR. At Sicily Island, Site 1, aggregate surface layer thicknesses were well defined and were found to be 5 to 6 in. (125 to 150 mm). At all the other sites, gradual transitions in CBR made thickness determinations difficult. As a means of comparing thicknesses of materials with reasonable quality at the various test sites, Table 4 provides depths at which CBR dropped to 10 percent or less. Once again, Sicily Island, Site 1, appears to offer the structure with the thinnest cover of relatively high CBR material (greater than 10 percent). The other three sites have comparable depths for low CBR material (10 percent or less), ranging from 10 to 17 in. (255 to 430 mm).

Based on findings from this field trip, two guidelines were found for the construction of pavement test sections when the test sections are intended to emulate conditions on levees in LA and MS.

a. The CBR of soil upon which new roads are constructed should be 5 to 10 percent.

b. When intending to construct a layer of sand clay gravel that should represent well-trafficked material in the field, the target density should be approximately 130 lb/ft^3 (2,080 kg/m^3) and the CBR should be 40 to 60 percent.

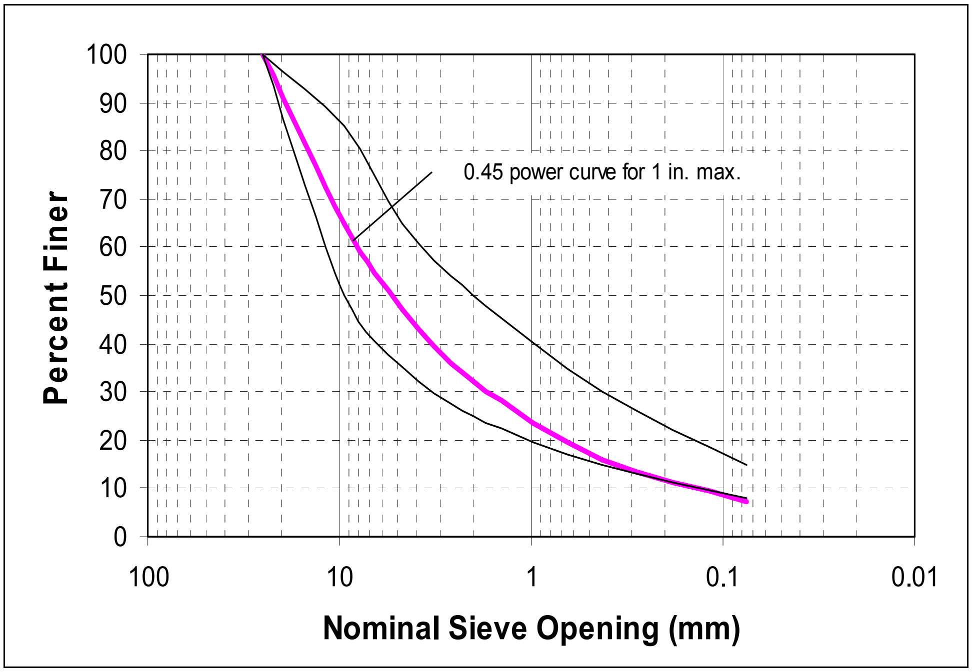

Figure 1. USACE gradation No. 1

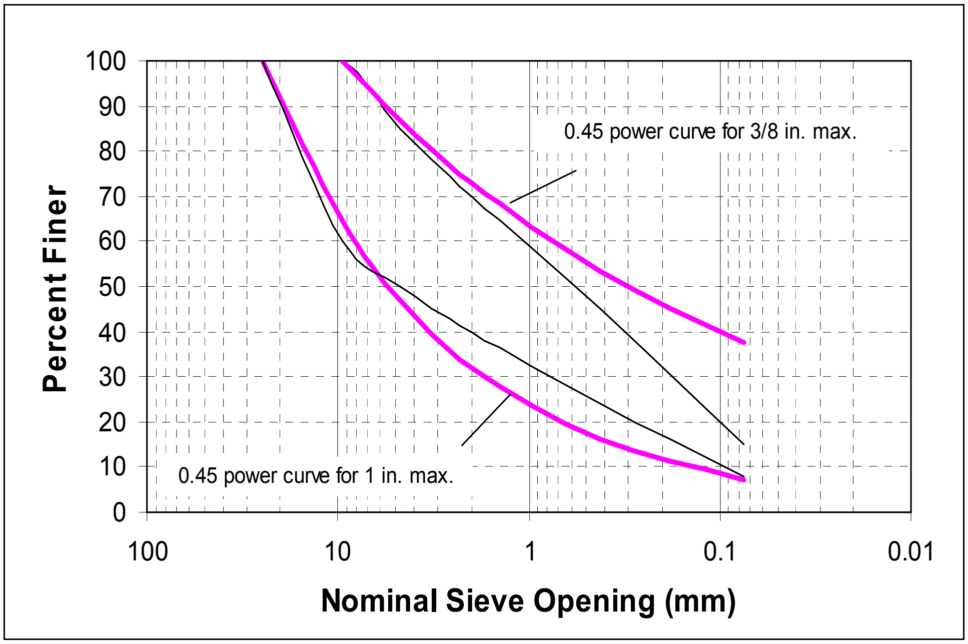

Figure 2. USACE gradation No. 2

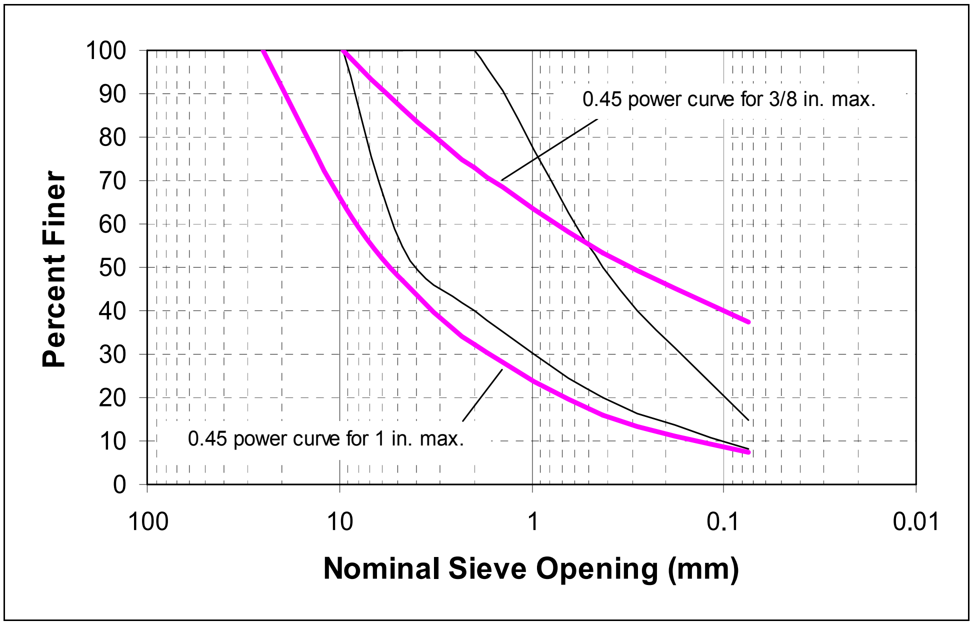

Figure 3. USACE gradation No. 3

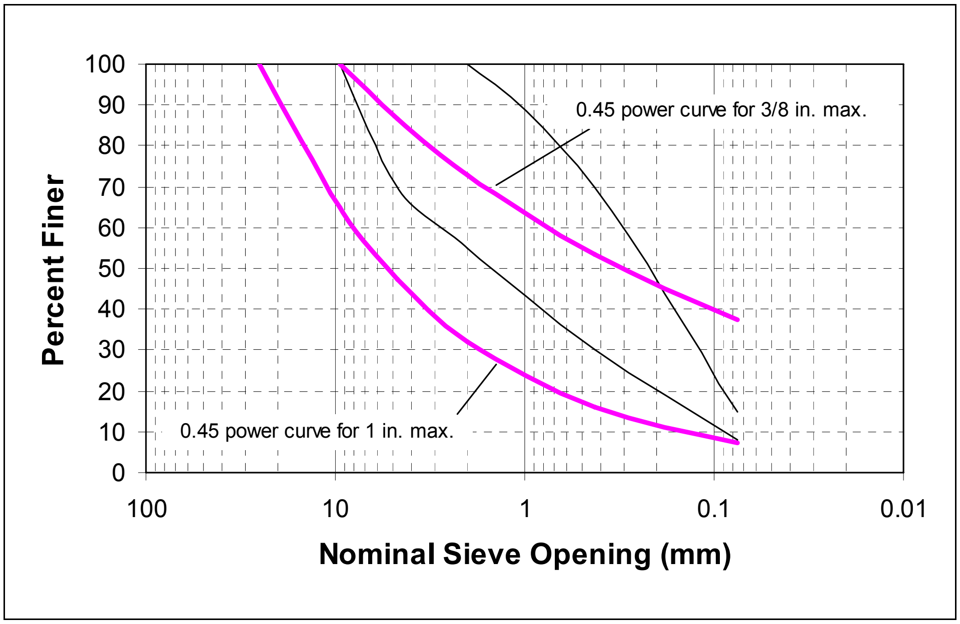

Figure 4. USACE gradation No. 4

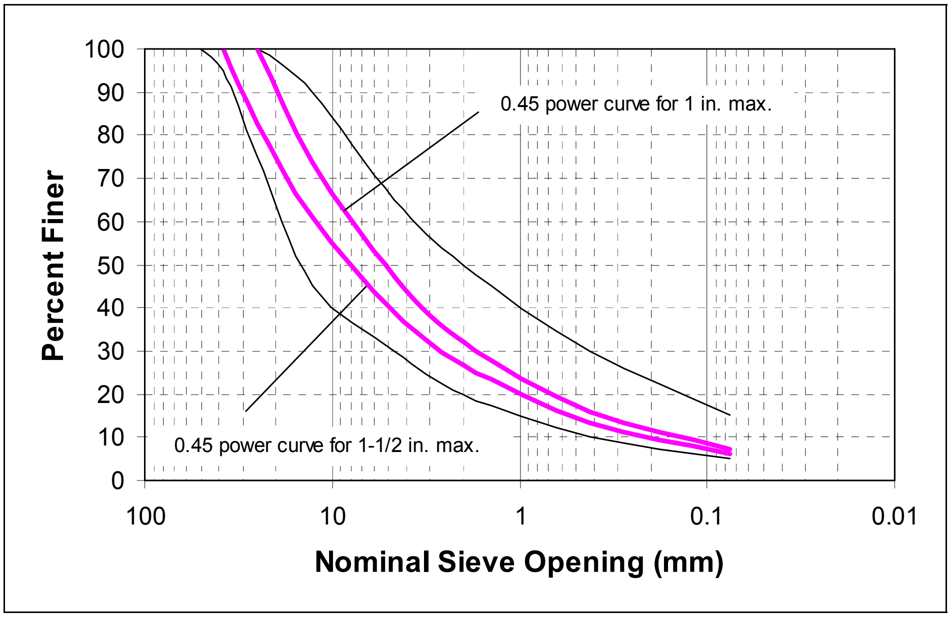

Figure 5. MVK gradation limits for sand clay gravel

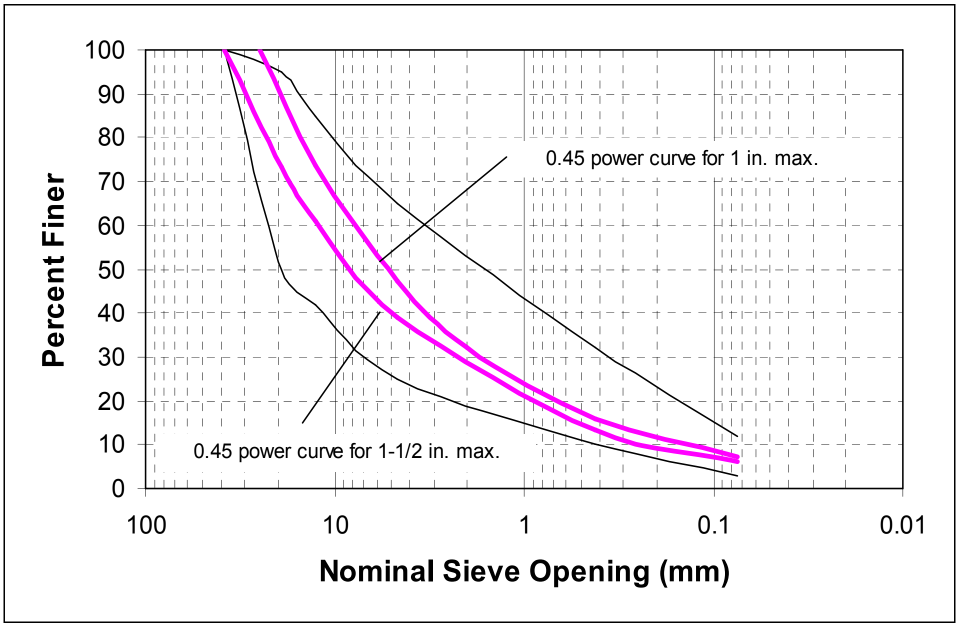

Figure 6. MVK gradation limits for crushed stone

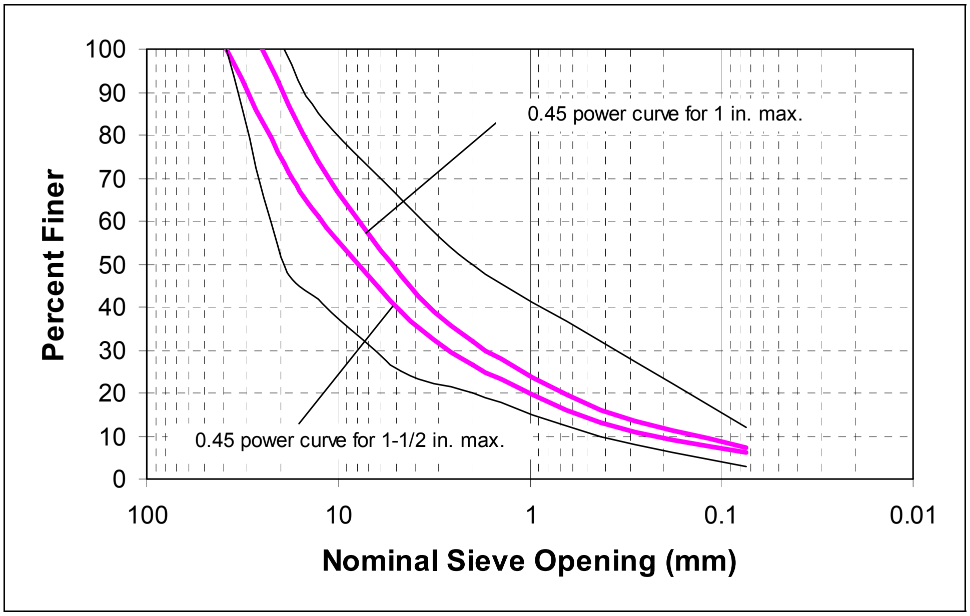

Figure 7. MVK gradation limits for crushed stone with binder

Photo 1. Sicily Island Items 1C and 1D Levee

Photo 2. West bank Mississippi River Levee, Sand Clay Gravel Site 2

2 Specifications Used by Agencies Other Than USACE

This chapter summarizes the specifications that are published by other agencies, namely the Federal Highway Administration, the U.S. Forest Service, several U.S. State Departments of Transportation, and South Africa.

Federal Highway Administration

The Federal Highway Administration (FHWA) specifies the use of crushed coarse material (FHWA 1999): "Furnish aggregates that consist of hard, durable particles or fragments of crushed stone, crushed slag, or crushed gravel meeting the appropriate gradation and conforming to the following:"

a. LA abrasion (AASHTO T 96) ≤50 percent after 500 revolutions.

b. Sodium sulfate soundness (AASHTO T 104) ≤12 percent after 5 cycles.

c. Durability index for coarse aggregate (AASHTO T 210) ≥ 35.

d. Durability index for fine aggregate (AASHTO T 210) ≥ 35.

e. Fractured faces (ASTM D 5821) ≥50 percent.

The aggregate durability index establishes an aggregate's resistance to generating fines when agitated in the presence of water. The fine aggregate (material passing the No. 4 sieve) can consist of natural or crushed sand and fine mineral particles.

Similar to other agencies, the FHWA requires that the aggregate be free from organic matter and lumps or balls of clay. The material must not break up when alternately frozen and thawed or wetted and dried.

The FHWA requires a maximum liquid limit (AASHTO T 89) for the fine fraction (passing No. 40 sieve) of 35 percent. Allowable plasticity indices (AASHTO T 90) are 4 to 12 percent. Aggregate grading (AASHTO T 27 and T 11) must conform to that shown in Table 5. The limits for grading target values provide an envelope around the 0.45 power curve for 3/4 in. maximum particle size (see Figure 8).

Table 5
Federal Highway Administration Grading Requirements for Surface Aggregate

Sieve Size	Percent Passing
25.0 mm (1 in.)	100
19.0 mm (3/4 in.)	97 – 100
4.75 mm (No. 4)	41 – 71 (7)
0.425 mm (No. 40)	12 – 28 (5)
0.075 mm (No. 200)	9 – 16 (4)

Note: Allowable deviations (+/-) from target values are shown in parentheses.

U.S. Forest Service

The U.S. Forest Service (USFS) specification (Forest Service 1996) is similar to the FHWA specification. The USFS also requires crushed materials, but its LA abrasion requirement was tightened to a maximum of 40 percent loss after 500 revolutions. While its liquid limit requirement is the same as for FHWA, the requirement for plasticity index (AASHTO T 90) depends on the percent passing No. 200 sieve (0.075 mm).

a. If percent passing No. 200 sieve is ≤12 percent, allowable plasticity index is 2 to 9 percent.

b. If percent passing No. 200 sieve is >12 percent, allowable plasticity index is 0 percent (i.e., must be non-plastic).

The USFS offers two options for grading (AASHTO T 27 and T 11): “One of the following aggregate gradation target distributions [Table 6] should be obtained by crushing, screening, and blending processes as necessary.” Both gradations can be considered well graded, as they both offer particle size distributions similar to 0.45 power curves (see Figures 9 and 10). Grading F is coarser than Grading G.

State Departments of Transportation

Specifications for nine state departments of transportation were reviewed. The states were spread fairly well around the continental United States: Alaska, Iowa, Louisiana, Maine, Michigan, North Dakota, South Dakota, Tennessee, and Washington (respective references are listed by state name). None of the states follow the FHWA specification exactly. All the states specify aggregate grading for surface course aggregates. About half the states require the aggregates to be crushed (see Table 7). Only Alaska, North Dakota, and Washington have a fractured face requirement for crushed coarse aggregate. Maine and Washington use the sand equivalent test to ensure that a sufficient proportion of fines is produced from crushing operations.

Table 6
U.S. Forest Service Grading Requirements for Surface Aggregate

Sieve Size	Grading F	Grading G
37.5 mm (1.5 in.)	100	---
25.0 mm (1 in.)	97 – 100	100
19.0 mm (3/4 in.)	76 – 89 (6)	97 – 100
9.5 mm (3/8 in.)	56 – 68 (6)	70 – 80 (6)
4.75 mm (No. 4)	43 – 53 (7)	51 – 63 (7)
1.18 mm (No. 16)	23 – 32 (6)	28 – 39 (6)
0.425 mm (No. 40)	15 – 23 (5)	19 – 27 (5)
0.075 mm (No. 200)	10 – 16 (4)[1]	10 – 16 (4)[1]

Note: Allowable deviations (+/-) from target values are shown in parentheses.
[1] If the plasticity index (PI) is greater than 0, the target value range for the 75-um sieve is 6 – 12 (4).

Every state except Maine uses the LA abrasion test as a measure of particle durability (see Table 7). Maine uses the micro-Deval test, which is a proposed AASHTO test method (AASHTO TP58-99). Louisiana and Tennessee include sulfate soundness as a durability requirement. Iowa includes a freeze-thaw degradation resistance test of its own design (Method 211 C). Alaska has its own durability test (ATM T-13), which produces results in terms of “degradation value.” Iowa and North Dakota limit the percent of shale particles among coarse aggregates.

For plasticity requirements, only Louisiana and Tennessee use restrictions on both liquid limit and plasticity index. Alaska, North Dakota, and South Dakota choose to only use a restriction on plasticity index. Iowa chooses to limit the percent mud balls in the fraction passing the No. 200 sieve. Every state limits the percent of fine particles. Every state except Tennessee limits the fraction of material passing the No. 200 sieve; Tennessee limits the fraction of material passing the No. 100 sieve.

Alaska specifies two grading options for crushed aggregate, as shown in Figures 11 and 12. Iowa specifies separate gradings for natural aggregate (Figure 13) and crushed stone (Figure 14). Louisiana specifies separate gradings for sand clay gravel (Figure 15) and crushed stone (Figure 16). Maine specifies a single grading for both natural and crushed aggregates (Figure 17). Michigan specifies separate gradings for natural aggregate (Figure 18) and crushed stone (Figure 19). North Dakota specifies two grading options for crushed aggregate, as shown in Figures 20 and 21. South Dakota specifies a single grading for crushed aggregate (Figure 22). Tennessee specifies a grading that applies to either natural or crushed aggregates (Figure 23). Washington specifies a single grading for crushed aggregate (Figure 24).

South Africa

The Republic of South Africa is included in this literature review because it has a unique approach to quality assurance of unbonded road surface aggregates. Two parameters are used to quantify the potential for aggregates to perform well in this capacity. The grading coefficient (Gc) reflects both coarseness of particles and degree of uniformity for the particle size distribution (Committee of State Road Authority 1990).

$$\mathrm{Gc} = (\%\mathrm{p}\ \ 1\,\mathrm{in.} - \%\mathrm{p}\ \ \mathrm{No.10}) \times \frac{\%\mathrm{p}\ \ \mathrm{No.4}}{100}$$

where

$\%p$ = percent passing the associated sieve size

The shrinkage product (*Sp*) reflects fineness and plasticity of the fine fraction.

Sp = linear shrinkage (%) × $\%p$ No. 40

Linear shrinkage is determined in accordance with British standard, BS 1377, Part 2 (BSI 1990), as described in Chapter 3. These two parameters provide the information necessary to plot aggregate characteristics on the graphical criterion shown in Figure 25. In this figure, the allowable aggregate characteristics include Gc between 16 and 34 as well as *Sp* between 100 and 365, with a preferable maximum of 240. For aggregates that have calculated Gc and *Sp* values outside of these preferred ranges, the figure includes general descriptions of probable road distress if the aggregates are used for unbonded surface course construction.

The South African specification also includes a restriction on the particles retained on the 1-1/2 in. sieve. For rural roads, these particles are limited to 5 percent by mass and, for urban roads, these particles are limited to 0 percent. As a strength criterion, the CBR of the aggregate blend must be at least 15 percent when the aggregate is compacted to at least 95 percent of the maximum density (i.e., optimum moisture and modified compactive effort, ASTM D 1557). This strength criterion is not so restrictive that it precludes the use of natural (i.e., uncrushed) aggregates.

Table 7
Summary of Selected State Department of Transportation Specifications

Material Property	Test Parameter	Alaska	Iowa	Louisiana	Maine	Michigan	North Dakota	South Dakota	Tennessee	Washington
Crushed Aggregate Required	NA	Yes	No	No	No	No	Yes	Yes	No	Yes
Fractured Faces	1+ faces	≥70%	NA	NA	NA	NA		NA	NA	≥75%
	2+ faces						≥10%			
Sand Equivalent	NA	NA	NA	NA	≥45	NA	NA	NA	NA	≥40
LA Abrasion	NA	≤45%	≤45%	≤40%	NA	≤50%	≤50%	≤40%	≤50%	≤35%
Sulfate Soundness	Na2SO4	NA	NA		NA	NA	NA	NA	≤15%	NA
	MgSO4			≤15%						
Liquid Limit	Natural	NA	NA	≤40	NA	NA	NA	NA	≤30	NA
	Crushed			≤25						
Plasticity Index	- #200 ≤ 12%	≤10	NA	≤4	NA	NA		4 to 12	≤8	NA
	- #200 > 12%			4 to 15						
	- #200 fraction[1]						≤15			
Fraction Passing #200 Sieve	Natural		≤15	10 to 25	0 to 7	9 to 16			NA[2]	
	Crushed	8 to 20	≥6	3 to 15		≤10	≤20	4 to 15		0 to 10

[1] Rather than testing the fraction passing #40 sieve, as is standard, the test is conducted on the fraction passing the #200 sieve.
[2] Percent passing the No. 100 sieve is limited to no more than 10 percent.

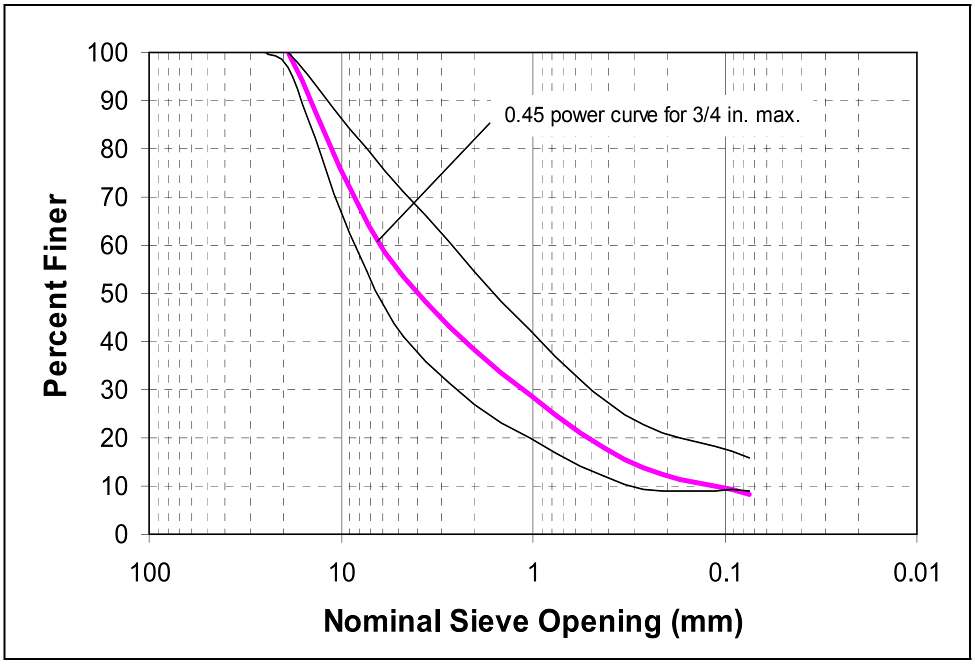

Figure 8. FHWA grading requirement

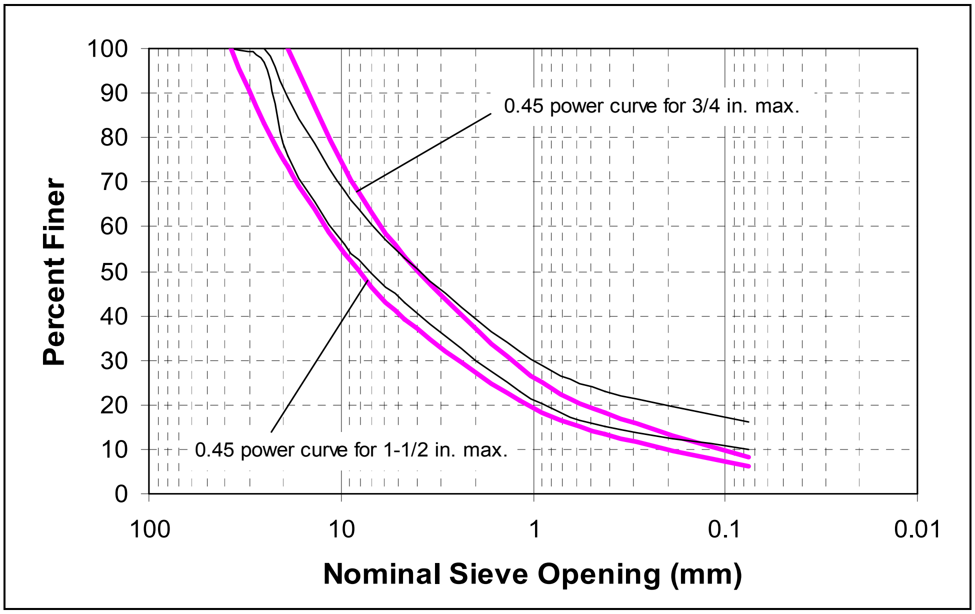

Figure 9. U.S. Forest Service grading F

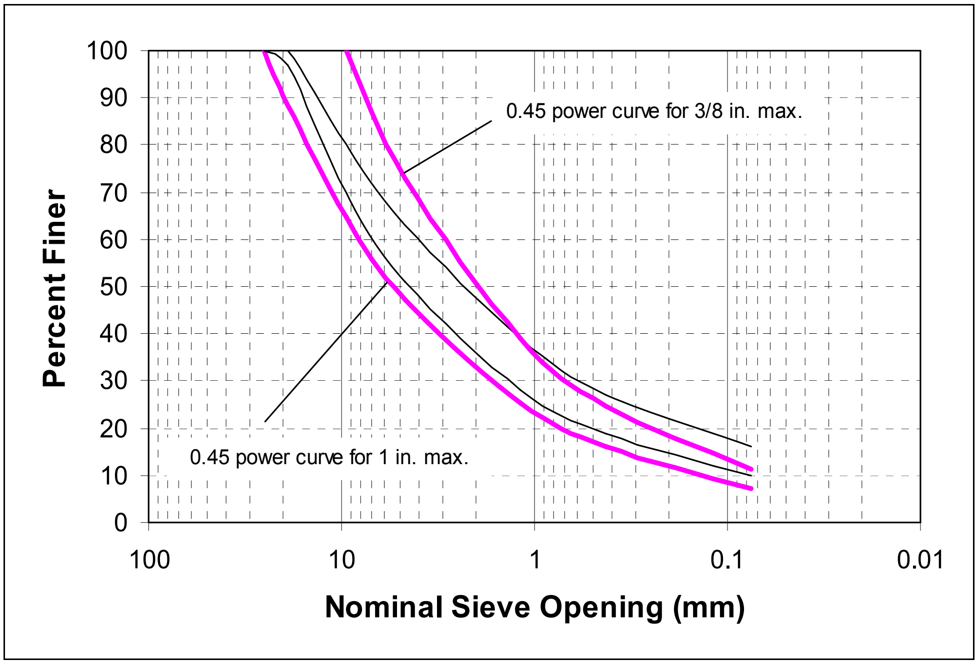

Figure 10. U.S. Forest Service grading G

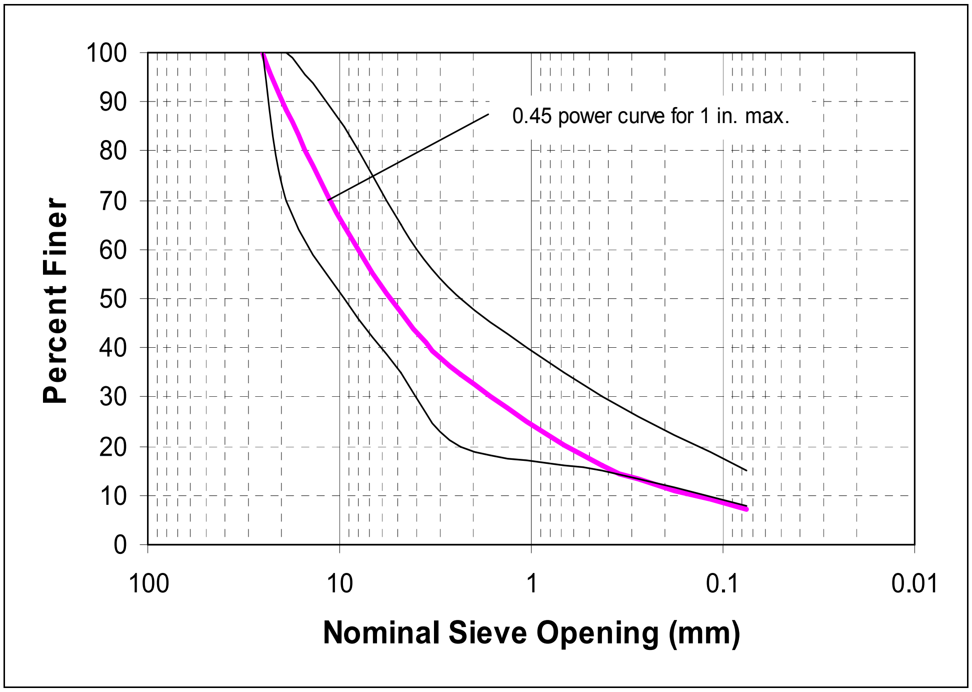

Figure 11. Alaska DOT grading E-1 for crushed aggregate

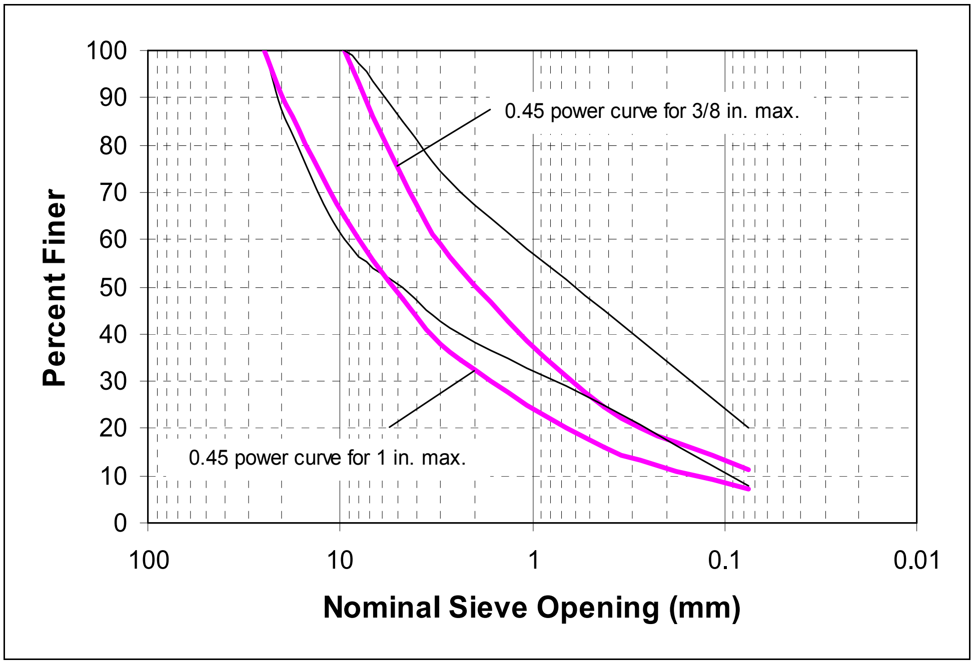

Figure 12. Alaska DOT grading F-1

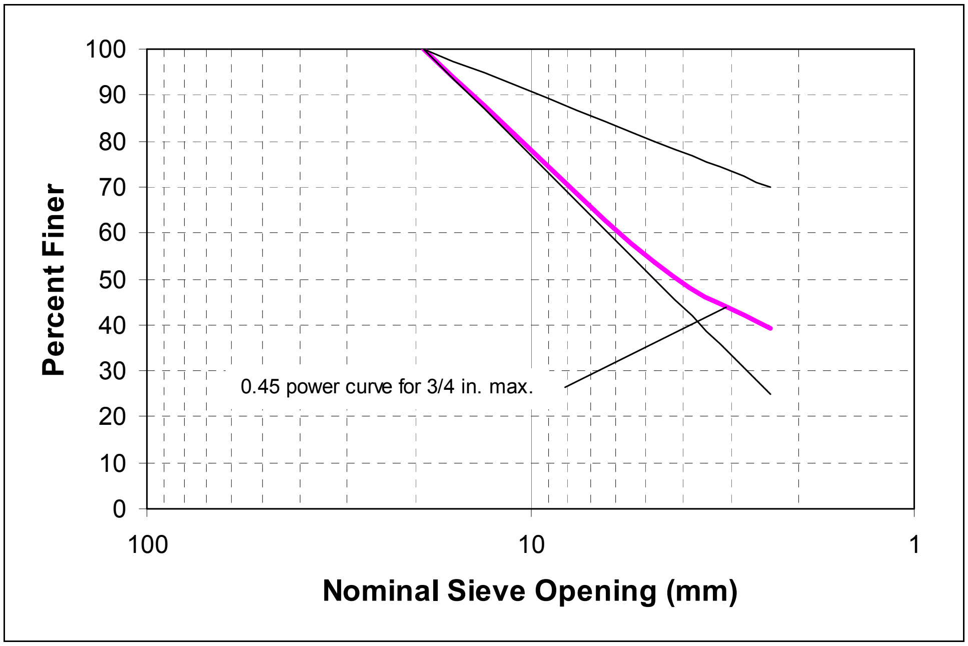

Figure 13. Iowa DOT grading No. 10 for natural aggregate

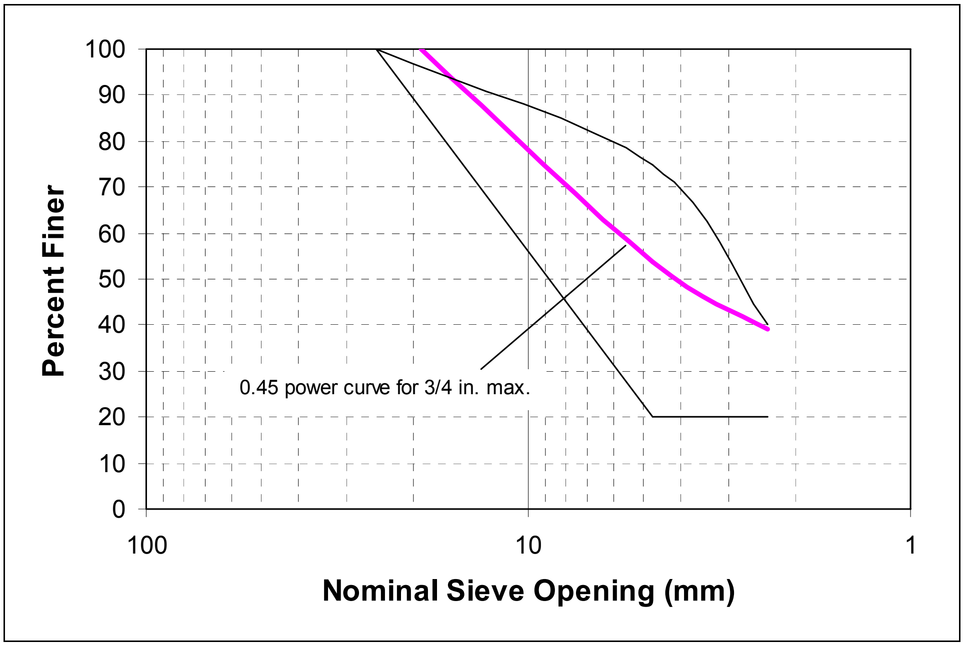

Figure 14. Iowa DOT Grading No. 11 for crushed stone

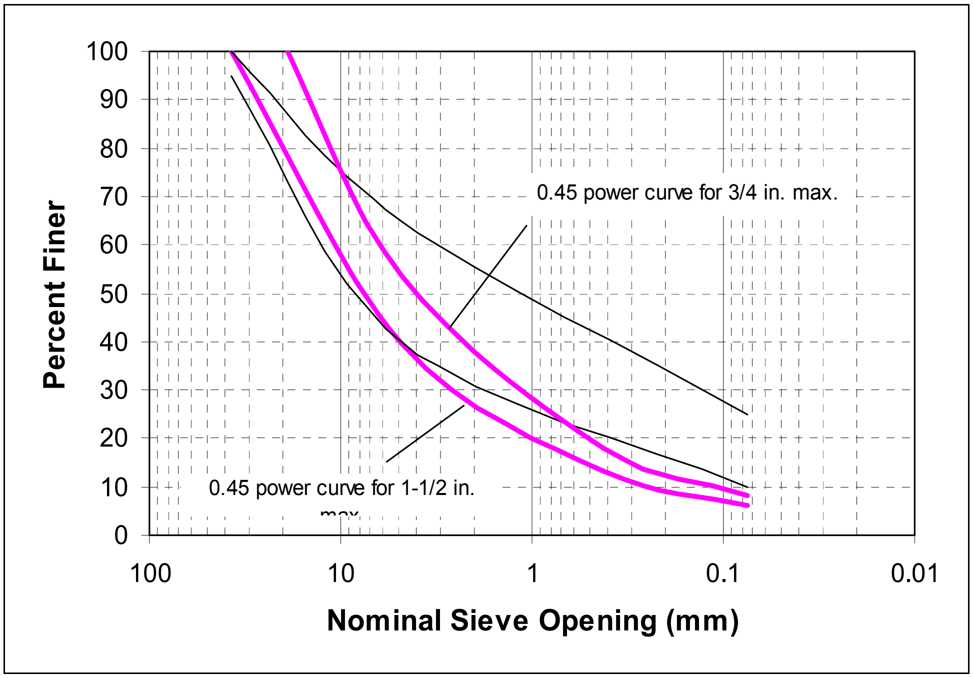

Figure 15. Louisiana DOT grading for sand clay gravel

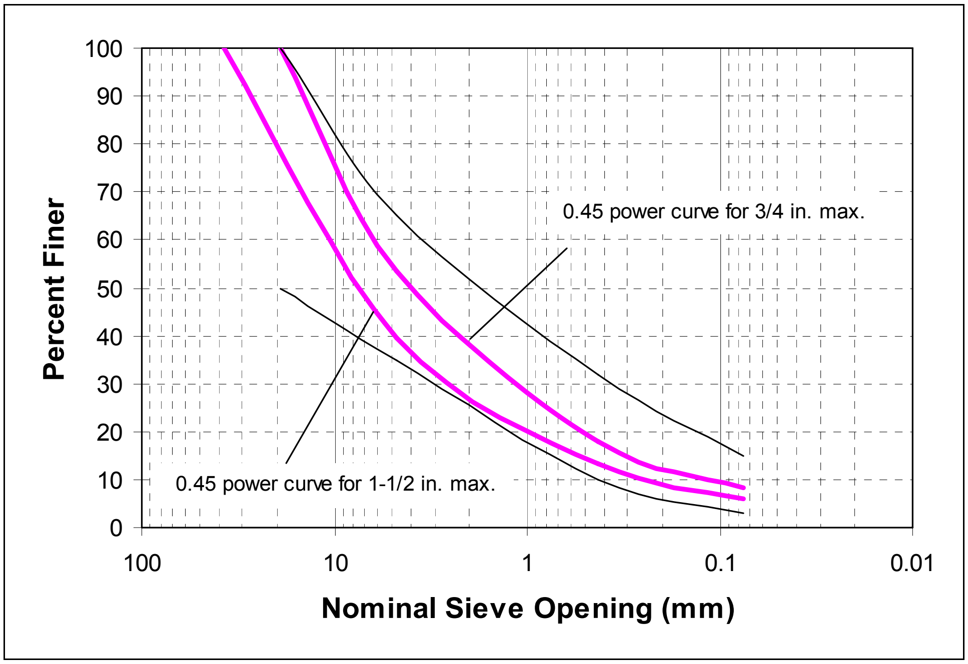

Figure 16. Louisiana DOT grading for crushed stone

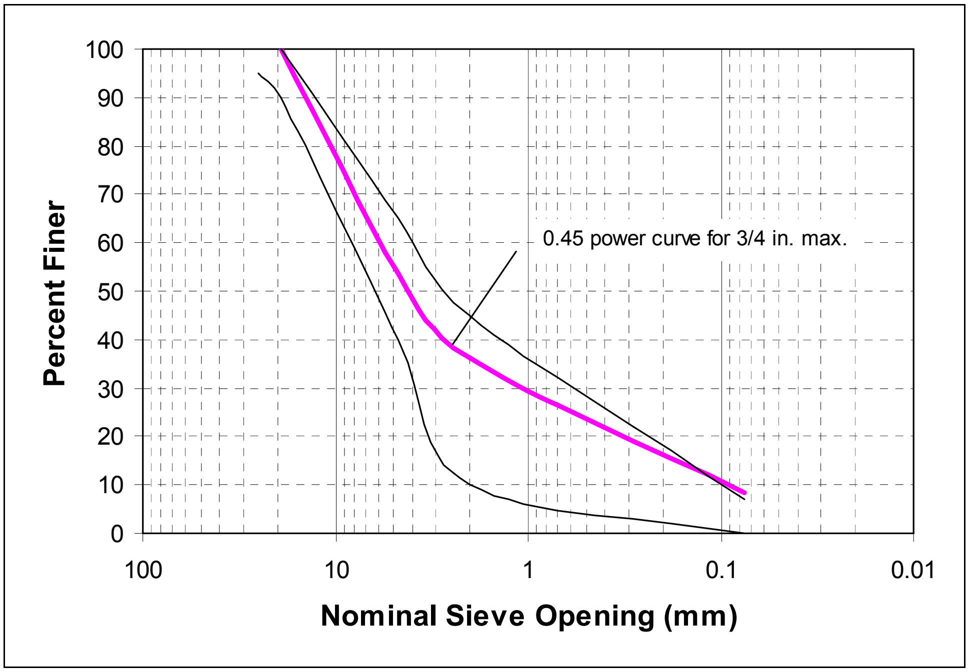

Figure 17. Maine DOT grading requirement

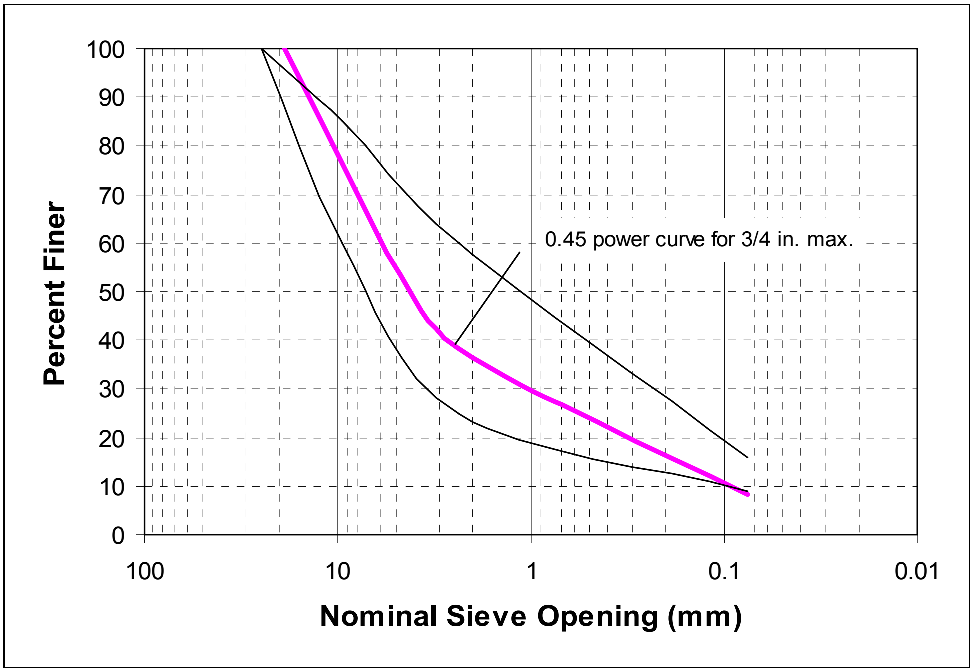

Figure 18. Michigan DOT grading for natural aggregate

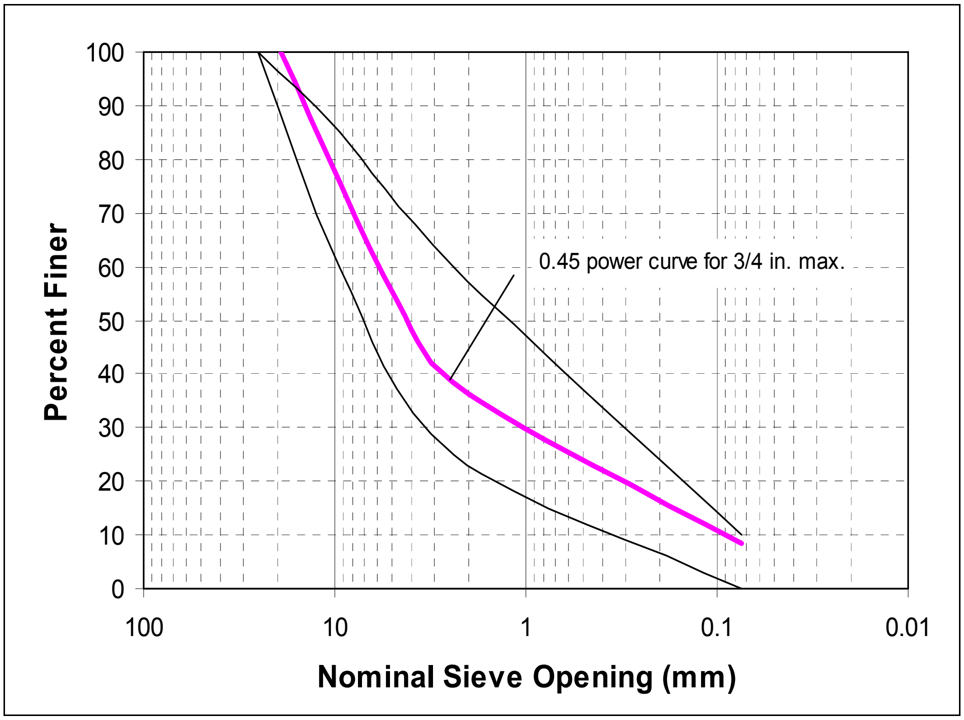

Figure 19. Michigan DOT grading for crushed stone

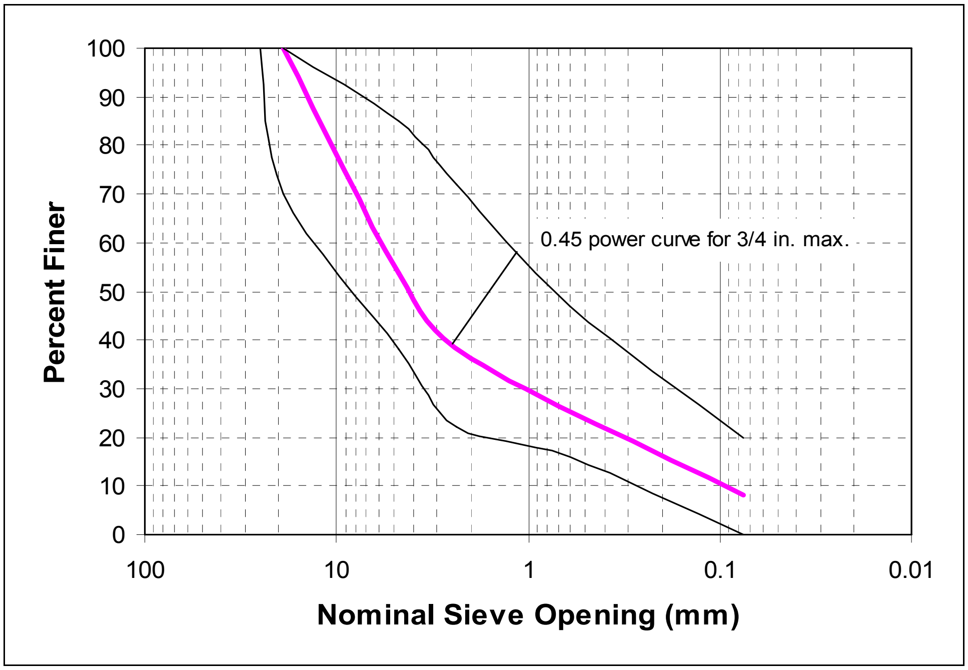

Figure 20. North Dakota DOT grading No. 12

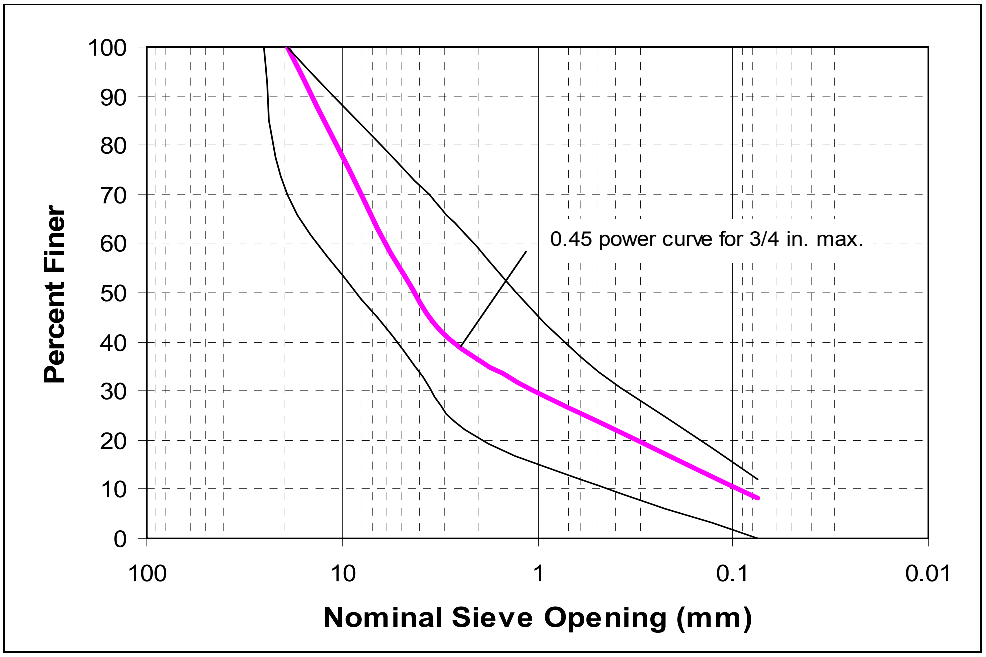

Figure 21. North Dakota DOT grading No. 13

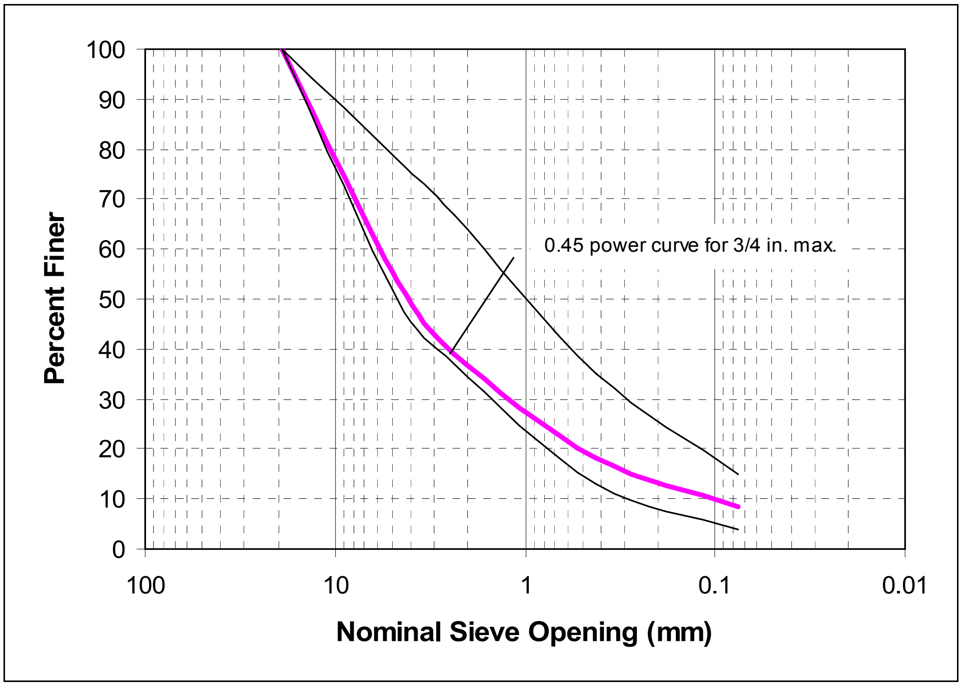

Figure 22. South Dakota DOT grading requirement

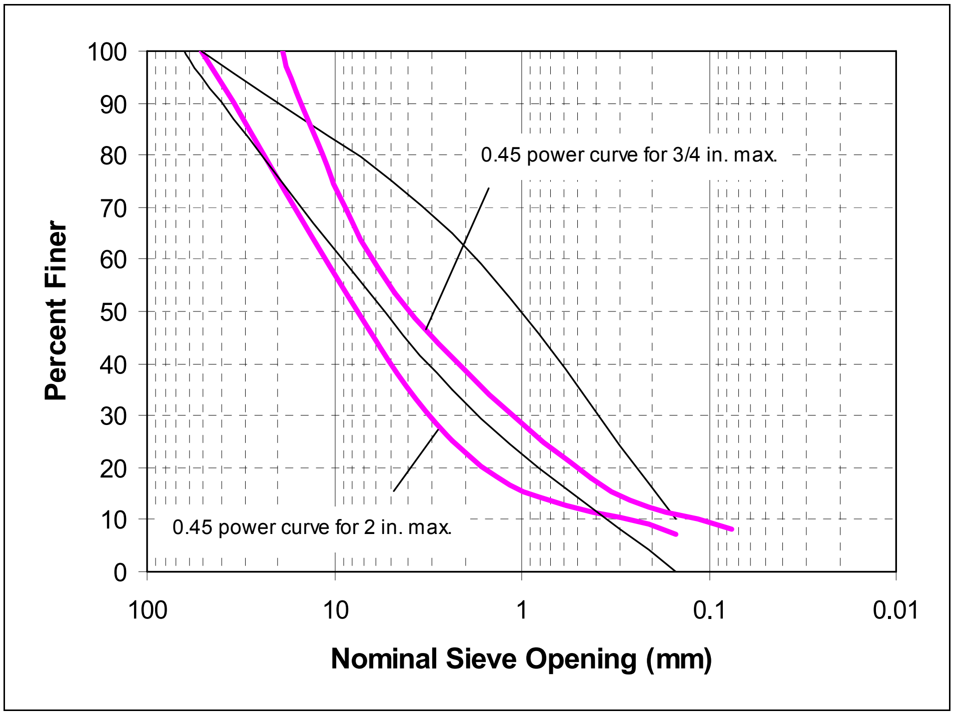

Figure 23. Tennessee DOT grading requirement

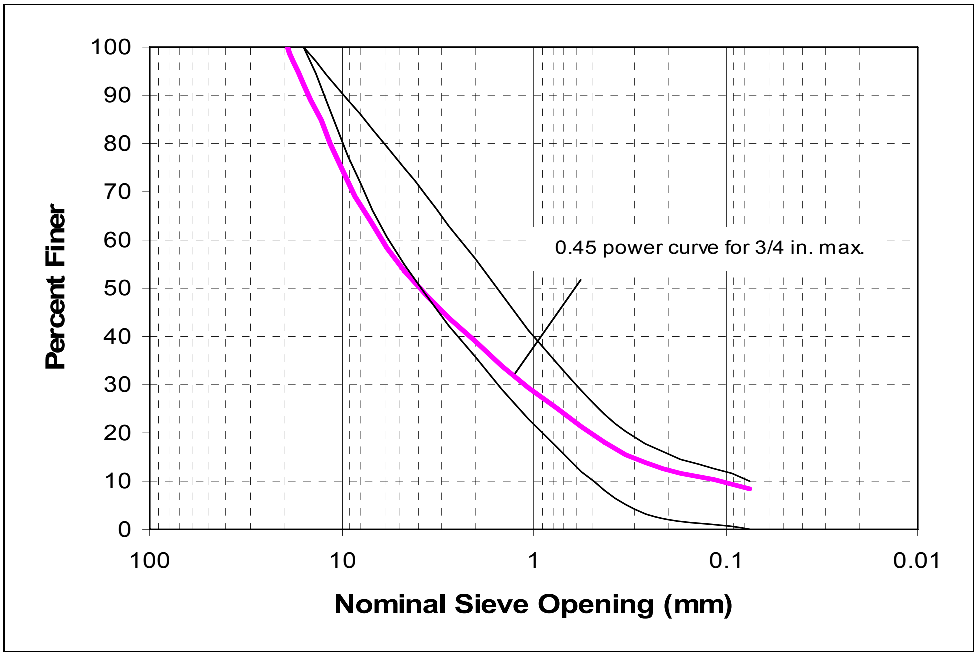

Figure 24. Washington DOT grading requirement

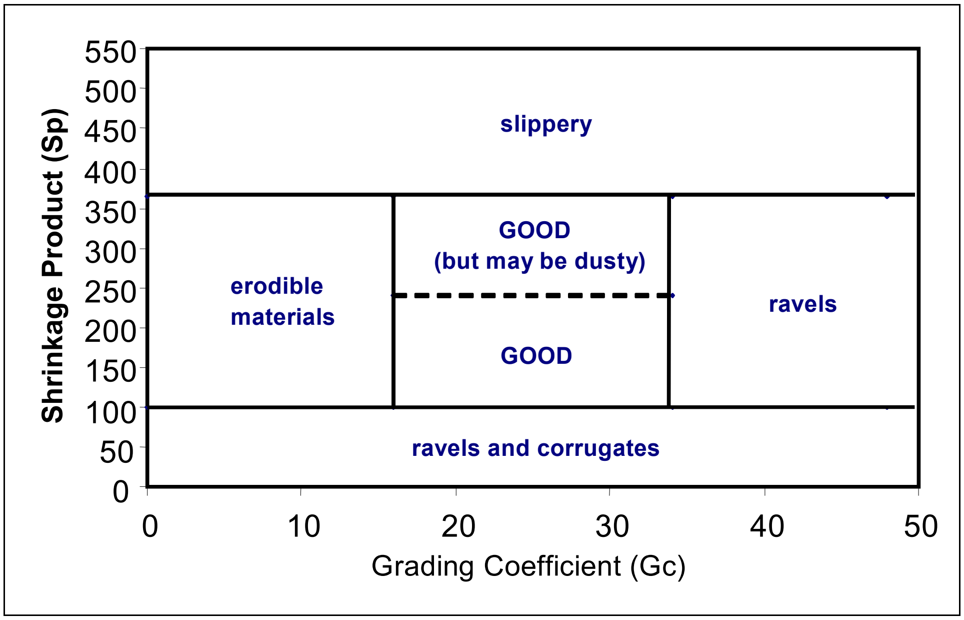

Figure 25. South African approach to selection criteria for unbonded road surface aggregates

3 Materials

Five aggregates were included in this study (see Table 8). While the sand-clay-gravel was a natural aggregate, all the other materials involved crushing operations. The sandstone with binder included crushed sandstone blended with lean clay soil. Unified soil classifications are shown in Table 9. For brevity, the abbreviated names shown in Table 9 will be used for reference the aggregates in this report.

Table 8
Aggregate Sources

Common Name	Source
Sand Clay Gravel	Greenwood Hill Gravel in Greenwood, MS
Limestone	Vulcan Materials Co., Reed Quarry, Gilbertsville, KY
Sandstone	Pine Bluff Sand and Gravel, River Mountain Quarry, Delaware, AR
Igneous Rock	McGeorge Corp., Granite Mountain Quarries, Little Rock, AR
Sandstone with Binder	Martin Marietta Aggregates, Sawyer Quarry, Sawyer, OK

Table 9
Aggregate Classifications

Common Name	Abbreviated Common Name	USCS[1] Group Symbol	USCS Group Name	Color
Sand Clay Gravel	SCG	SC	Gravelly Clayey Sand	Brown
Limestone	LST	GW-GM	Sandy Silty Gravel	Gray
Sandstone	SST	GP-GM	Sandy Silty Gravel	Gray
Igneous Rock	IGN	GP	Sandy Gravel	Gray
Sandstone with Binder	SSB	GC	Sandy Clayey Gravel	Brown

[1] Unified Soil Classification (ASTM D 2487).

Particle size distributions are shown in Figure 26. The igneous (IGN) aggregate was the overall coarsest. The SCG had the least amount of coarse (plus No. 4) material. The SCG and SSB aggregates had the largest portion finer than the No. 40 sieve. The LST and SST aggregates seemed to be most densely graded, based on their proximity to the 0.45 power curve.

Additional aggregate grading characteristics are shown in Tables 10 through 12. Notably, Table 10 shows that SST and IGN aggregates have the highest percentages of coarse particles. Table 11 shows that the SCG and SSB aggregates have highest percentages of fine particles (finer than the No. 200 sieve). Table 12 includes effective size (D10), or the particle size for which 10 percent if finer, uniformity coefficient (Cu) and coefficient of curvature (Cc). Lower values of Cu indicate more uniformly graded (i.e., open-graded) aggregates. For distinguishing between uniform gradations and a dense-graded (i.e., well-graded) materials, a value of 4 is used for gravel and a value of 6 is used for sand (Krebs and Walker 1971). Based on that criterion, none of these aggregates would be considered uniformly graded. It should be mentioned that gap-graded (or skip-graded) materials may yield high values for Cu, but are not considered to be well graded. The Cc further describes the shape of the particle grading curve to help overcome this limitation of the Cu. A well-graded material should have a Cc between 1 and 3; gap-graded materials are unlikely to meet this criterion (Krebs and Walker 1971). Only the LST aggregate meets this Cc requirement for being well graded.

Table 10
Percent Passing Selected Coarse Sieves

Abbreviated Common Name	% Passing 38.1 mm (1.5 in.) Sieve	% Passing 25.4 mm (1 in.) Sieve	% Passing 19 mm (3/4 in.) Sieve	% Passing No. 4 Sieve[1]
SCG	100	100	95.3	68.5
LST	100	96.9	88.2	52.7
SST	100	86.4	67.3	31.5
IGN	100	93.1	65.2	22.5
SSB	100	90.1	77.6	48.5

[1] Nominal particle size for No. 4 sieve = 4.76 mm (0.19 in.).

Table 11
Percent Finer Than Selected Small Particle Sizes

Abbreviated Common Name	% Passing No. 10 Sieve[1]	% Passing No. 40 Sieve[1]	% Passing No. 200 Sieve[1]	% Finer Than 0.002 mm
SCG	59.6	32.6	14.4	7.5
LST	28.9	11.8	6.3	2.5
SST	24.4	18.9	6.8	2.0
IGN	15.5	8.1	3.6	1.0
SSB	41.3	34.7	22.8	8.0

[1] Nominal particle sizes for No. 10, No. 40, and No. 200 sieves = 2.00 mm (0.079 in.), 0.425 mm (0.017 in.), and 0.075 mm (0.0029 in.), respectively.

Table 12
Aggregate Grading Characteristics

Abbreviated Common Name	D60	D30	D10	Cu	Cc
SCG	2.1	0.39	0.01	210	7.2
LST	6.0	2.1	0.29	20.8	2.6
SST	16.2	4.2	0.13	124	8.3
IGN	17.5	7.7	0.72	24.4	4.7
SSB	9.5	0.16	0.005	1,900	0.54

[1] D## = size (mm) for which ##% is finer. Cu = uniformity coefficient, Cc = coefficient of curvature.

The minus No. 40 fractions for LST, SST, and IGN aggregates were all non-plastic and were classified as silty sand (SM) materials based on gradation (see Table 13). The fine fractions for SCG and SSB aggregates were classified as lean clay (CL). The fines from these two aggregates had very similar Atterberg limit characteristics.

Table 13
Fine Fraction Atterberg Limits

Abbreviated Common Name	Liquid Limit[1], %	Plastic Limit[1], %	Plasticity Index, %	Minus No. 40 Sieve USCS
SCG	31	13	18	CL
LST	NP[2]	NP[2]	NP[2]	SM
SST	NP[2]	NP[2]	NP[2]	SM
IGN	NP[2]	NP[2]	NP[2]	SM
SSB	28	14	14	CL

[1] ASTM D 4318.
[2] NP = non-plastic.

Table 14 shows specific gravity and absorption values for the aggregates. The LST and IGN coarse aggregates have the lowest absorption potential, as one might expect. Table 15 provides durability information. The SCG and LST aggregates showed the lowest losses in Los Angeles abrasion. The SST aggregates showed the highest loss. In the magnesium sulfate soundness test, the SST and SSB aggregates had substantially higher losses than the other three aggregates.

Table 14
Specific Gravities and Absorptions

Abbreviated Common Name	Coarse Fraction[1] BSG[2] (OD basis)	Coarse Fraction[2] BSG (SSD basis)	Coarse Fraction % Absorption	Fine Fraction SG[2]
SCG	2.48 – 2.51	2.53 - 2.56	2.0 – 2.1	2.69
LST	2.50 – 2.67	2.57 – 2.68	0.2 – 0.3	No data[3]
SST	2.50 – 2.54	2.55 – 2.58	1.6 – 1.8	No data[3]
IGN	2.59 – 2.60	2.61 – 2.62	0.5 – 0.8	2.66
SSB	2.27 – 2.48	2.36 – 2.54	2.2 – 3.9	2.72

[1] Coarse fraction is retained on the No. 4 sieve; Fine fraction passes the No. 4 sieve.
[2] BSG = bulk specific gravity, SG = specific gravity.
[3] Assumed value = 2.65 for zero air void calculations.

Table 15
Abrasion Resistance and Durability

Abbreviated Common Name	Los Angeles Abrasion[1] (% loss)	Sulfate Soundness[2] (% loss)
SCG	18.2	1.0
LST	18.8	0.3
SST	33.5	4.2
IGN	27.3	0.4
SSB	27.8	6.4

[1] ASTM C 131, grading B.
[2] ASTM C 88, magnesium sulfate, coarse fraction.

Particle shape characteristics for the aggregates are shown in Tables 16 and 17, coarse and fine fractions, respectively. While the SSB aggregate had the highest proportion of flat and/or elongated coarse aggregates, the SCG aggregate had the lowest proportion. While the LST and IGN aggregates had the highest proportions of flat and/or elongated fine particles, the SST aggregate had the lowest proportion.

Table 16
Flat and/or Elongated Coarse Particles

Abbreviated Common Name	2:1 Ratio	3:1 Ratio
SCG	27.9	4.2
LST	42.3	5.8
SST	42.4	5.5
IGN	42.2	5.8
SSB	46.3	10.8

ASTM D 4791, weighted average for the following particle sizes: 1-1/2 in., 1 in., 3/4 in., 1/2 in., and 3/8 in.

Table 17
Flat and/or Elongated Fine Particles (3:1 Ratio)

Abbreviated Common Name	No. 10 Sieve	No. 40 Sieve	No. 200 Sieve	Weighted Average
SCG	13.3	13.6	13.8	13.7
LST	26.9	25.8	13.9	23.0
SST	17.7	11.5	2.8	6.1
IGN	19.4	23.2	20.6	21.8
SSB	32.5	9.4	15.4	14.3

CRD-C 120.

Table 18 shows some additional characteristics for the fine fraction of the aggregates. These characteristics are less well-known than those presented previously. The uncompacted voids percentage provides a simple measure of roundness and smoothness for the fines. Method A involves a "standard" grading, which includes the following size fractions and mass percentages for a 0.40 lb sample: No. 8 to No. 16 (23.2 percent), No. 16 to No. 30 (30.0 percent), No. 30 to No. 50 (37.9 percent), and No. 50 to No. 100 (8.9 percent). The 0.40 lb g blend of particles free-falls into a cylinder of known volume. Knowing the bulk specific gravity of the particles, the volume of voids in the cylinder can be calculated. The more rounded and smooth the particles, the tighter they are expected to compact after free-fall, thus finishing with smaller percentages of "uncompacted voids." This test is used by asphalt technologists for the purpose of ensuring that the fine particles in asphalt mixtures are sufficiently angular and rough in texture, thus ensuring mixture stability. A popular asphalt mixture design method called Superpave Level 1 (Asphalt Institute 1995) specifies minimum uncompacted void percentages of 40 or 45, depending on both the depth of asphalt from the pavement surface and the level of anticipated traffic. Based on the results in Table 11, the SCG seems to have the most smooth and rounded particles. The SCG fines would not pass either of the Superpave aggregate requirements.

Table 18
Additional Characteristics for the Fine Fraction

Abbreviated Common Name	Uncompacted Voids[1] (%)	Sand Equivalent[2] (%)	Linear Shrinkage[3] (%)
SCG	36.5	20	6.1
LST	44.8	73	1.1
SST	45.6	23	0.2
IGN	46.5	61	0.5
SSB	42.5	10	6.4

[1] AASHTO T 304, Method A. Although there is a similar ASTM test, the AASHTO test is preferred because it requires washing of the particles.
[2] AASHTO T 176.
[3] BS 1377, Part 2 (BSI 1990).

The sand equivalent (SE) test is a rapid method for indicating the relative proportion of plastic fines and dust to sand size particles. This AASHTO test (T 176) is performed on the minus No. 4 sieve material. An 85-ml tin of fine particles is added to a graduated cylinder that contains a small quantity of flocculating solution. The cylinder is then agitated by standard means for the purpose of removing fines from the surfaces of sand-size particles. After adding additional solution in a manner that tends to force the plastic fines into suspension, the graduated cylinder is allowed to stand for 20 min. After this sedimentation period, the top of the clay suspension is noted as the "clay reading." Then a weighted foot is lowered into the graduated cylinder for the purpose of obtaining a "sand reading." The SE value is defined as the ratio of the height of sand to the height of plastic fines, reported as a percentage (Barksdale 1991). Therefore, higher values indicate higher proportions of sand. A typical minimum sand equivalency for aggregate used in hot mix asphalt concrete varies from 45 to 50 (Barksdale 1991). While the LST and IGN aggregates in this study had the highest SE values (see Table 18), the SSB aggregate had the lowest SE value. Among the aggregates in this study, only the LST and IGN would meet typical hot mix asphalt requirements as presented by Barksdale (1991).

The linear shrinkage test is part of a British standard, BS 1377, Part 2 (BSI 1990). This test is used by road authorities in South Africa as part of their specification for unbonded road surface aggregates (see Chapter 2 for details). The linear shrinkage test is conducted on the portion of aggregates that pass the No. 40 sieve. The fines are conditioned to a moisture state near their liquid limit and are pressed into a trough-shaped mold (see Figure 27) while ensuring to remove all air possible. The soil is leveled with the top of the mold and then the apparatus filled with soil is dried at progressively hotter temperatures to a maximum of 105 to 110 ºC. The dried soil will slide out of the mold easily as long as the mold is previously coated with a thin film of silicone grease or petroleum jelly. The dried length of the specimen is measured with calipers and the linear shrinkage is calculated as a percent change in length. The more "plastic" a soil, the more it will shrink. The South African road authority uses this test to ensure that the plasticity of fines in unbonded road surface aggregates is sufficient, yet not excessive. Although the use of this British standard in the United States is not common, some state departments of transportation (DOTs) include similar linear bar shrinkage tests in their specifications (e.g., Tex-107-E for the Texas DOT, SD 303 for the South Dakota DOT, and CA Test 228 for the California DOT). The bars in these state DOT tests are typically shaped as rectangular prisms, similar to the British standard.

The full aggregate blends were tested for compaction characteristics and strength (see Tables 19 and 20). The minimum and maximum unit weights (ASTM D 4254 and D 4253, respectively) were conducted with the aggregates in oven-dry condition. Unit weights were calculated after filling a 0.5-ft^3 cylindrical mold. Minimum unit weight was obtained by filling the mold with aggregate in as loose a condition as possible. This was accomplished by gently lowering the aggregate into the mold with a large scoop, then trimming the aggregate to level with the top of the mold using a straightedge. Maximum unit weight was determined in the same size mold. The aggregate was vibrated into the mold with a 100-lb cylindrical surcharge weight. The vibrating table was calibrated to a double amplitude of vertical vibration of 0.013 in. at 60 Hz. The aggregates with the high fines (minus No. 200 sieve) contents (SCG and SSB) were found to have the lowest loose unit weights (Table 19). However, these two aggregates gained the highest percentages of density during vibration. The LST and IGN aggregates gained the smallest percentages of density during vibration. The SST aggregate was found to have the highest unit weight among all the aggregates in both minimum and maximum unit weight conditions.

Table 19
Dry Compaction Characteristics

Abbreviated Common Name	Minimum Unit Weight[1], lb/ft^3 (kg/m^3)	Maximum Unit Weight[2], lb/ft^3 (kg/m^3)	Percent Change, Min. to Max. Unit Weight
SCG	88.1 (1410)	103.9 (1665)	17.9
LST	103.1 (1650)	113.6 (1820)	10.2
SST	106.6 (1710)	122.1 (1955)	14.5
IGN	105.4 (1690)	119.0 (1905)	12.9
SSB	87.2 (1395)	102.7 (1645)	17.8

[1] ASTM D 4254, oven-dry
[2] ASTM D 4253, oven-dry

Standard Proctor tests were conducted on the aggregates using 6-in.-diameter molds (Method C). All aggregates appeared to behave similarly in terms of their moisture-density curves. Optimum moisture contents ranged from 6.5 to 8.0 percent (see Table 20 and Figures 28, 30, 32, 34, and 36). Maximum dry unit weights ranged from 127.5 to 133 pcf. The reported moisture contents for the IGN aggregate are not accurate, however, because of its free-draining characteristics. As-molded CBR values when samples are compacted near optimum moisture content are shown in Table 20. These values were obtained by interpolation from Figures 29, 31, 33, 35, and 37. The SCG and SSB aggregates offered the lowest as-molded CBR values when compacted near optimum. The LST and IGN aggregates were the only aggregates that offered high as-molded CBR values when compacted wet of optimum. This is likely attributable to their relatively high permeabilities. For soaked CBR tests, the aggregates were again compacted near their optimum moisture contents and they were allowed to soak for 4 days. Under these conditions, the CBR values for SCG and SSB fell to about 15 percent. The other three aggregates (LST, SST, and IGN) all retained CBR values higher than 45 percent.

Conformance of Materials to USACE Specifications

The gradations of as-received aggregates are compared to the most appropriate grading option in both the Unified Facilities Guide Specification UFGS-02731 (UFGS 2004) and the specification developed by the Vicksburg District. Recall from Chapter 1 that the UFGS includes four grading options that are numbered 1 through 4. Fineness increases with increasing number. Recall from Chapter 1 that the MVK specification includes three grading options titled “Sand Clay Gravel,” “Crushed Stone,” and “Crushed Stone with Binder.”

Table 20
Properties of Compacted Aggregates

Abbreviated Common Name	Optimum Moisture Content[1], %	Maximum Dry Unit Weight[1], lb/ft^3 (kg/m^3)	As-Molded CBR[2], %	Soaked CBR[2], %
SCG	7.5	132.5 (2120)	30	16.3
LST	6.5	127.5 (2040)	77	48.9
SST	7.5	133.0 (2130)	82	62.1
IGN	8.0[3]	130.0 (2080)	165	169
SSB	8.0	130.5 (2090)	25	15.3

[1] Standard compaction (ASTM D 698, Method C).
[2] Compacted near optimum moisture content.
[3] Not accurate due to free-draining condition.

The grading of SCG conformed to UFGS No. 2, but it was finer than allowed by MVK (see Figure 38). The grading of LST conformed to UFGS No. 1, but it was slightly coarser than allowed by MVK (see Figure 39). This is labeled as marginal conformance in the summary table, Table 21. The grading of SST was slightly too coarse for UFGS No. 1, but it conformed to the MVK requirements (see Figure 40). The SST will be considered to have marginal conformance to UFGS No. 1. The grading of IGN was too coarse for UFGS No. 1, but it was only slightly too coarse for MVK (See Figure 41). The IGN will be considered to have marginal conformance to the MVK specification. The SSB was gap-graded in nature: it included relatively large proportions of both coarse particles (> No. 4 sieve) and fine particles (< No. 40 sieve). As such, it did not meet the requirements of either UFGS or MVK (see Figure 42).

All aggregates met the LA abrasion requirements for both UFGS and MVK. All aggregates met the flat and/or elongated requirements for UFGS. All aggregates met the liquid limit requirement of ≤35 percent for UFGS. For the MVK specification, which includes a liquid limit requirement of ≤30 percent, the SCG conformed marginally (LL = 31). The UFGS requires plastic index (PI) to be in the range of 4 to 9 percent. None of the aggregates met this requirement: The PIs for SCG and SSB were too high and the PIs for LST, SST, and IGN were nonexistent (= 0). The UFGS was developed for sand clay gravel materials, so the PI requirement does not truly apply to the granular crushed materials, which included LST, SST, and IGN. The MVK requirements for PI are dependent on whether the aggregate is sand clay gravel, crushed stone, or crushed stone with binder. Crushed stone has no requirement for PI, so LST, SST, and IGN all conformed. Sand clay gravel and crushed stone with binder are required to have PIs in the range of 5 to 15 and 4 to 9, respectively. Each of these aggregates met its respective requirement only marginally (PIs were slightly higher than specified). All aggregate conformances to specifications are summarized in Table 21.

Table 21
Summary of Conformance for As-Received Aggregates to USACE Specifications

Specification Requirement	SCG	LST	SST	IGN	SSB
(UFGS 2004)					
Grading	Y[1]	Y	M	N	N
LA Abrasion	Y	Y	Y	Y	Y
Flat and/or Elongated	Y	Y	Y	Y	Y
Liquid Limit	Y	Y	Y	Y	Y
Plasticity Index	N	N	N	N	N
(MVK 2004)					
Grading	N	M	Y	M	N
LA Abrasion	Y	Y	Y	Y	Y
Liquid Limit	M	Y	Y	Y	Y
Plasticity Index	M	Y	Y	Y	M

[1] Y = conformance, M = marginal conformance, N = non-conformance

Conformance of Materials to Federal Highway Administration and U.S. Forest Service Specifications

The Federal Highway Administration (FHWA) and the U.S. Forest Service both require the use of crushed material, so the sand clay gravel would not meet their requirements. All the crushed aggregates (LST, SST, IGN, and SSB) meet the LA abrasion and sulfate soundness requirements for both agencies. All crushed aggregates meet the liquid limit requirements for both agencies, but none of the crushed aggregates met plasticity index requirements. While the LST, SST, and IGN aggregates were not sufficiently plastic, the plasticity index of the SSB aggregate was too high. While the LST and SST aggregates met requirements for fine particles (percent passing the No. 200 sieve), the IGN aggregate had insufficient fines and the SSB aggregate had excessive fines.

Relative to both FHWA and USFS grading requirements, the SCG had insufficient particles in the range of No. 10 sieve to No. 40 sieve, thus the SCG was gap-graded with percent finer too high in that same range of particle sizes (see Figures 43 and 44). The LST was close to meeting requirements for both agencies. Relative to FHWA, the LST had slightly too many particles larger than 3/4 in. Relative to both FHWA and the USFS, the LST was slightly insufficient in particles smaller than the No. 200 sieve (see Figures 45 and 46). Relative to the requirements of both agencies, the SST had too many particles larger than the No. 4 sieve. The SST was also insufficient in particles smaller than No. 200 sieve (see Figures 47 and 48). The IGN aggregate was entirely too coarse for the requirements of either the FHWA or the USFS (see Figures 49 and 50). Relative to the FHWA requirements, the SSB aggregate had too many particles larger than 3/4 in. Relative to both FHWA and the USFS, the SSB was excessive in particles smaller than the No. 40 sieve (see Figures 51 and 52).

Conformance of Materials to South African Specifications

All aggregates were compared to the South African requirements in Figure 53. The grading coefficient (Gc) parameter accounts for overall aggregate coarseness and for the shape of the particle size distribution. The shrinkage product (Sp) parameter accounts for aggregate fineness (percent passing No. 40 sieve) and plasticity (i.e., linear shrinkage). Both the SCG and SSB aggregates meet the requirements as defined by Gc and Sp. In addition, both of these aggregates meet the South African maximum size requirement (percent passing 1-1/2 in.) and the strength requirement: CBR is 15 percent or greater when the aggregate is compacted to at least 95 percent of the maximum density found in accordance with ASTM D 1557. Even with only standard compaction (ASTM D 698) near optimum moisture, the SCG and SSB provided CBRs of 30 and 25 percent, respectively. The LST, SST, and IGN aggregates all failed the South African requirements primarily because they offered little plasticity; thus, their linear shrinkage values were very low (less than or equal to 1.1 percent).

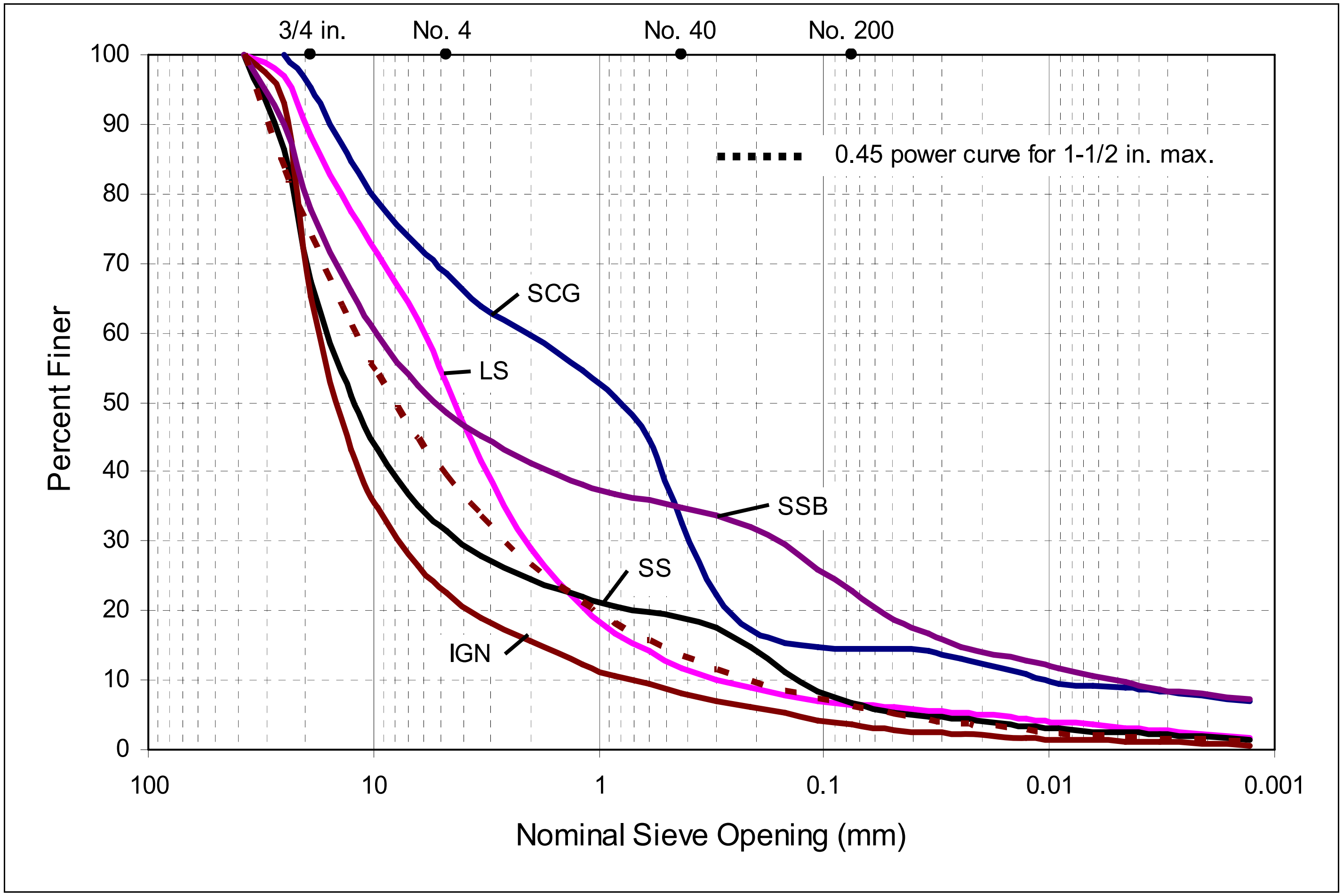

Figure 26. Particle size distributions for as-delivered materials

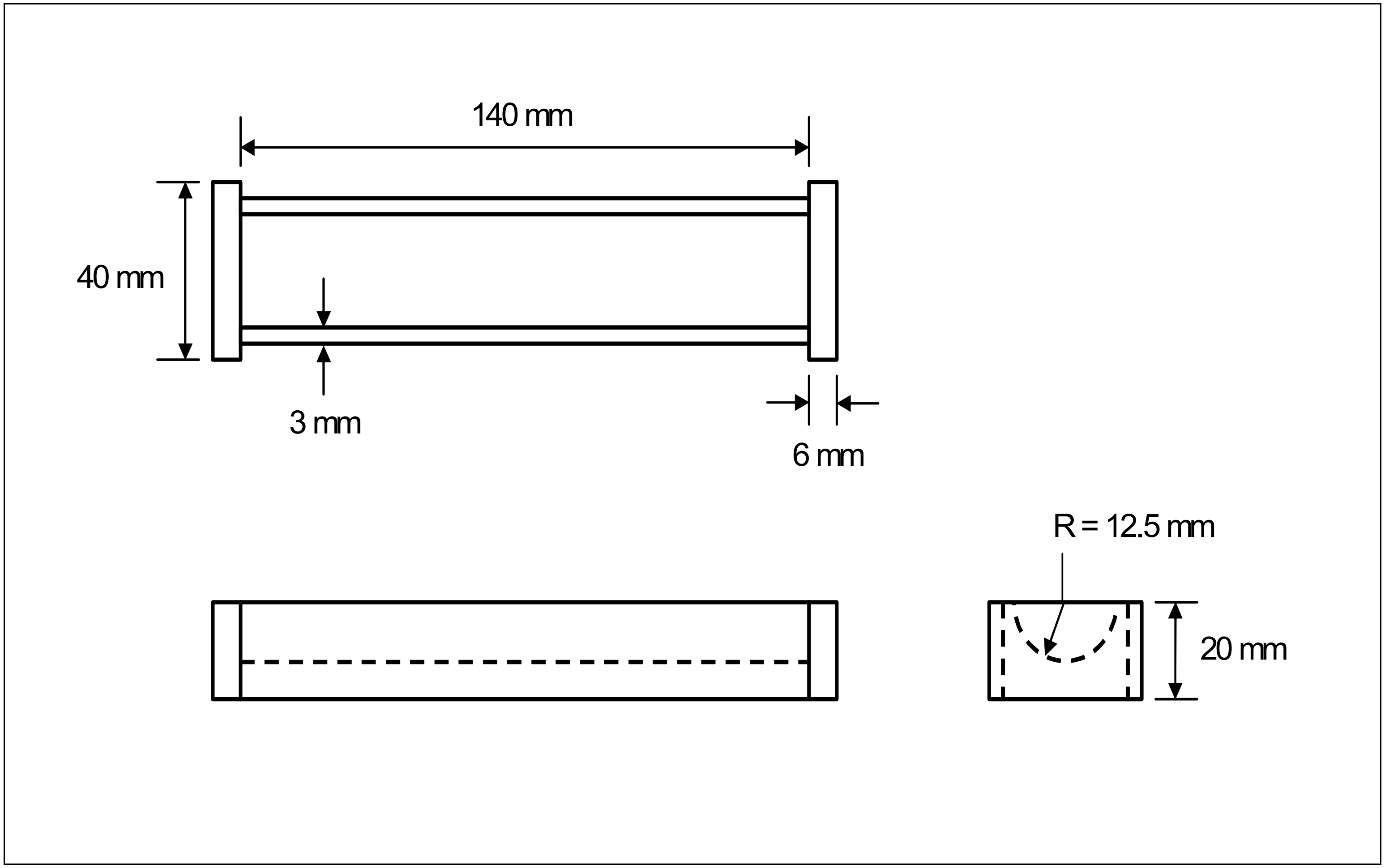

Figure 27. Linear shrinkage apparatus (after BS 1377, Part 2)

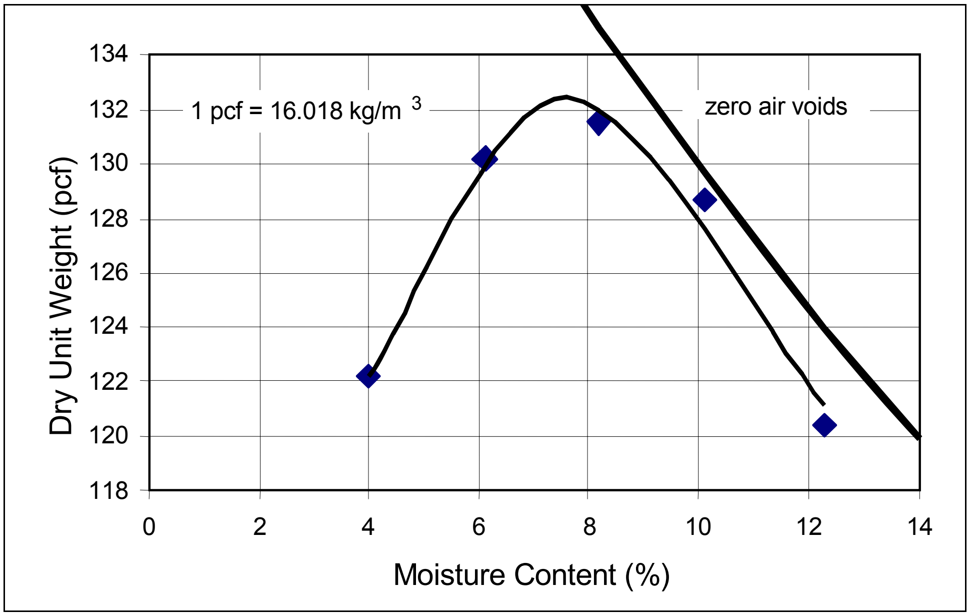

Figure 28. Standard proctor curve for the SCG material

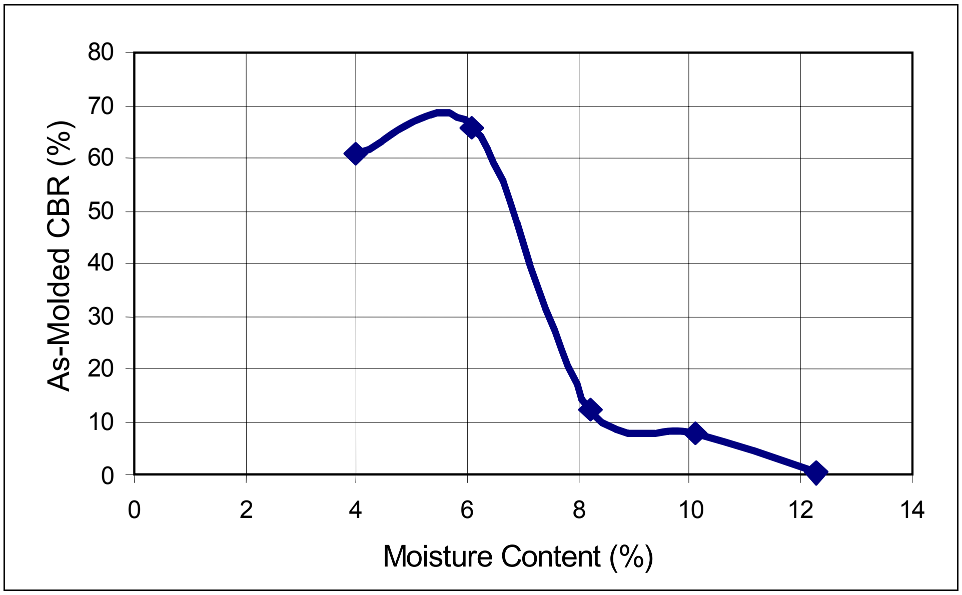

Figure 29. As-molded CBR values for the SCG material

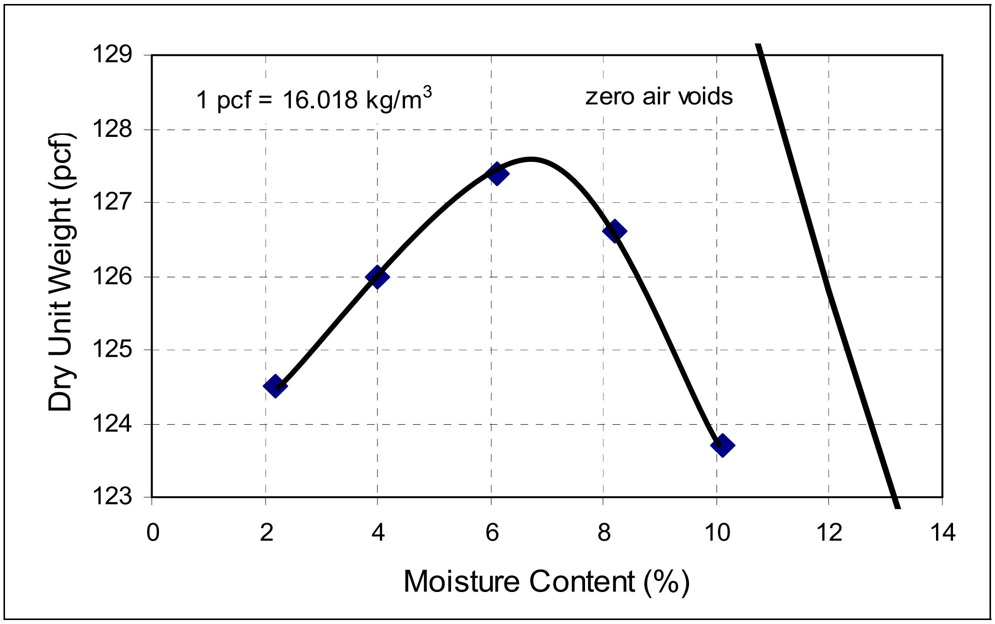

Figure 30. Standard proctor curve for the LST material

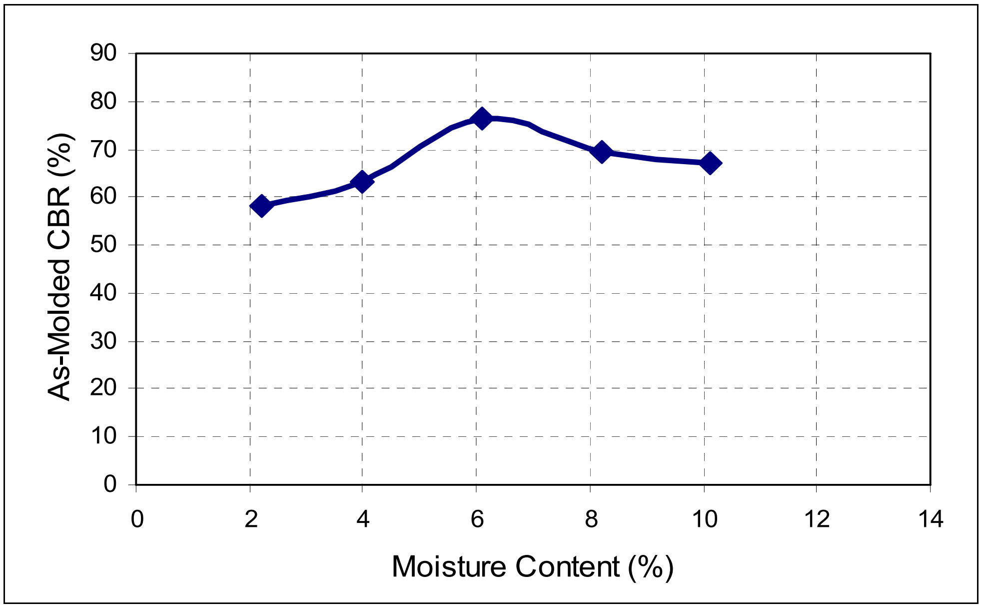

Figure 31. As-molded CBR values for the LST material

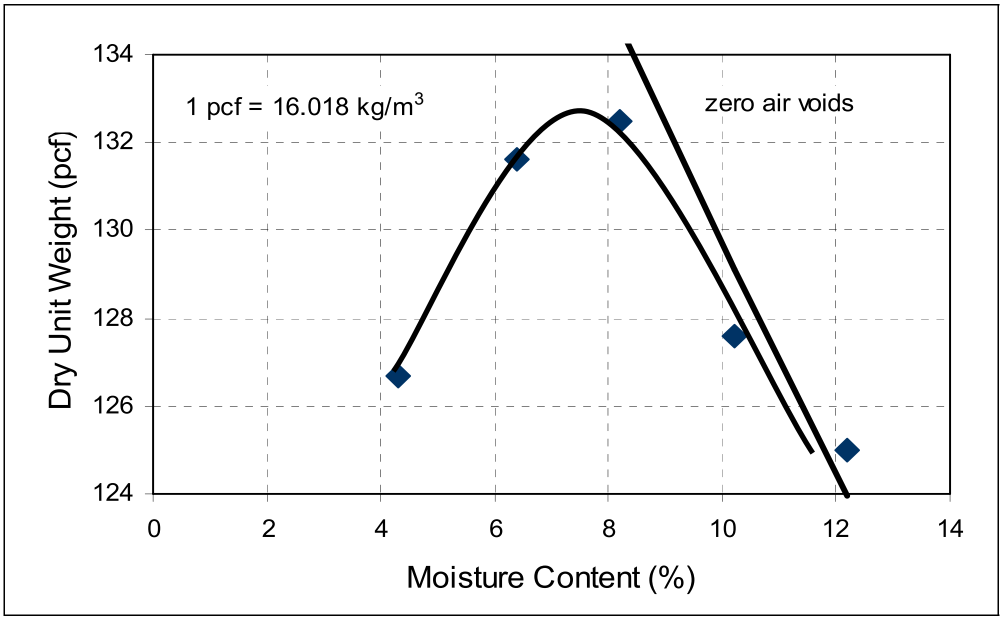

Figure 32. Standard proctor curve for the SST material

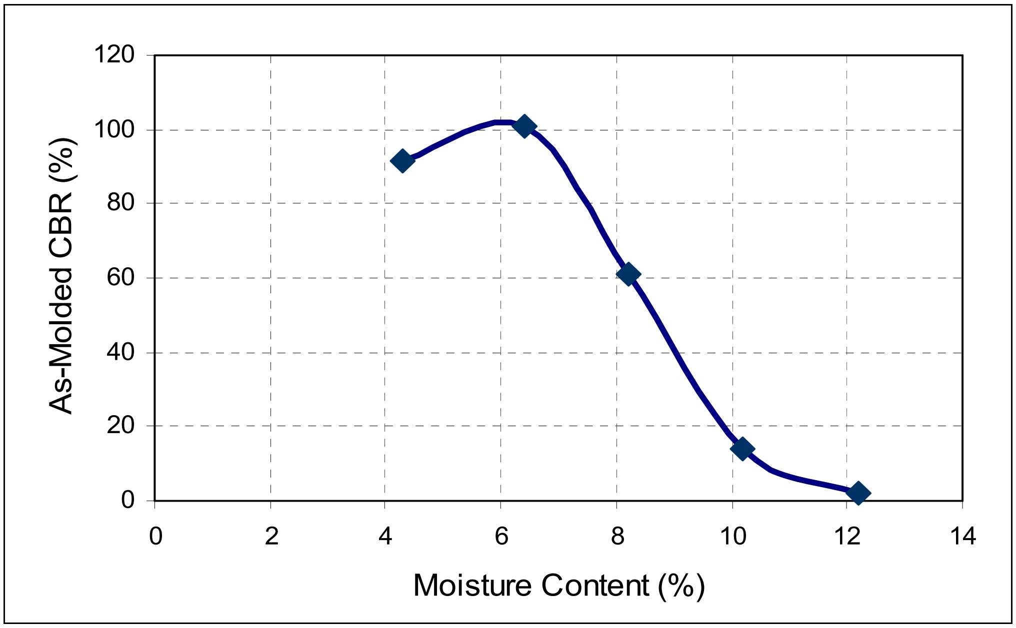

Figure 33. As-molded CBR values for the SST material

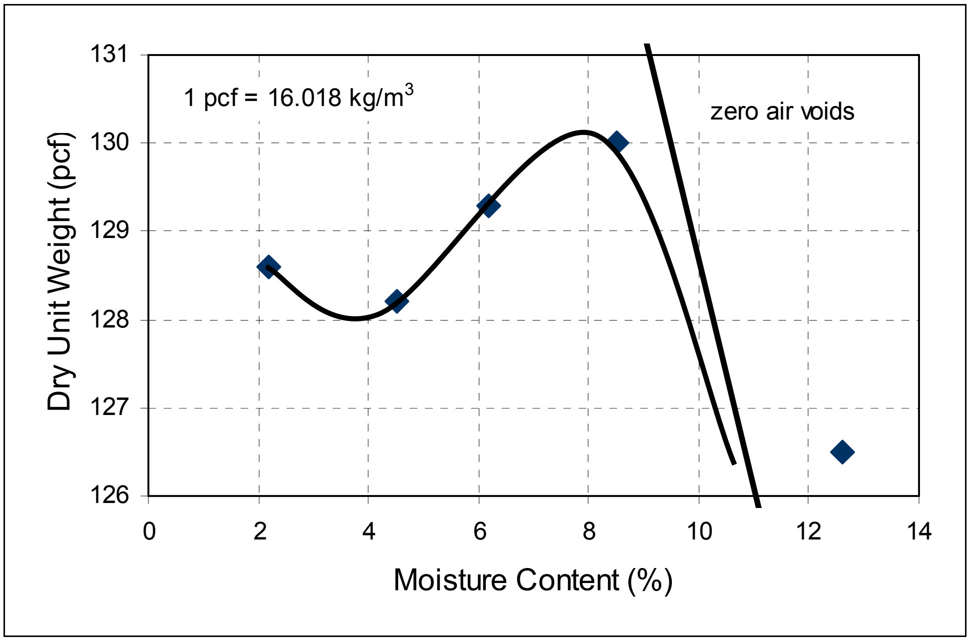

Figure 34. Standard proctor curve for the IGN material

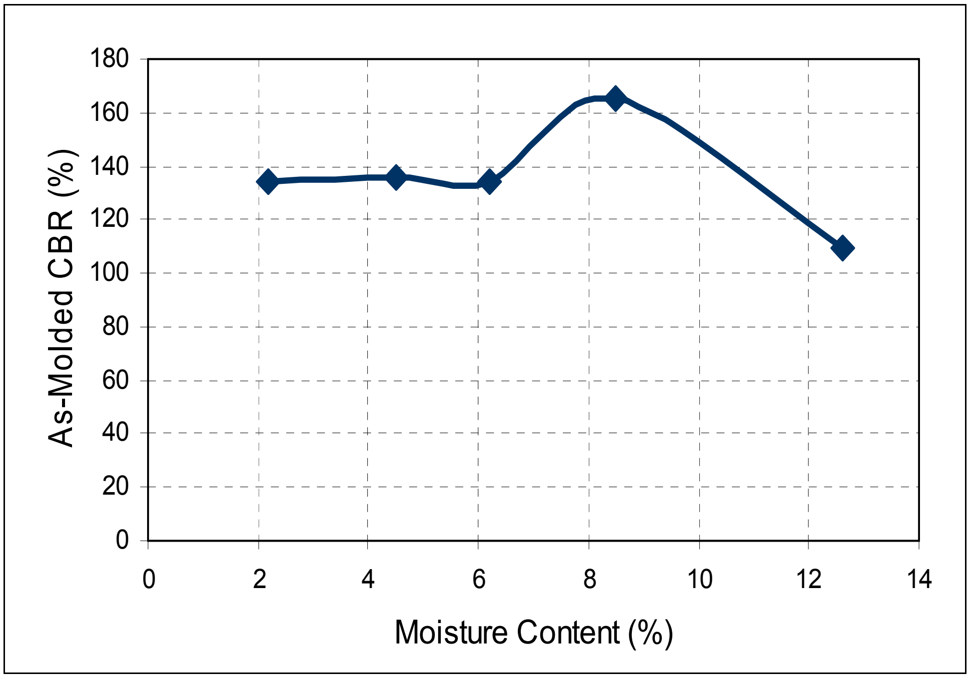

Figure 35. As-molded CBR values for the IGN material

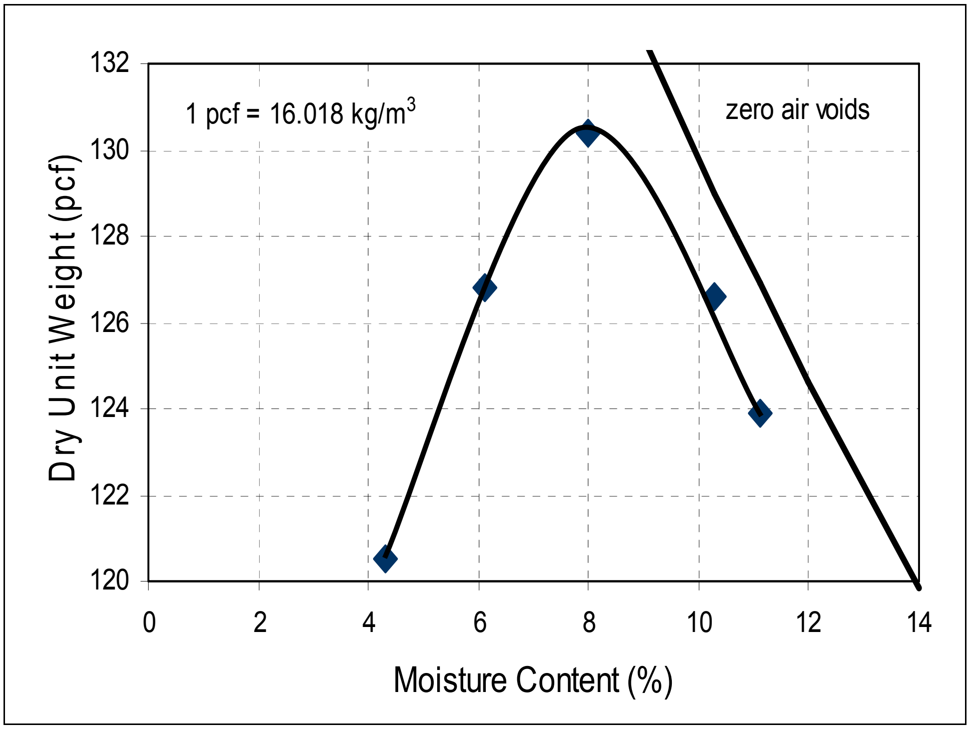

Figure 36. Standard proctor curve for the SSB material

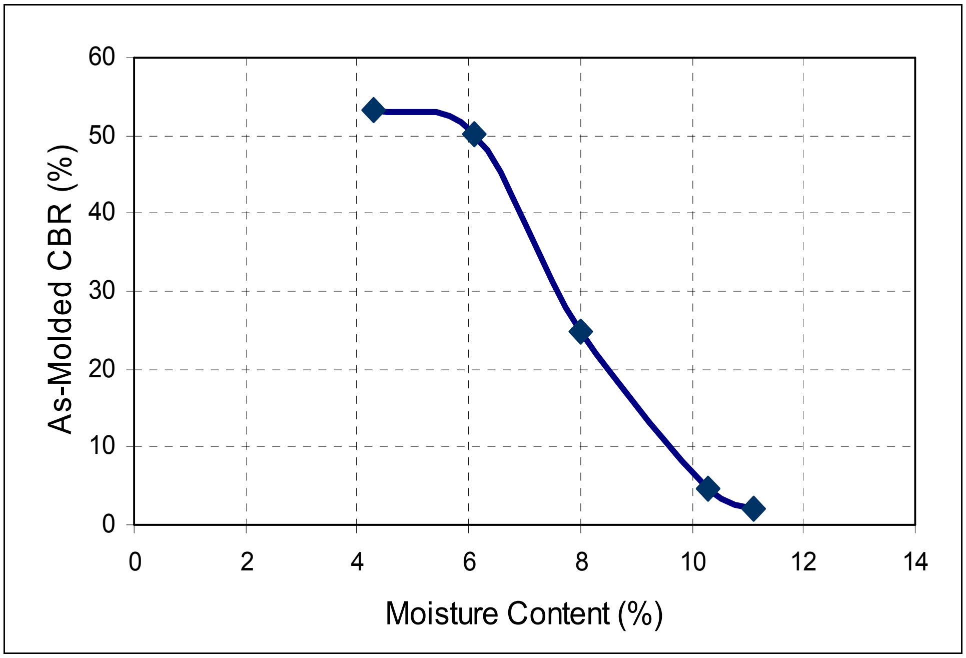

Figure 37. As-molded CBR values for the SSB material

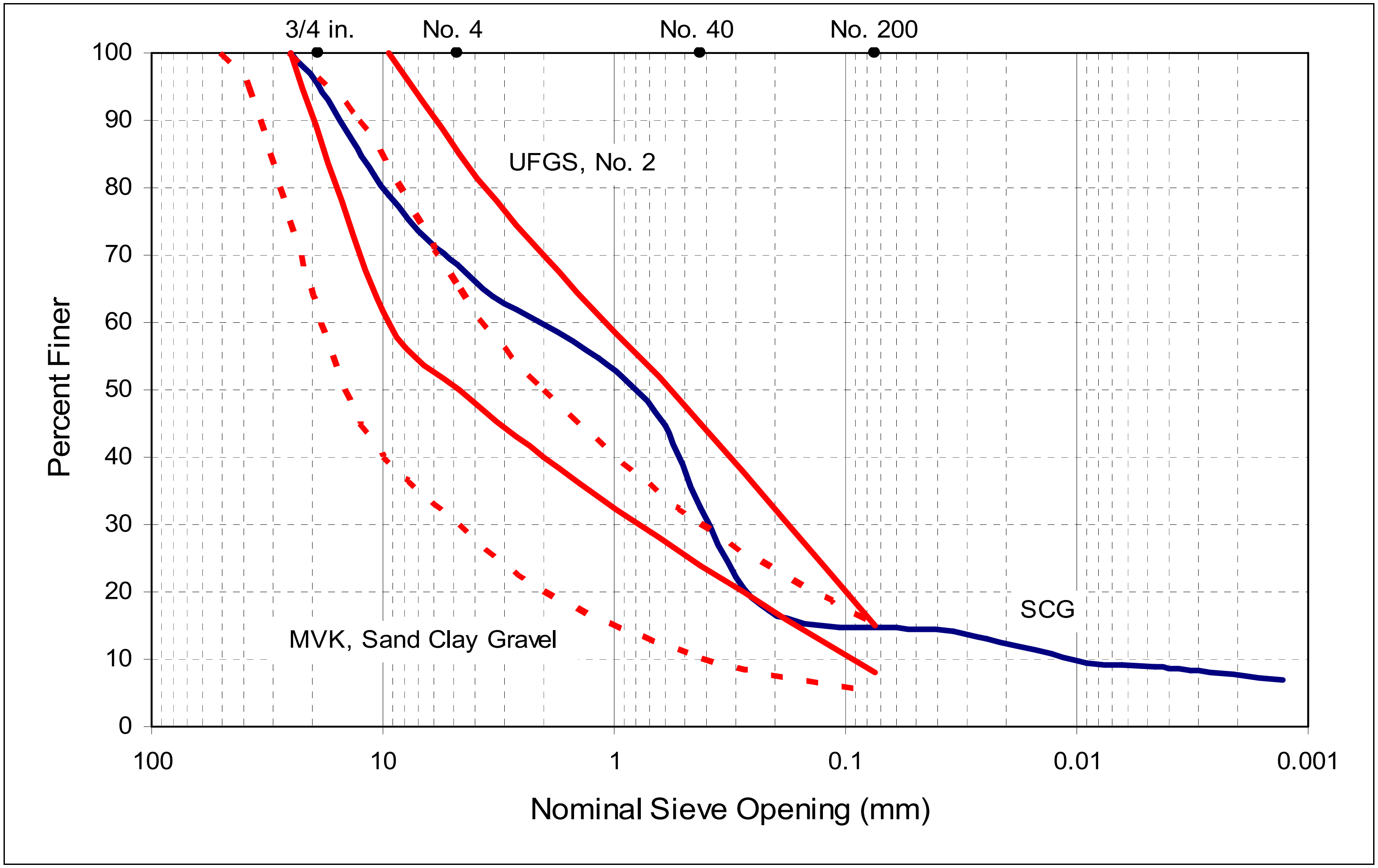

Figure 38. Comparison of as-received SCG grading to USACE specifications

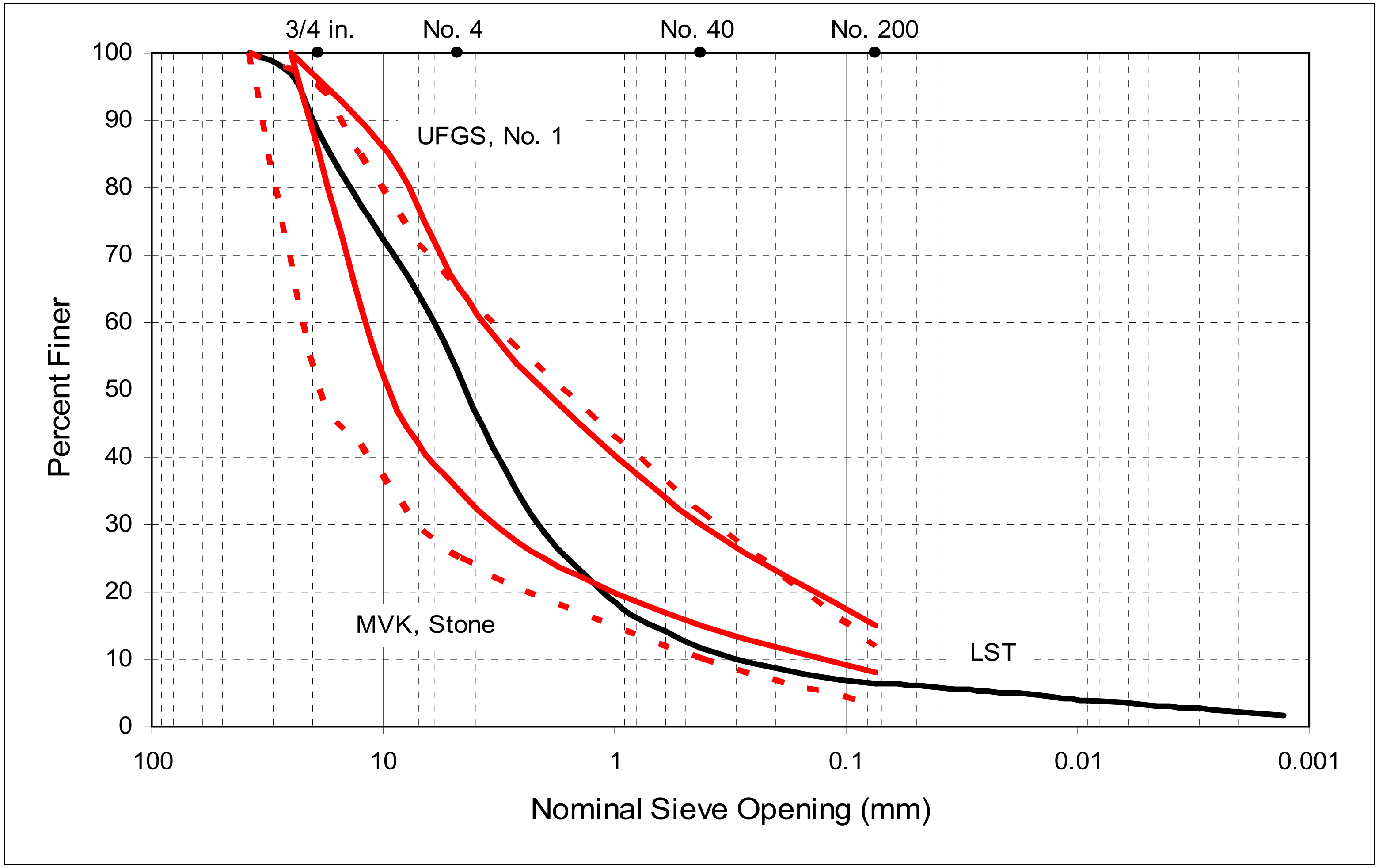

Figure 39. Comparison of as-received LST grading to USACE specifications

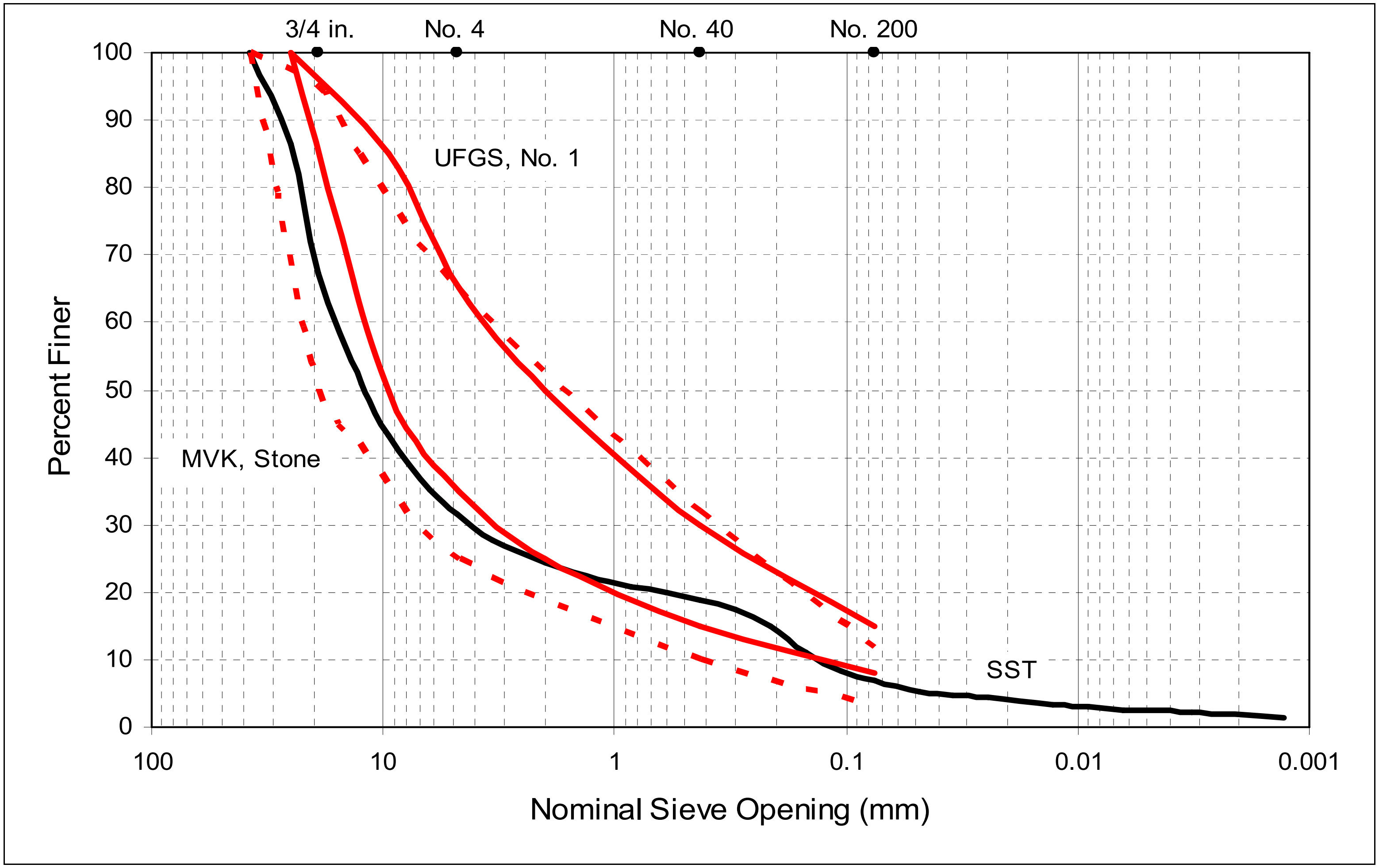

Figure 40. Comparison of as-received SST grading to USACE specifications

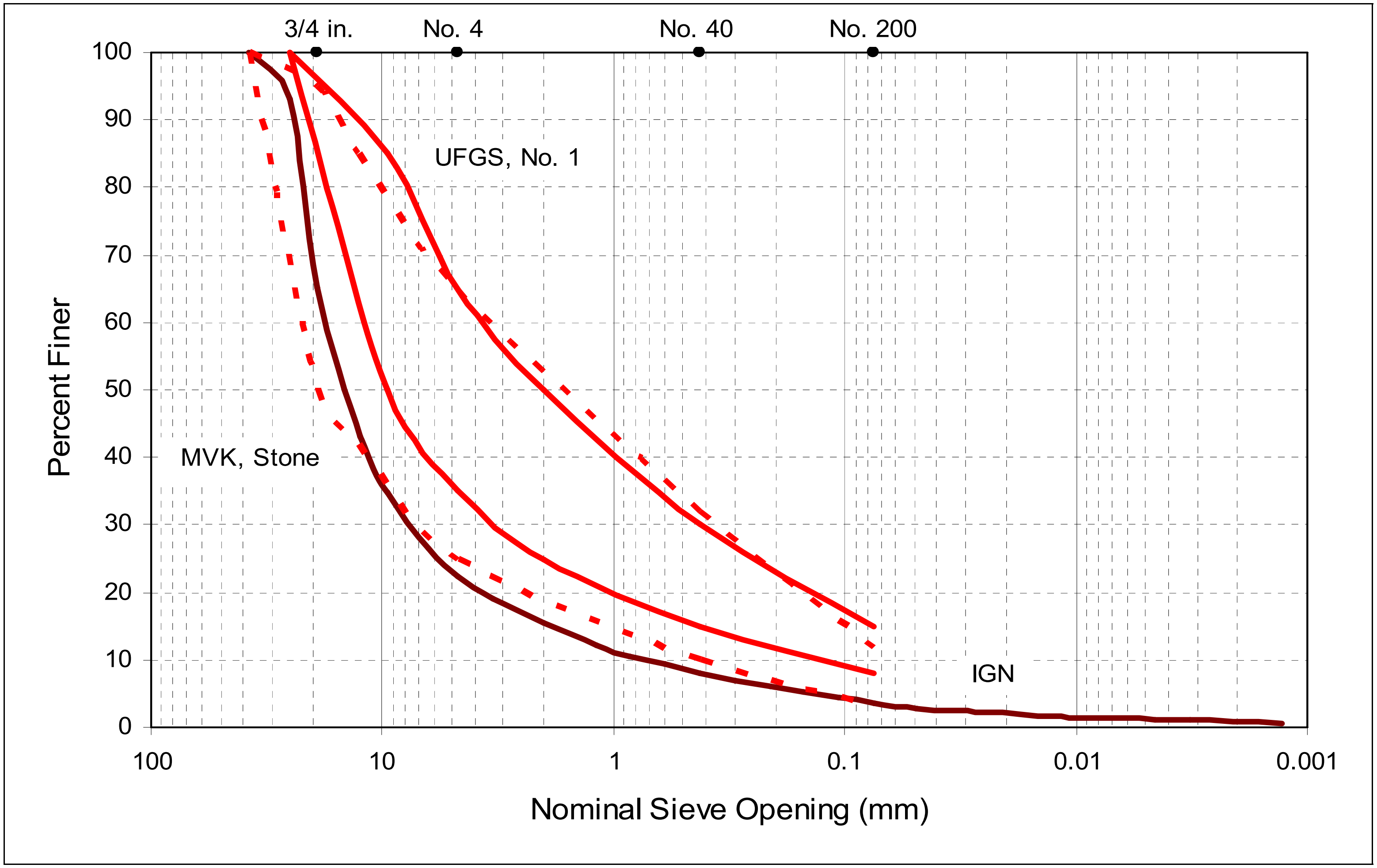

Figure 41. Comparison of as-received IGN grading to USACE specifications

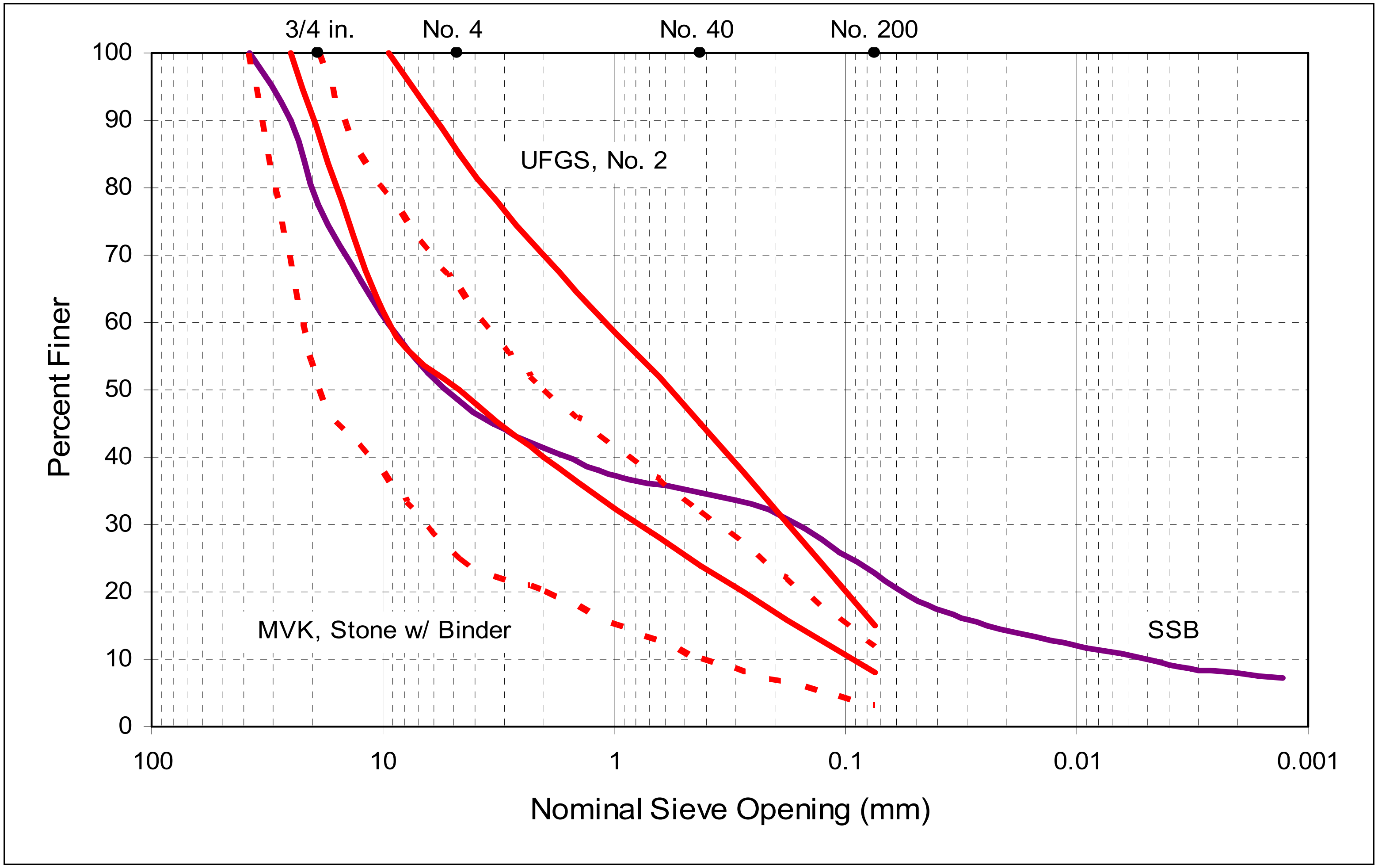

Figure 42. Comparison of as-received SSB grading to USACE specifications

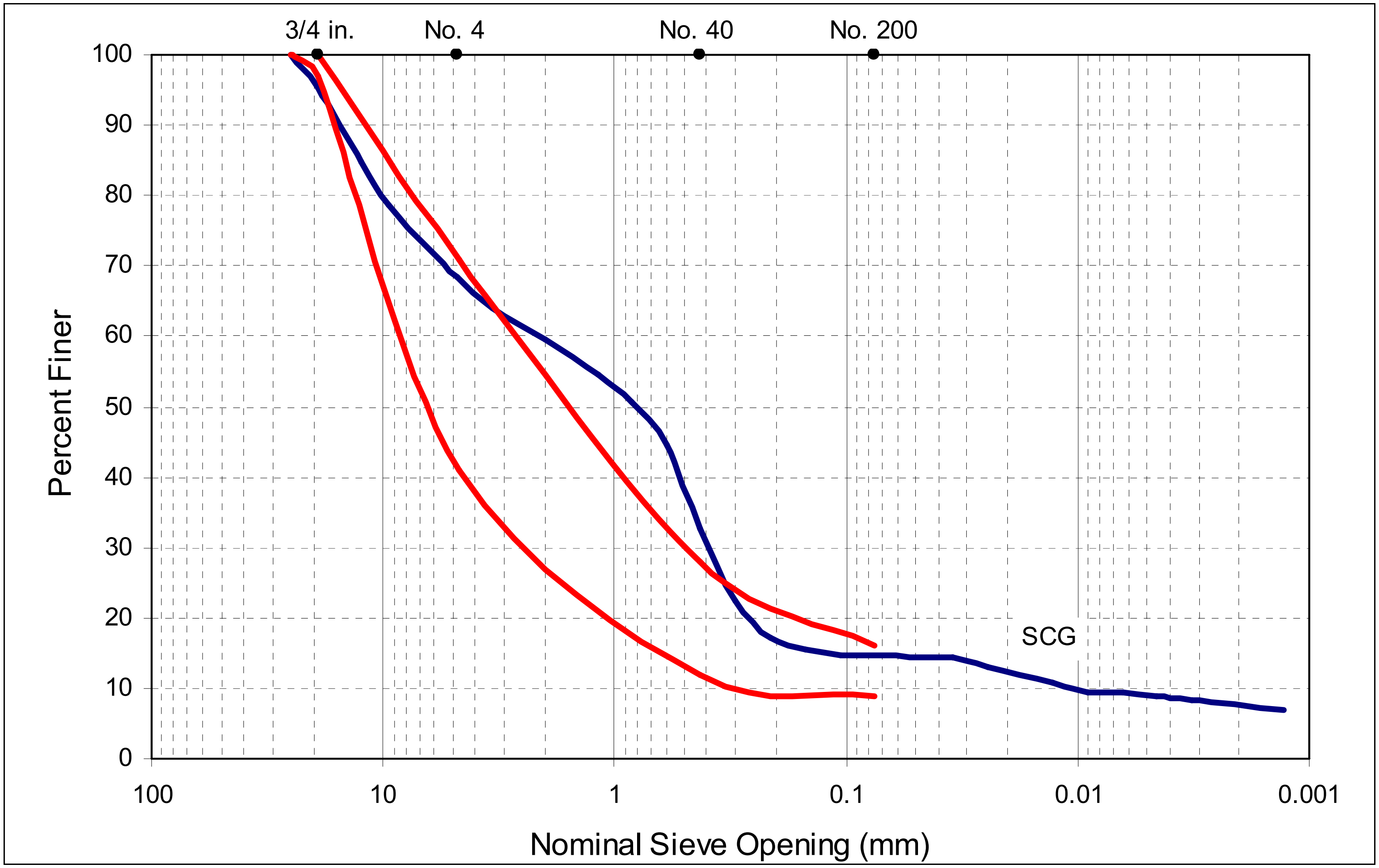

Figure 43. Comparison of as-received SCG grading to FHWA specifications

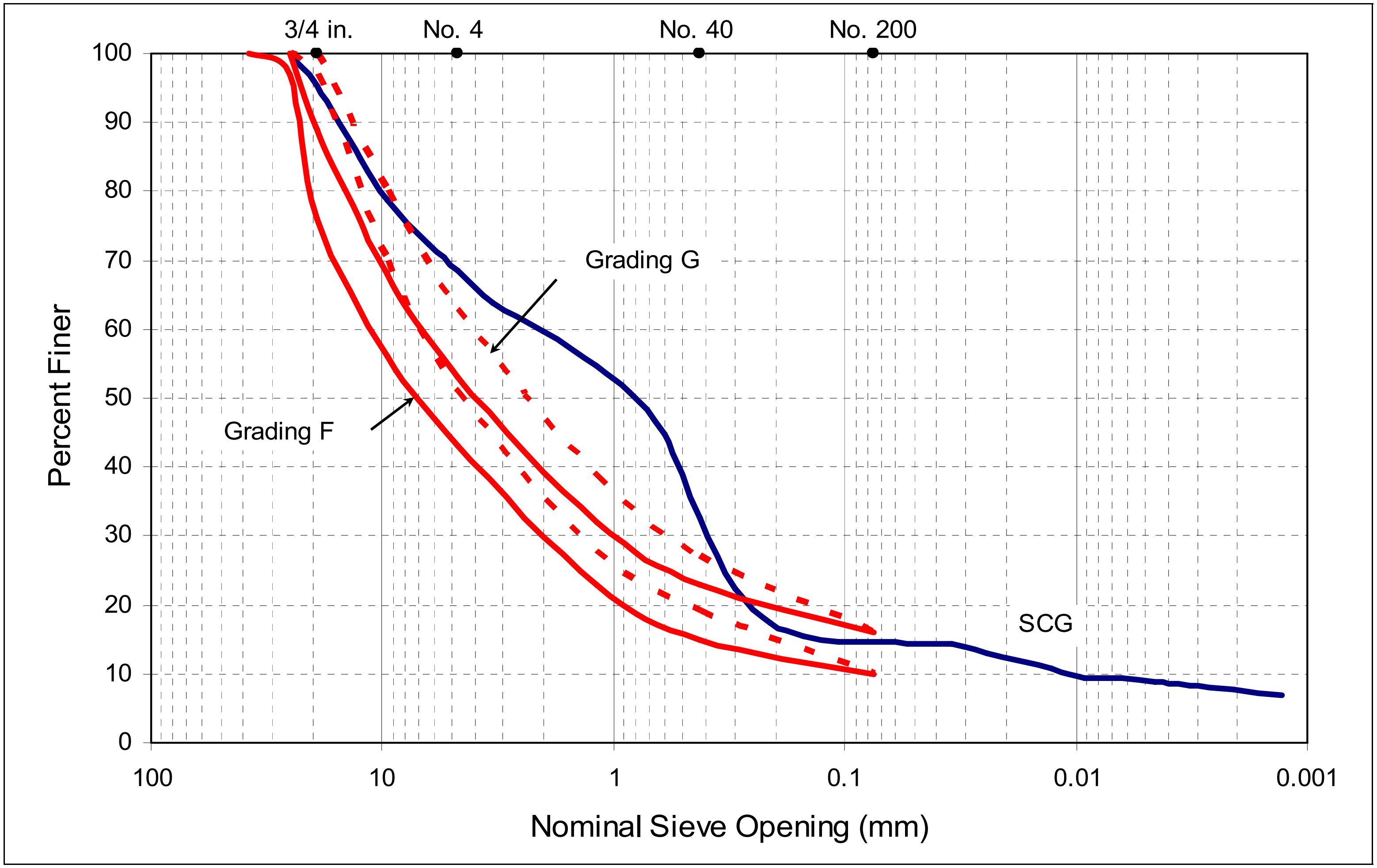

Figure 44. Comparison of as-received SCG grading to USFS specifications

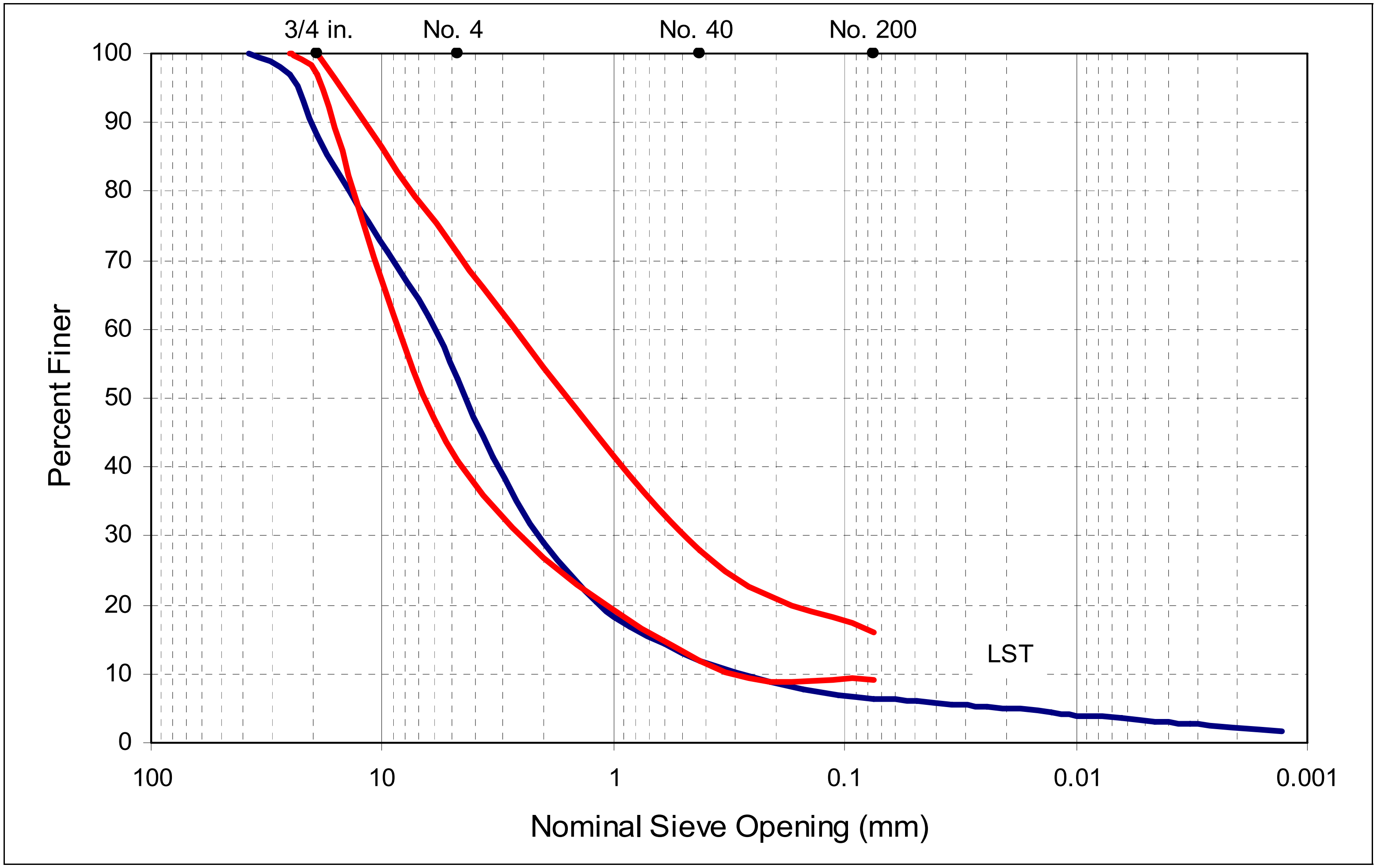

Figure 45. Comparison of as-received LST grading to FHWA specifications

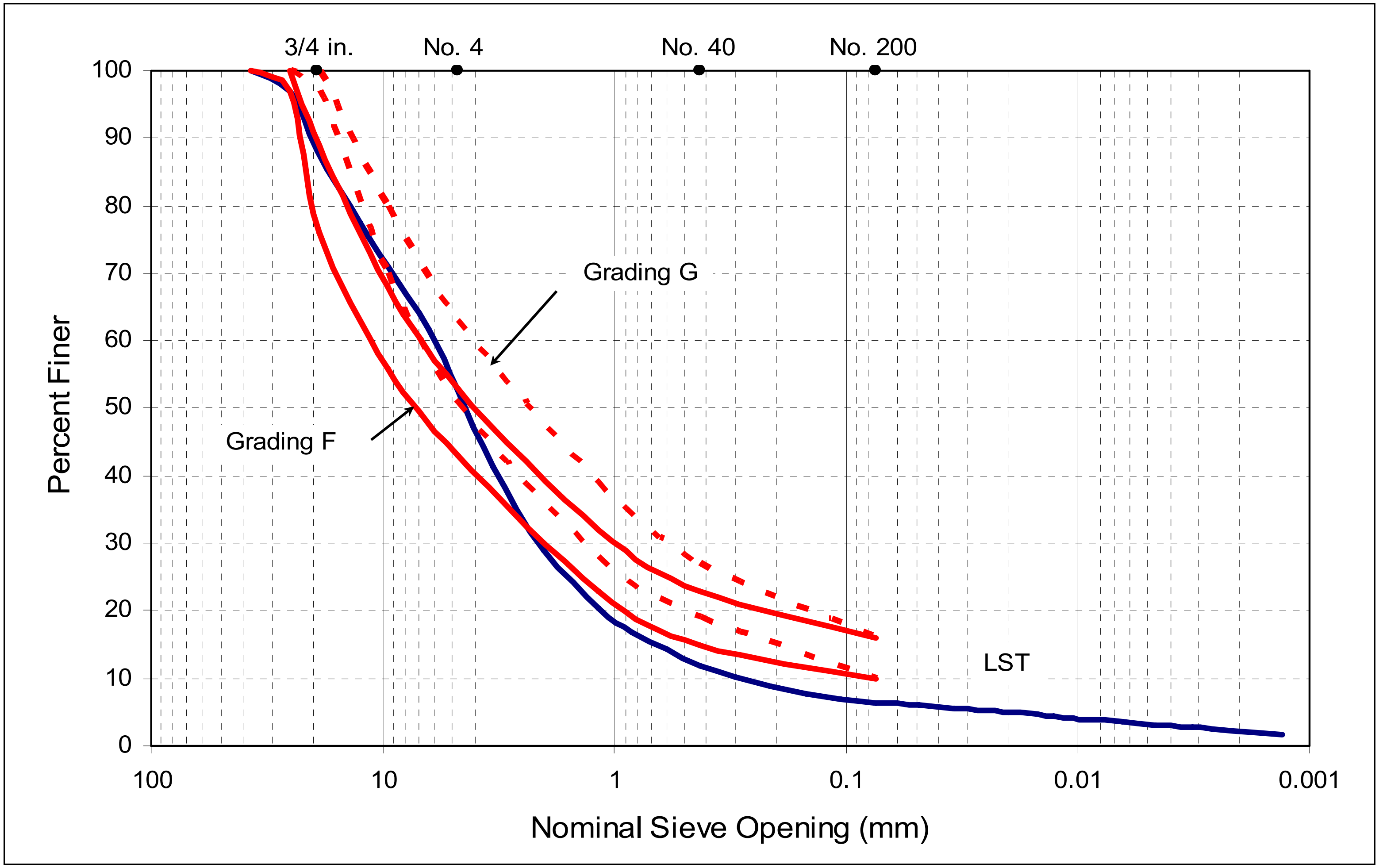

Figure 46. Comparison of as-received LST grading to USFS specifications

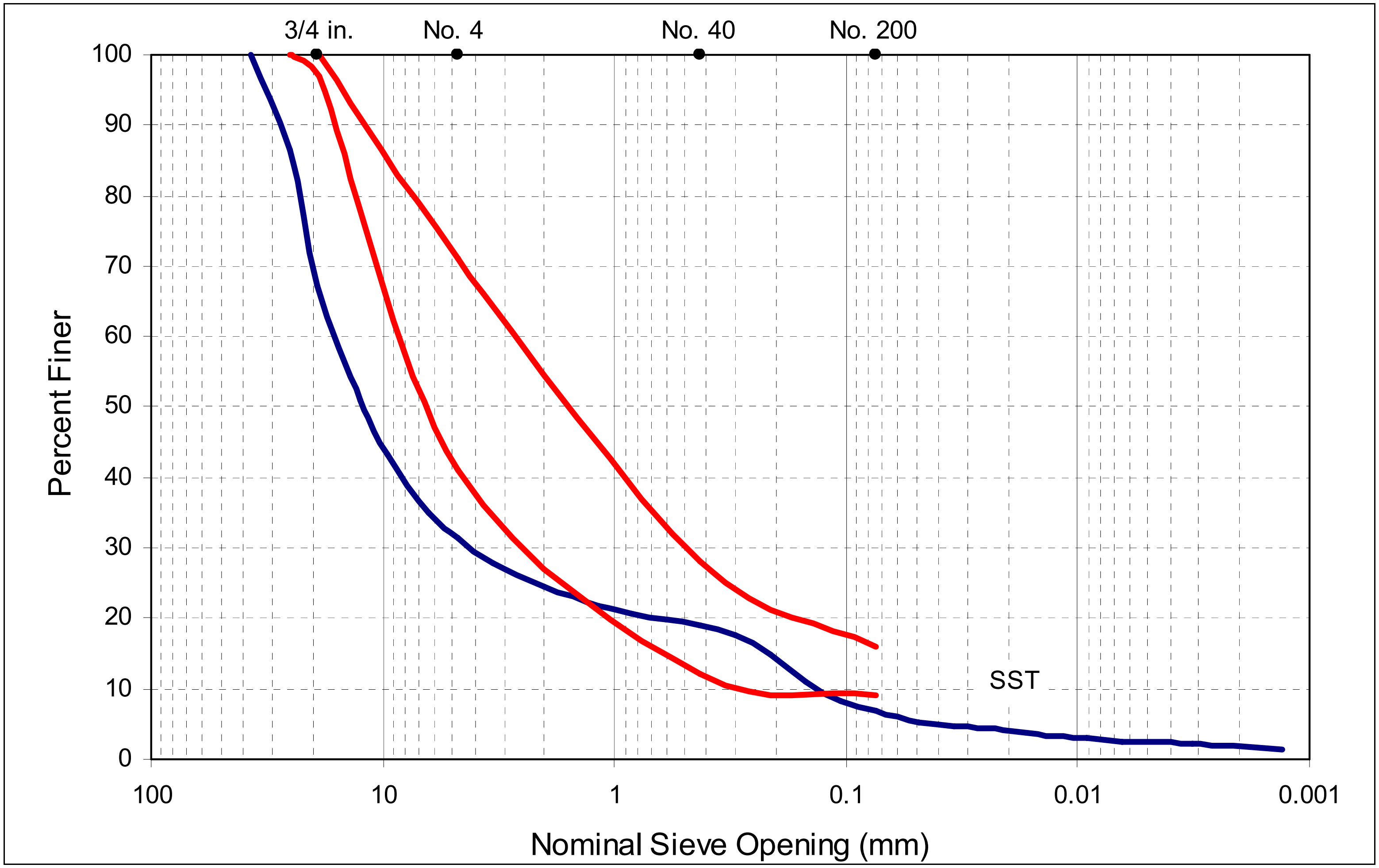

Figure 47. Comparison of as-received SST grading to FHWA specifications

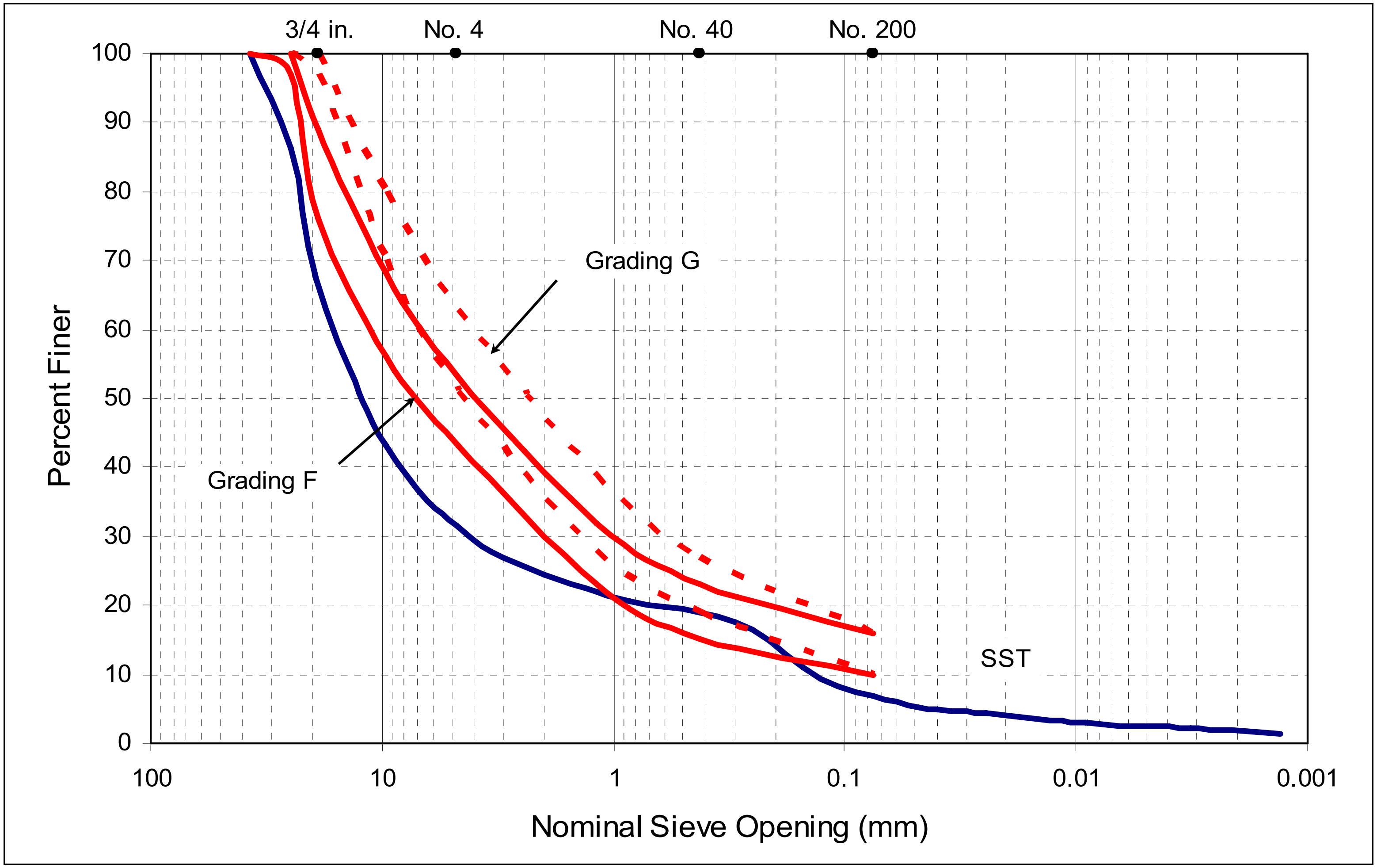

Figure 48. Comparison of as received SST grading to USFS specifications

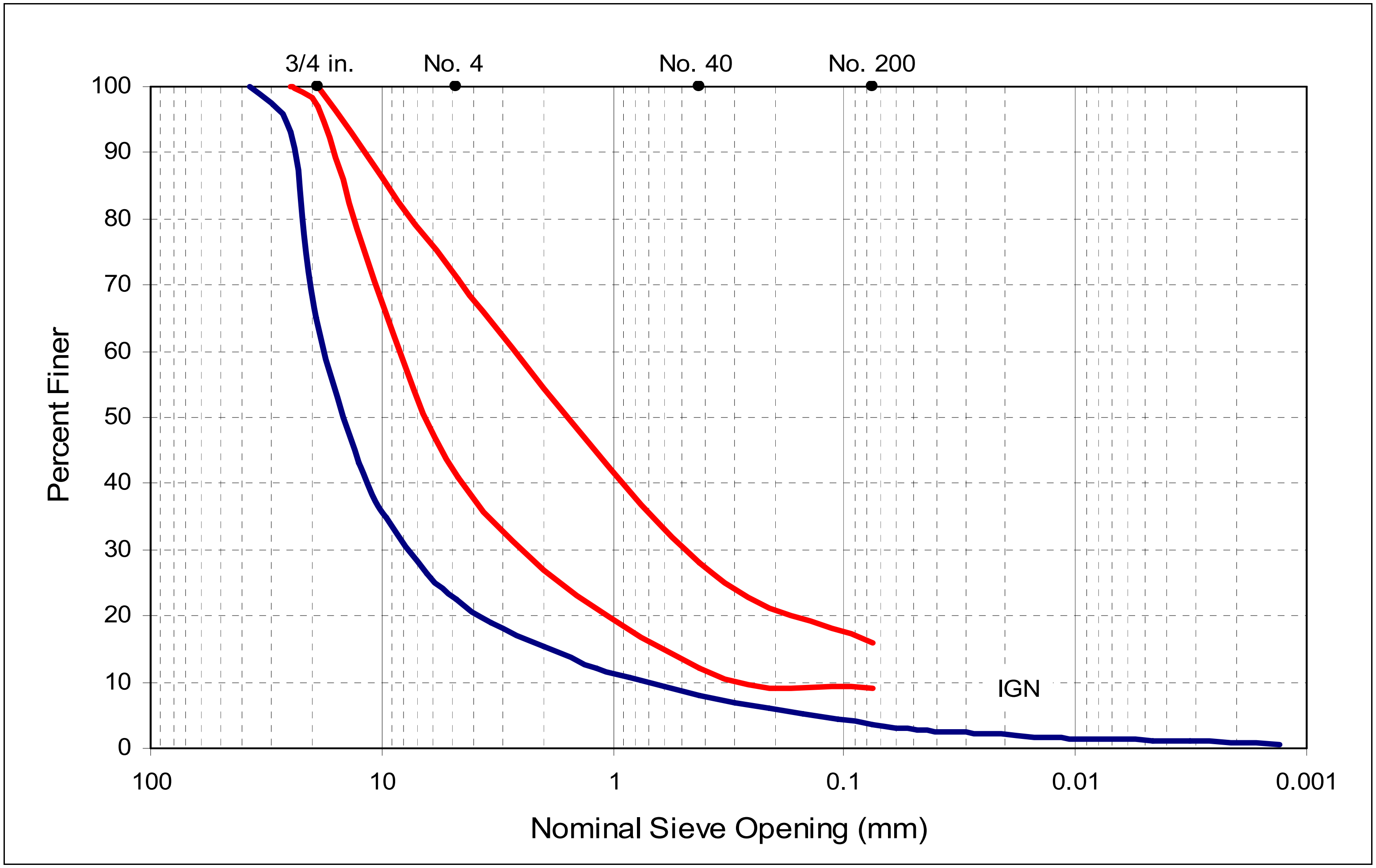

Figure 49. Comparison of as-received IGN grading to FHWA specifications

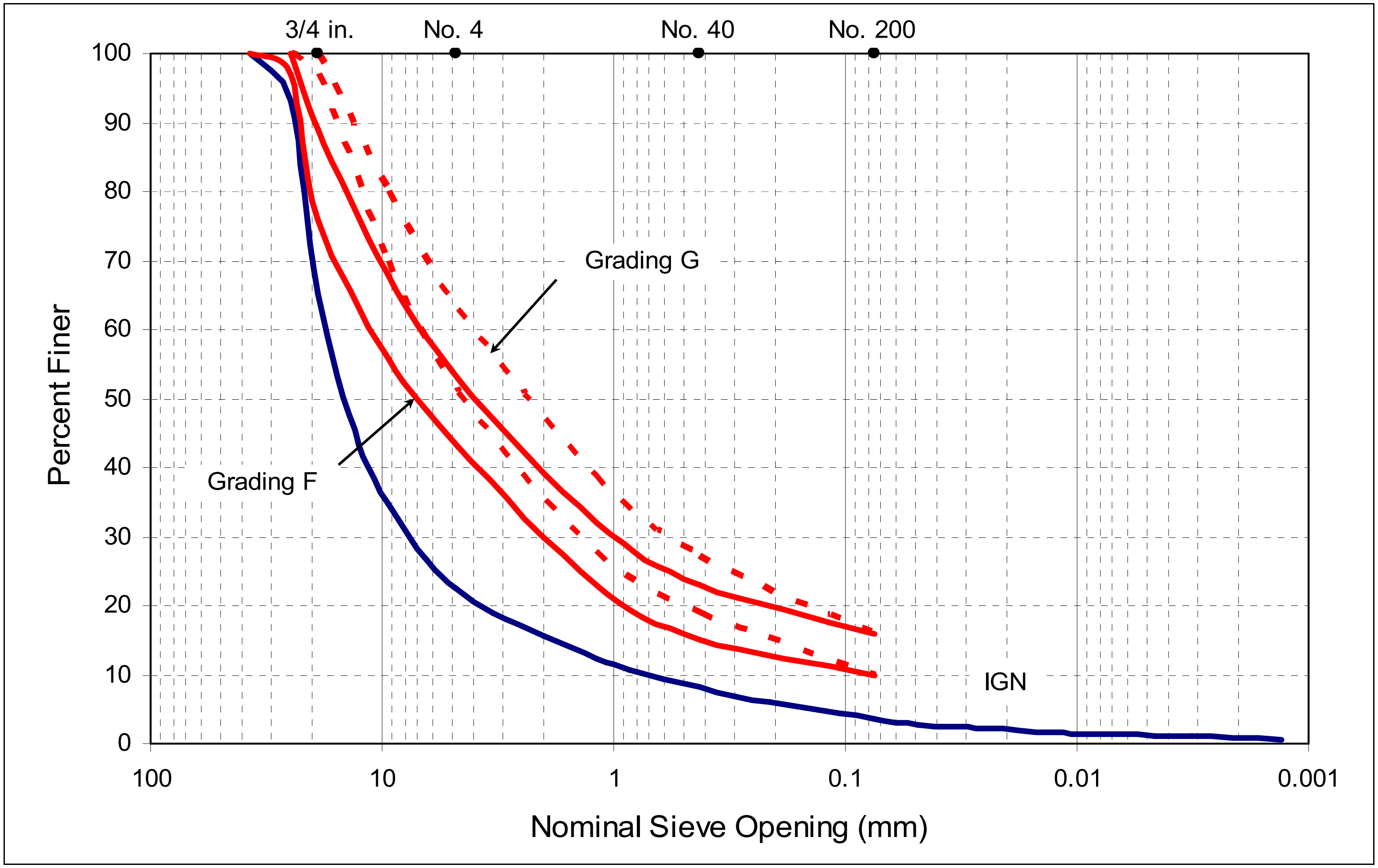

Figure 50. Comparison of as-received IGN grading to USFS specifications

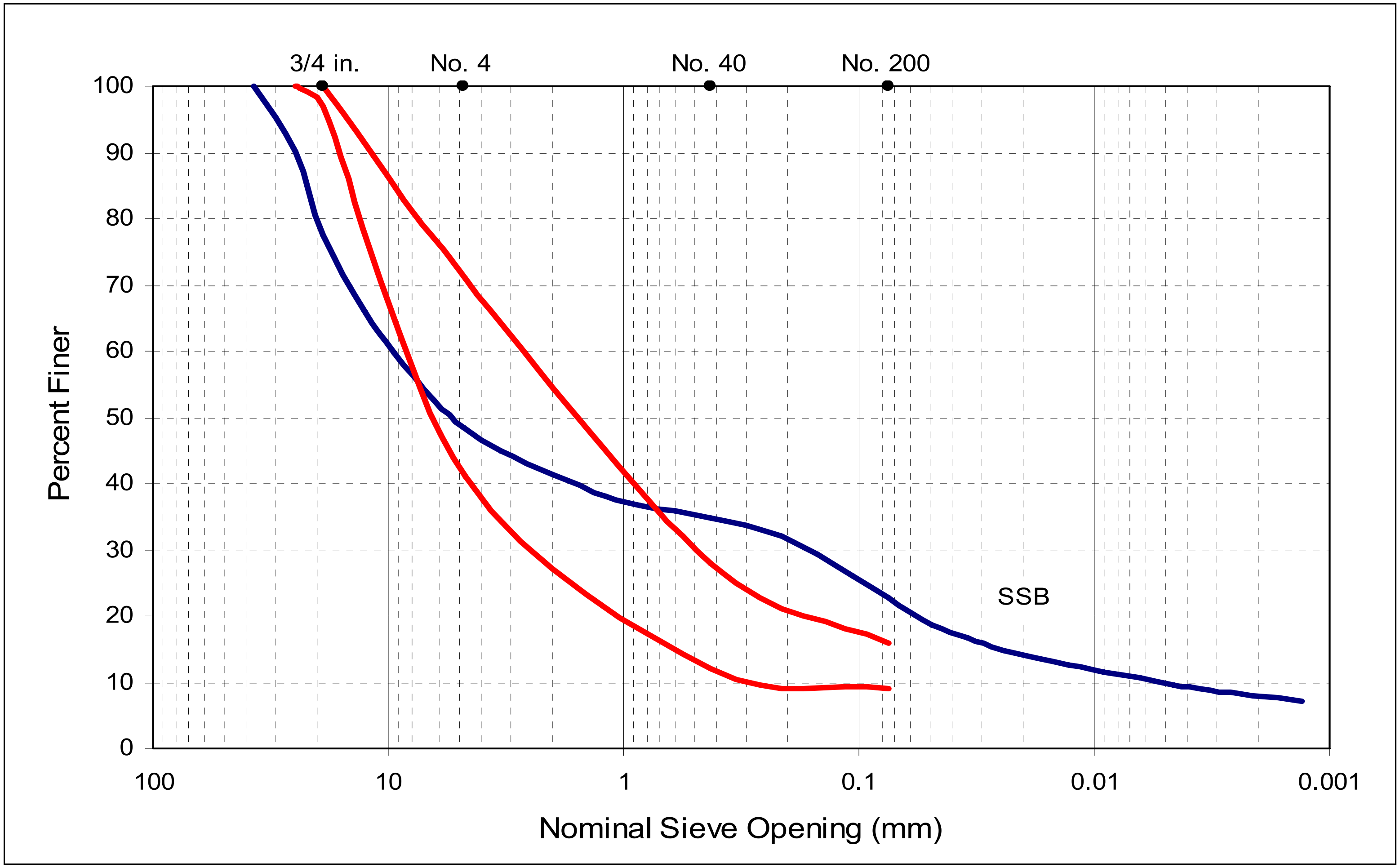

Figure 51. Comparison of as-received SSB grading to FHWA specifications

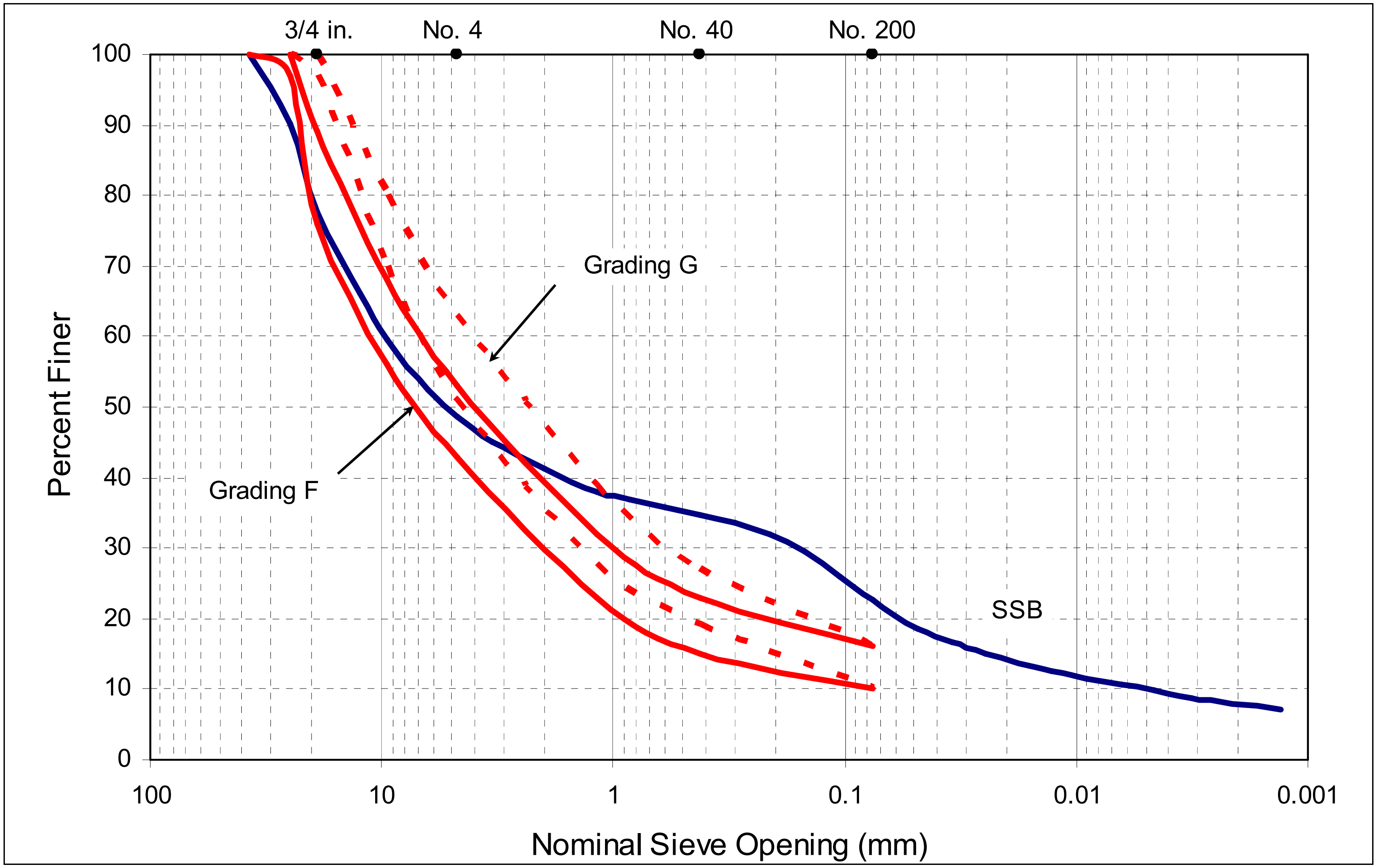

Figure 52. Comparison of as-received SSB grading to USFS specifications

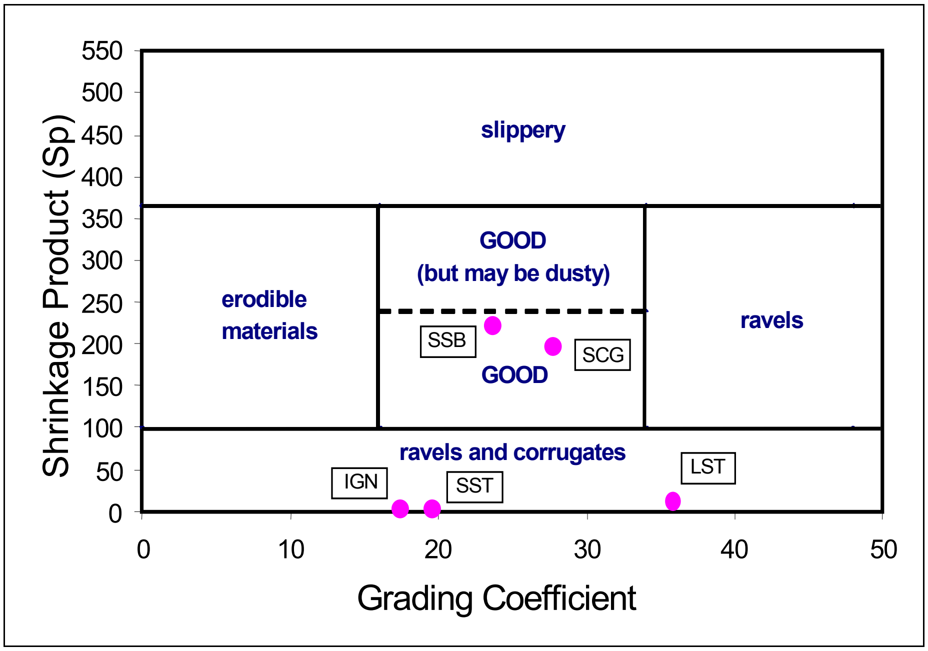

Figure 53. Comparison of as-received aggregates to South African specifications

4 Procedures

The effectiveness with which the five materials serve as unbonded road surfacings was investigated by constructing and trafficking pavement test sections at the USACE ERDC/WES (Waterways Experiment Station) in Vicksburg, MS. The test sections included one designed to emulate new construction (aggregate on top of fine-grained soil) and one designed to emulate road maintenance (aggregate on top of previously existing aggregate). Both test sections were built at a test track located at WES (see Figure 54).

The “New Construction” test section involved placing 150 mm (6 in.) of compacted aggregate directly on top of a fine-grained soil subgrade. The “Maintenance” test section involved placing 150 mm (6 in.) of compacted aggregate on top of sand clay gravel; the sand clay gravel served to represent an existing levee road upon which additional surfacing thickness was needed. The chronology of events is shown in Table 22.

Table 22
Chronology of Events

Date(s)	Event
06-May-04	Completed necessary fill and construction of East curve on track.
28-May-04	Completed surveying and placing grade stakes.
21-Jun-04	Field trip to levees in MS and LA.
15-Jul-04	Final aggregates delivered to WES.
29-Jul-04	Completed construction of the Maintenance test section.
03-Aug-04	Tilled, moistened, and recompacted subgrade for New Construction test section.
05-Aug-04	Completed construction of the New Construction test section.
11-Aug-04	Started trafficking both test sections.
17-Nov-04	Stopped trafficking due to the wet winter. Covered the test sections with plastic.
03-Feb-05	Started trafficking only the Maintenance test section.
05-Apr-05	Completed trafficking on the Maintenance test section
15-Apr-05	Started and completed trafficking on the New Construction test section.

Construction

The existing aggregate surfacing on the test track was removed from both the New Construction and Maintenance test sections. This aggregate consisted of crushed limestone and had been placed on the track in the early 1990s. The aggregate on the New Construction test section was removed completely, exposing the underlying fine-grained subgrade. The subgrade soil had been classified previously as a lean clay (CL) with a liquid limit of 32 percent and a plasticity index of 12 percent (Grau 1993). The soil was measured to have optimum moisture and maximum dry density of 15 percent and 117 pcf (1875 kg/m^3), respectively, in accordance with the AASHTO T-180 test method (Grau 1993). The aggregate on the Maintenance test section was removed to a depth of approximately 5 in. (125 mm), leaving some naturally cemented aggregate in-place. This working platform was deemed sufficient for the Maintenance test section because construction would include a 6 in. (150 mm) lift of sand clay gravel, followed by a 6 in. (150 mm) lift of experimental aggregate surfacing.

After a small amount of earth movement, a 250 ft × 35 ft wide (75 m × 11 m wide) working platform was completed for the both the New Construction and Maintenance test sections. Proper drainage was also ensured along the sides of the test sections. The final road sections would be 50 ft (15 m) long and 30 ft (9 m) wide for each material test item, within the two test sections. The layout for the test items within test sections is shown in Figure 55.

The maintenance test section was constructed first. Prior to placing the first layer of SCG material (that to be overlaid), the underlying soil/limestone mixture was tested for density and strength. Measurements by nuclear density gage found the dry unit weight and moisture content to be 131 pcf (2,100 kg/m^3) and 3.1 percent, respectively. The dynamic cone penetrometer (DCP) measurements, converted to CBR values, are shown in Table 23. This layer did not require any compaction. The first layer of SC material was placed at a thickness of 6 in. (150 mm) and was compacted with four passes of a vibratory steel drum roller (CAT CS-433E). Dry unit weight and moisture content were 131 pcf (2,100 kg/m^3) and 7.1 percent, respectively. The measured dry unit weight was similar to that found for the levee-surface sand clay gravel materials during the field trip described in Chapter 1. DCP measurements are shown in Table 23. The top of the soil/limestone mixture, residing at a depth of 6 in. (150 mm), had been softened by rain.

Table 23
CBR Measurements on Maintenance Test Section

Depth Below Surface, in. (mm)	Surface Material	
	Limestone/Clay Construction Platform, Prior to Placing the First SCG Layer	First SCG Layer, to be Overlaid by Test Aggregates
3 (75)	30 to 80	15 to 30
6 (150)	20 to 35	10 to 20
12 (300)	10 to 20	7 to 25
18 (450)	15 to 40	10 to 50
24 (600)	No data	30 to 40

In accordance with directions of the MVK, the moisture contents of surface aggregates were not adjusted prior to placement. In order to emulate normal field construction, materials were to be placed as-is and were to be compacted lightly in a manner to simulate compaction by delivery trucks. The granular surface materials were relatively dry. The SCG and SSB materials had retained slightly more moisture at the time of construction. Moisture contents, measured by microwave oven, follow.

a. SCG – 7.5 percent

b. LST – 1.3 percent

c. SST – 2.9 percent

d. IGN – 3.0 percent

e. SSB – 8.4 percent

These test aggregates were compacted with 16 coverages by a John Deere 550G track dozer, followed by smoothing with a static steel wheel roller. Densities and moistures, as measured 2 weeks after construction was completed, are shown in Table 24.

Table 24
Physical Properties of Test Aggregates

Item No.	Aggregate	Dry Density		Moisture Content, %
		lb/ft^3 (kg/m^3)	CV (%)	
1	SCG	125.6 (2,010)	2.0	5.3
2	LST	114.8 (1,840)	1.9	1.7
3	SST	119.4 (1,910)	2.7	2.6
4	IGN	121.1 (1,940)	2.6	1.4
5	SSB	122.7 (1,965)	3.7	4.7

Construction for the “New Construction” test section first required removal of all old surface aggregate materials in order to expose the underlying CL soil. Based on findings from the field trip described in Chapter 1, the target CBR for the fine-grained subgrade was 5 to 10 percent. The exposed soil had relatively high and variable strengths, as determined by DCP, even after it was pulverized and then recompacted with a vibratory roller. The top (6 in.) had CBR values of 5 to 25 percent. To provide a uniform and weaker construction surface, the soil was pulverized again to a depth of 12 in. (300 mm), water was added during pulverization to increase moisture content, and the soil was recompacted. Soil properties after the initial processing and after the second pulverization with wetting are shown in Table 25.

Table 25
Subgrade Properties Under New Construction Section

Property	First Pulverization and Recompaction		Second Pulverization, with Wetting Prior to Recompaction	
	Mean	Range[1]	Mean	Range[1]
Moisture Content, %	9.7	7.7 to 11.3	11.4	9.6 to 13.0
Dry Unit Weight, pcf[2]	112.6	108.7 to 114.6	107.1	102.9 to 110.9
Minimum CBR, % (0 to 6 in.)		5 to 25		6 to 20
Minimum CBR, % (6 to 12 in.)		6 to 30		5 to 20
Minimum CBR, % (12 to 24 in.)				

[1] Measurements were obtained at stations 0+25, 0+75, 1+25, 1+75, 2+25.
[2] 1 lb/ft^3 = 16.02 kg/m^3

Compaction was intended to emulate that which would be accomplished in the field for the MVK. The MVK specification is designed to accommodate rapid, inexpensive construction. As such, specialized compaction equipment is avoided and target densities for compacted aggregate are not used. The MVK specification requires the surface aggregate to be placed in a single lift and compacted to a final thickness of 6 in. (150 mm). Guidance suggests a loose thickness of 9 in. (230 mm) for sand clay gravel and a loose thickness of 7 in. (180 mm) for crushed stone and crushed stone with binder materials. Further,

> The surfacing shall not be placed on a wet surface. The surface course shall be compacted as evenly and densely as practicable by the controlled movement of the hauling equipment over the entire area. After the new surfacing material has been placed and compacted, it shall be dressed with a motor grader or similar equipment to present a uniform appearance and a smooth riding surface, without sharp breaks or depressions which will collect or hold water (MVK 2004).

Trafficking

Trafficking included several vehicles, allowing for increases in vehicle weight as needed. The lightest vehicle was a pickup truck with 500 lb of steel secured to its bed (see Table 26). The medium weight vehicles included a dump truck and a flat bed truck, each with dual rear tires. The dump truck was used empty, but the flat bed truck had additional weight supplied by equipment and 1000 lb of lead. The heaviest vehicle was an emulsion truck with dual-tandem rear tires. The emulsion truck was loaded with 750 gal of water so that the load on its tandem rear axles would be approximately double the load on the flat bed's single rear axle (Table 26). The footprint dimensions for the vehicles are shown in Figures 56 and 57.

Table 26
Characteristics of Trafficking Vehicles

Characteristic	Vehicle[1]			
	A	B	C	D
Rear Tire(s) Configuration	single	dual	dual	dual
Rear Axle(s) Configuration	single	single	single	tandem
Front Axle Load (lb)	2,600	6,800	5,500	5,700
Rear Axle(s) Load (lb)	2,400	7,500	11,000	21,800
Rim Diameter (in.)	16	22.5	20	20
Tire Inflation Pressure (psi)	40	110	80	80
Tire Tread Width (in.)	7	9	8	8.5

[1] A = Dodge Ram 1500 pickup truck, B = Ford F800 dump truck, C = Ford F700 flatbed CBR truck, and D = GMC 7000 emulsion truck.

Roadway Performance

The performance of pavements will be presented one lane at a time and in the following order.

a. Maintenance test section, dry lane.

b. Maintenance test section, wet lane.

c. New construction test section, dry lane.

d. New construction test section, wet lane.

The trafficking and road performance for each individual lane will be presented chronologically. However, the lanes were not trafficked in the order shown above. The choice of trafficking dry or wet lanes on any particular day was dependent on weather. Also, in some cases traffic was applied to both test sections (i.e., full loop) and, in some cases, traffic was applied to only one test section (i.e., the other test section was by-passed). Precipitation and daily median temperature (calculated as median of daily high and daily low) for the entire duration of trafficking are shown in Figure 58. Precipitation was measured by a rain gage. Temperatures were obtained from the Weather Channel website for Vicksburg's particular zip code.

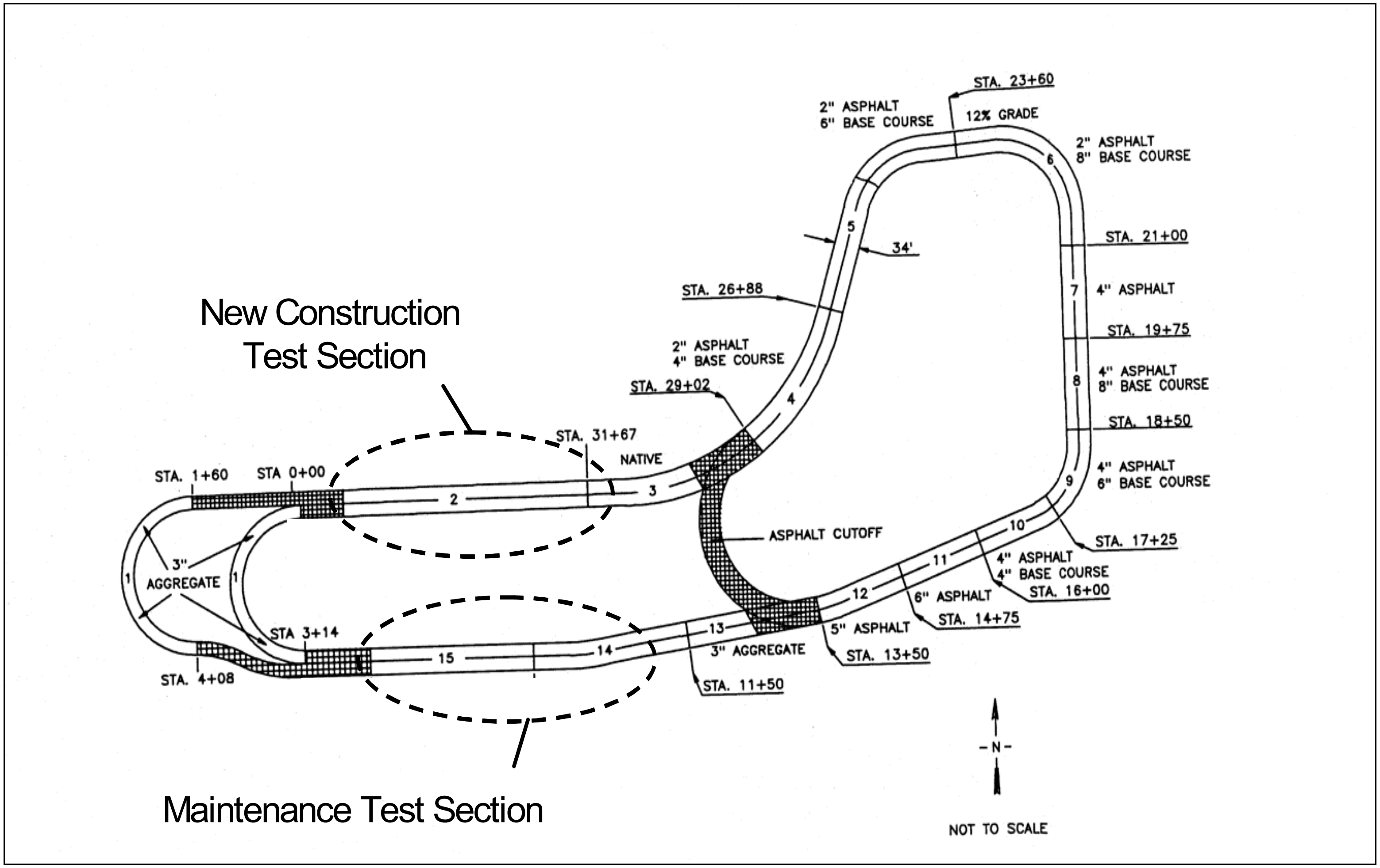

Figure 54. Test track with approximate locations of test sections

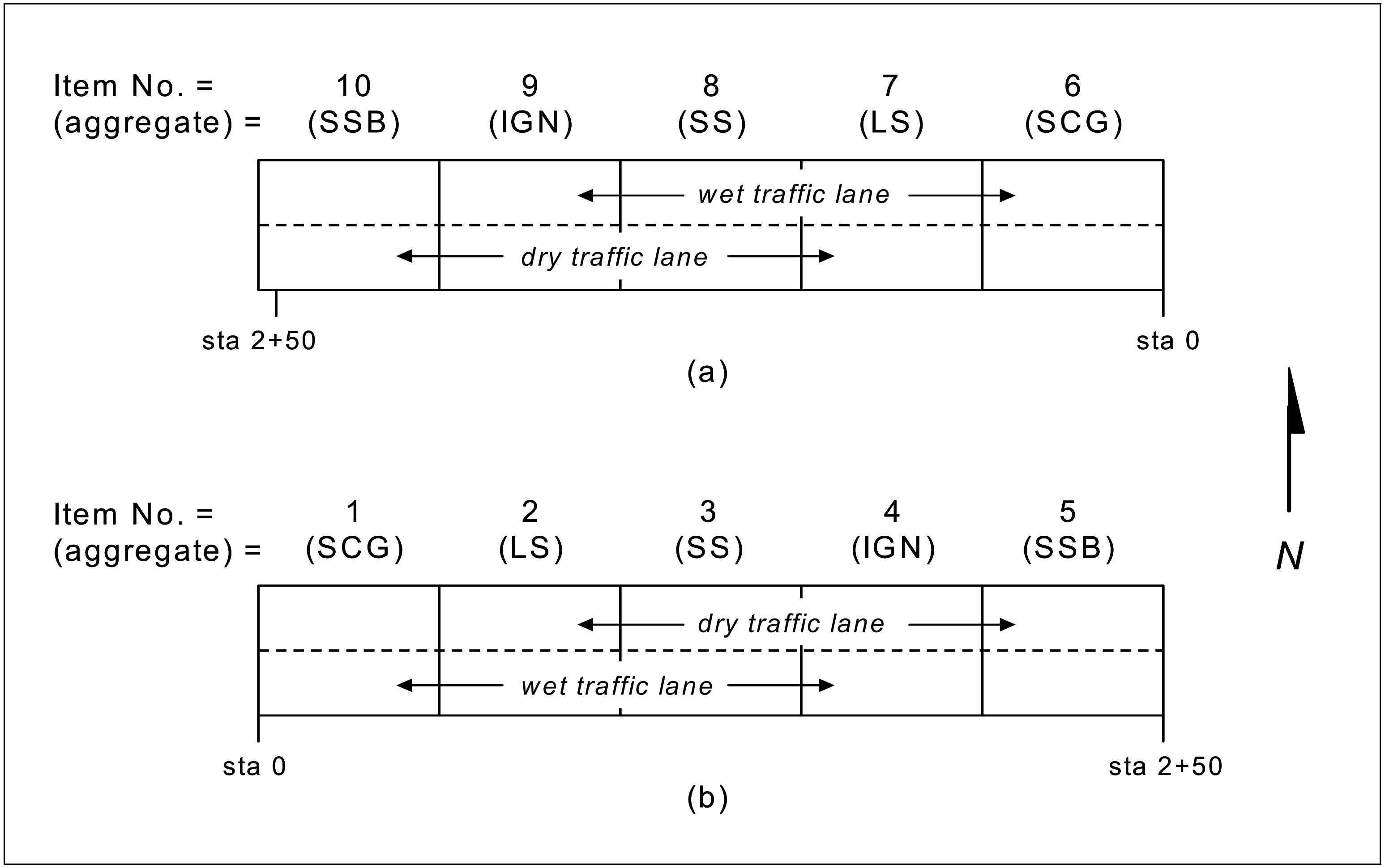

Figure 55. Test item layout for the (a) construction and (b) maintenance test sections

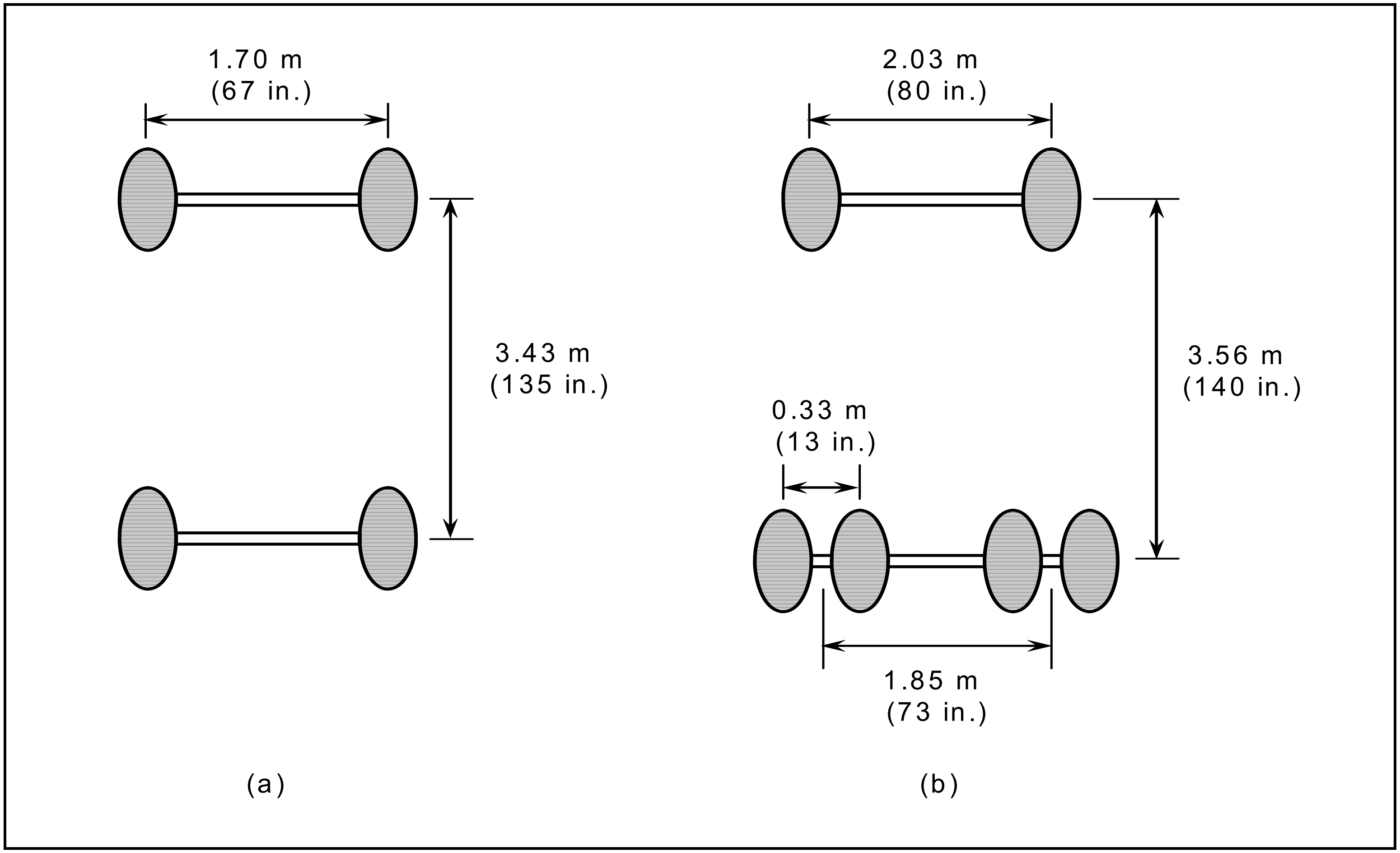

Figure 56. Footprint dimensions for the (a) pickup truck and the (b) dump truck

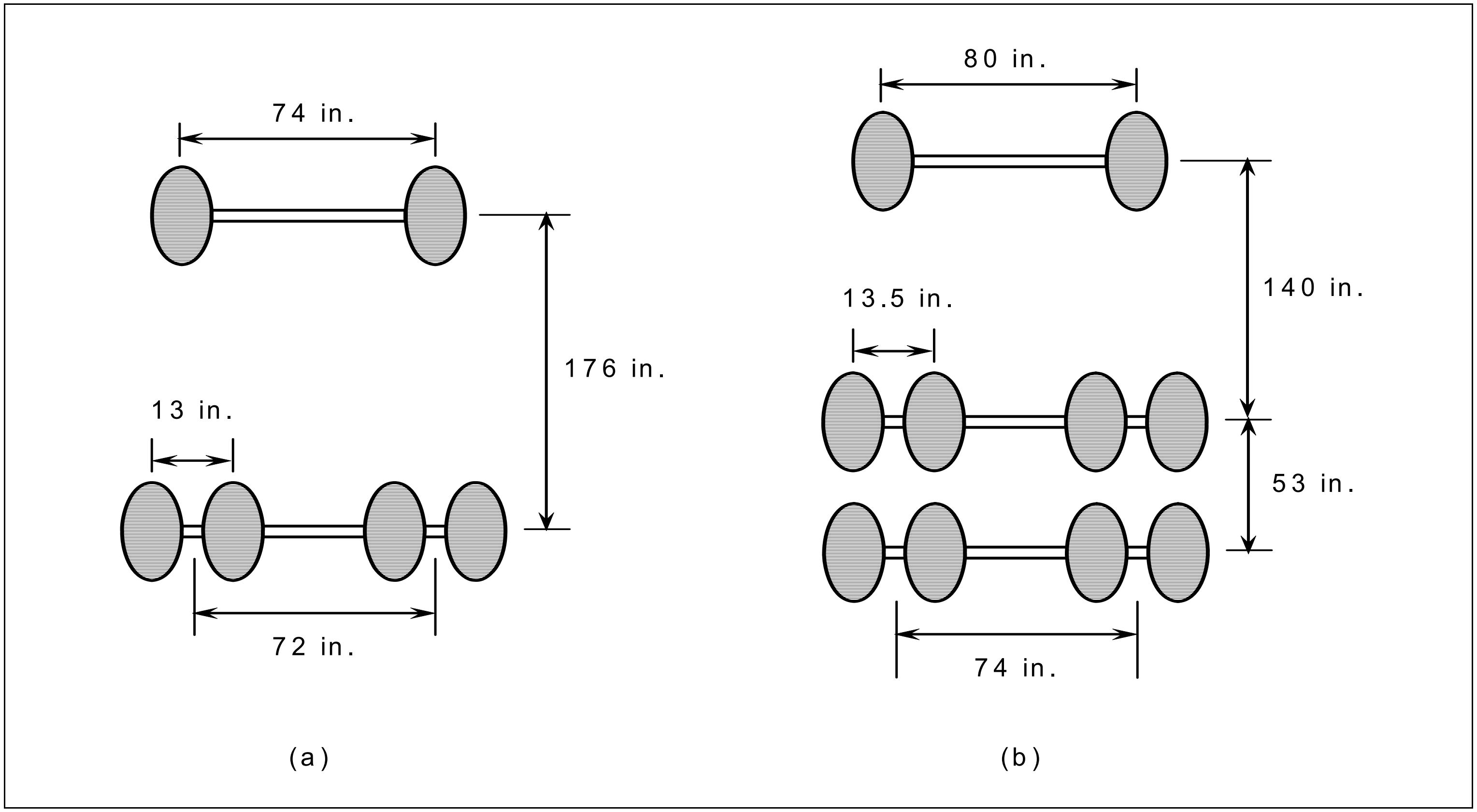

Figure 57. Footprint dimensions for the (a) flatbed CBR truck and the (b) emulsion truck

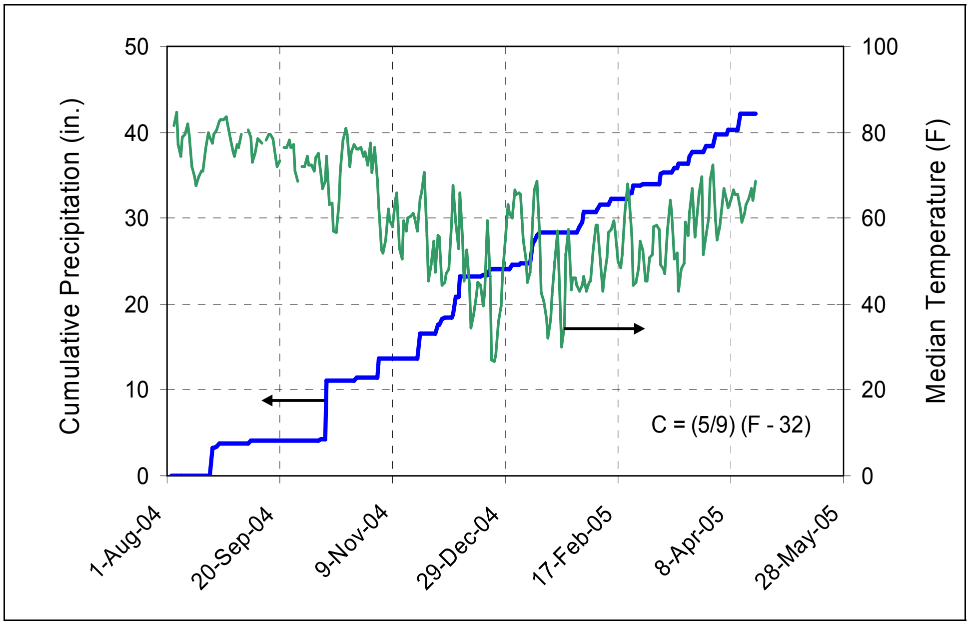

Figure 58. Precipitation and median temperature

5 Maintenance Test Section, Dry Lane

Description

The chronology of trafficking events for this lane is shown in Table 27. The pickup truck was driven over the lane for 2,500 passes over a period of 2.5 months (August to October 2004). During November 2004, the dump truck traveled over the lane only 15 times when trafficking had to be stopped. With each loop, the truck was passing over both the Maintenance test section and the New Construction test section. Rutting in the New Construction test section necessitated that traffic be stopped. Traffic was not applied to this lane again until the following spring. In April 2005, the emulsion truck drove over this lane 200 times. With each loop, the emulsion truck by-passed the New Construction test section.

Table 27
Chronology of Trafficking Events for Maintenance Test Section, Dry Lane

Date(s)	Event
11-Aug-04	50 seating[1] passes with pickup truck.
12-Aug-04	Smoothed lane by backblading.
13-Aug-04	150 passes with pickup truck.
17-Aug-04	500 cumulative passes with pickup truck.
23-Sep-04	1,500 cumulative passes with pickup truck.
27-Oct-04	2,500 cumulative passes with pickup truck.
10-Nov-04	Smoothed lane by hand raking.
17-Nov-04	15 passes with dump truck.
07-Feb-05	Smoothed lane by backblading
05-Apr-05	200 passes with emulsion truck.

[1] Seating passes were followed by smoothing or blading; ruts were not measured; they were accomplished to “seat” the test section.

Moisture contents for the surface aggregates stayed relatively constant during the application of pickup truck traffic (see Figure 59). Because of their higher proportions of fines, the moisture contents for SCG and SSB remained about twice those for LST, SST, and IGN. Dry unit weights for surface aggregates started relatively low and in the range of 115 to 125 pcf (see Figure 60). This occurred as a result of the minimal compaction during construction and because the materials were placed in a moisture condition less than optimum. Although the SCG and SSB did not have the highest maximum dry densities (ASTM D 698) among the aggregates, they had the highest dry unit weights at the beginning of trafficking (see Figure 60). Their compaction was made easier by their ability to retain moisture in stockpiles during dry construction weather. The dry unit weights of surface aggregates all increased during trafficking (see Figure 60), leveling off in the range of 125 to 130 pcf.

The old roadway materials and the subgrade conditions under the surface aggregates in the Maintenance test section remained in stable condition during trafficking, as can be ascertained from Tables 28 through 30, columns 4 and 5. The confined strengths for LST, SST, and IGN surface materials remained relatively constant, as can be ascertained from Tables 28 through 30, column 3. Confined strengths are those achieved near the bottom of the 6-in. lift, away from the unconfined surface. SCG and SSB behaved similarly in that their highest strengths were measured at 1,500 passes. From 0 to 1,500 passes the materials would benefit from the compactive effects of traffic. The strengths at 2,500 passes likely were lower than at 1,500 passes, owing to the effects of 0.3 in. of rain, which occurred 3 days before trafficking was completed and the dynamic cone penetrometer (DCP) tests were conducted (see Appendix A).

All materials performed well during pickup truck traffic in these dry conditions; however, the SCG and SSB materials performed best. Worst-case rutting for SCG and SSB never exceeded 1-1/2 in. (see Figures 61 and 65). Each of LST, SST, and IGN showed peak rutting early in traffic up to 1,500 passes, then decreased in rutting from 1,500 to 2,500 passes (see Figures 62, 63, and 64). These materials started with relatively low densities and, because of their granular nature, surface particles moved under traffic to the outside of the wheelpaths (see Appendix c, Photos C6 and C8). This early particle movement also caused small corrugations in the LST and IGN materials (see Photos C3 and C4). These corrugations eventually smoothed out under traffic. The LST, SST, and IGN materials densified under traffic and the natural wander of the trafficking vehicle ultimately decreased the evidence of rutting. Ultimately, these materials appeared to be stable under traffic.

Dump truck traffic was applied to the dry lanes in both the Maintenance and New Construction test sections simultaneously. After only 15 passes, traffic was stopped because of rutting in the New Construction test section. No rutting was evident in the Maintenance test section; all items were stable under traffic. The moisture, density, and DCP data are shown Tables 31 and 32 for completeness.

The emulsion truck, which was the heaviest traffic (Figures 66-70), traveled over the Maintenance test section while by-passing the New Construction test section. Moisture, density, and DCP data were obtained immediately after trafficking (see Tables 33 and 34). Retention of moisture by SCG and SSB are still evident. Higher densities were measured in the wheelpaths, as compared to centerline. The DCP data show that the underlying road structure is of high strength. DCP data for the surface materials do not correlate with performance, as will be evident. The DCP has difficulty providing strength information on aggregate surface materials that are only 6 in. thick.

Table 28
Dynamic Cone Penetrometer Data for Pickup Truck Traffic at 0 Passes

Item	Station	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	0 + 12.5	80 to 100	100	10 at 20 in.
	0 + 25	30 to 40	100	15 at 20 in.
	0 + 37.5	100	100	25 at 20 in.
2 (LST)	0 + 62.5	20	100	15 at 20 in.
	0 + 75	30	100	15 at 25 in.
	0 + 87.5	15	100	20 at 20 in.
3 (SST)	1 + 12.5	20	60	10 at 25 in.
	1 + 25	40	100	10 at 20 in.
	1 + 37.5	30	80	15 at 20 in.
4 (IGN)	1 + 62.5	20	100	30 at 20 in.
	1 + 75	8	80 to 100	20 at 25 in.
	1 + 87.5	10	100	25 at 25 in.
5 (SSB)	2 + 12.5	25	60	30 at 20 in.
	2 + 25	50	80	30 at 15 in.
	2 + 37.5	50 to 60	100	50 at 15 in.

Table 29
Dynamic Cone Penetrometer Data for Pickup Truck Traffic at 1,500 Passes

Item	Station	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	0 + 12.5	100	100	No data
	0 + 25	100	100	No data
	0 + 37.5	100	100	25 at 20 in.
2 (LST)	0 + 62.5	20	100	20 at 20 in.
	0 + 75	15	100	10 at 25 in.
	0 + 87.5	30 to 40	100	15 at 20 in.
3 (SST)	1 + 12.5	20	80	20 at 20 in.
	1 + 25	60 to 70	100	15 at 20 in.
	1 + 37.5	50	100	15 at 20 in.
4 (IGN)	1 + 62.5	15	80 to 100	10 at 20 in.
	1 + 75	30	100	10 at 25 in.
	1 + 87.5	20	80	15 at 20 in.
5 (SSB)	2 + 12.5	60 to 70	100	30 at 20 in.
	2 + 25	60 to 70	100	15 at 25 in.
	2 + 37.5	100	100	30 at 20 in.

Table 30
Dynamic Cone Penetrometer Data for Pickup Truck Traffic at 2,500 Passes

Item	Station	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	0 + 12.5	40	100	20 at 15 in.
	0 + 25	30 to 40	100	20 at 20 in.
	0 + 37.5	20	70 to 80	10 at 25 in.
2 (LST)	0 + 62.5	25	100	8 at 25 in.
	0 + 75	20	80	25 at 25 in.
	0 + 87.5	20	80	20 at 25 in.
3 (SST)	1 + 12.5	25	60	10 at 20 in.
	1 + 25	40	100	10 at 25 in.
	1 + 37.5	50	100	30 at 20 in.
4 (IGN)	1 + 62.5	35	100	7 at 20 in.
	1 + 75	20	90	15 at 20 in.
	1 + 87.5	25	80	15 at 20 in.
5 (SSB)	2 + 12.5	60	80	25 at 20 in.
	2 + 25	60	100	25 at 25 in.
	2 + 37.5	40	80	30 at 20 in.

Table 31
Nuclear Density Gage Data Prior to 15 Passes with the Dump Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
1 (SCG)	6.2	129.7
2 (LST)	2.2	127.1
3 (SST)	4.3	128.4
4 (IGN)	3.0	130.0
5 (SSB)	6.0	128.8

Table 32
Dynamic Cone Penetrometer Data Prior to 15 Passes with the Dump Truck

Item	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	15 to 20	60	20 at 15 in.
2 (LST)	6 to 15	60	10 at 25 in.
3 (SST)	25 to 30	100	20 at 25 in.
4 (IGN)	15	60	5 at 25 in.
5 (SSB)	30 to 50	100	30 at 18 in.

Table 33
Nuclear Density Gage Data After 200 Passes with the Emulsion Truck

Item	Moisture Contents (%) of Surface Aggregates		**Dry Unit Weights (pcf) of Surface Aggregates**	
	Wheelpath	Centerline	Wheelpath	Centerline
1 (SCG)	7.5	6.7	130.1	127.7
2 (LST)	2.8	3.6	130.2	122.5
3 (SST)	3.2	3.1	129.9	125.7
4 (IGN)	2.1	3.0	135.7	132.9
5 (SSB)	4.5	4.5	135.4	128.2

Table 34
Dynamic Cone Penetrometer Data After 200 Passes with the Emulsion Truck

Item	Confined CBR for Surface Material, Before Traffic	Confined CBR for Surface Material, After Traffic	High CBR for Underlying Road Material
1 (SCG)	30	10	100
2 (LST)	6	8	100
3 (SST)	15 to 20	15 to 20	100
4 (IGN)	15	10 to 20	100
5 (SSB)	50	15	100

Under the heavy emulsion truck traffic, Item 1 (SCG) rutted excessively (see Figure 34). Although conditions were dry, the rounded nature of the SCG aggregates was not sufficiently stable. Among the other items, SST and SSB performed the best with worst-case rutting less than 1-1/2 in. The LST and SST items had worst-case rutting of 2 to 3 in. See Photos C21 through C30.

Summary for Dry Lane, Maintenance Test Section

Under pickup truck traffic, all unbonded surfacing materials performed adequately, but the materials with higher fine contents (SCG and SSB) performed the best. The high-fines aggregates compacted efficiently and were less susceptible to loose aggregate movement at the road surface.

Under the heavy emulsion truck traffic, the aggregate with rounded particles (SCG) performed the worst. The two sandstone aggregates (SST and SSB) performed the best, possibly because of their combination of angularity and sufficient proportion of finer particles, relative to LST and IGN.

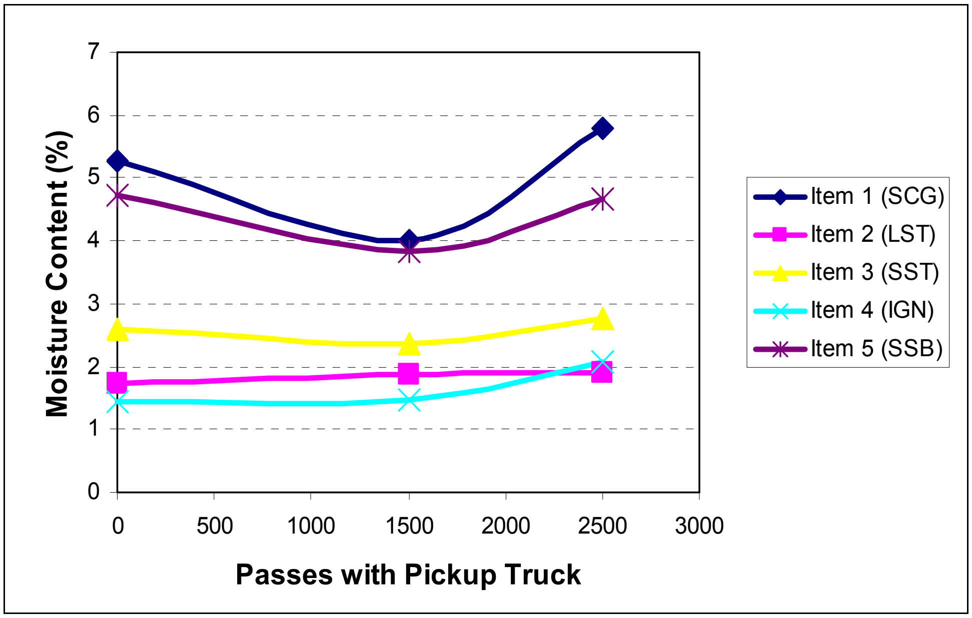

Figure 59. Moisture contents for surface aggregates on maintenance test section, dry lane, 2,500 passes with pickup truck

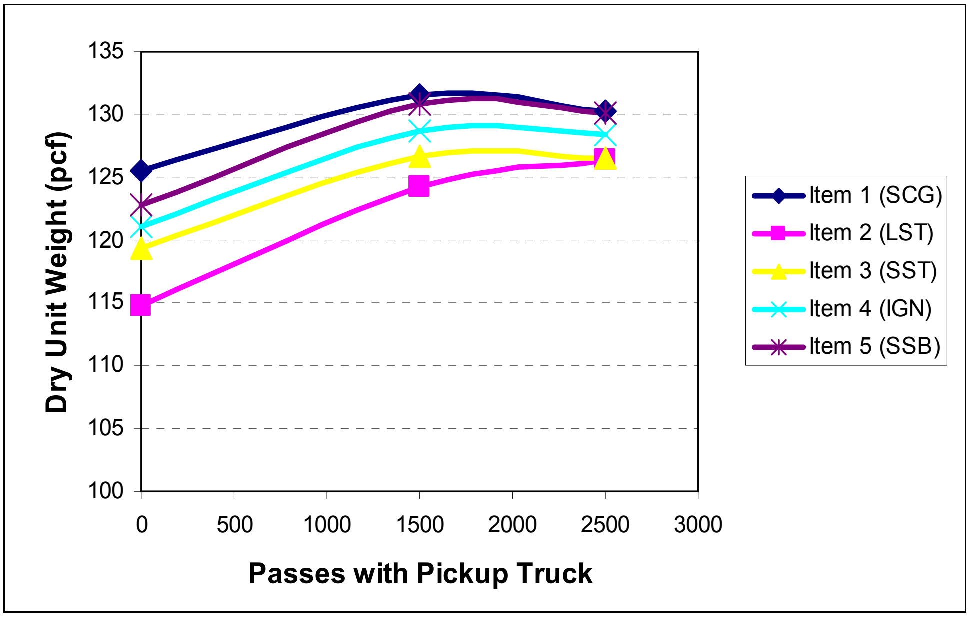

Figure 60. Dry unit weights for surface aggregates on maintenance test section, dry lane, 2,500 passes with pickup truck

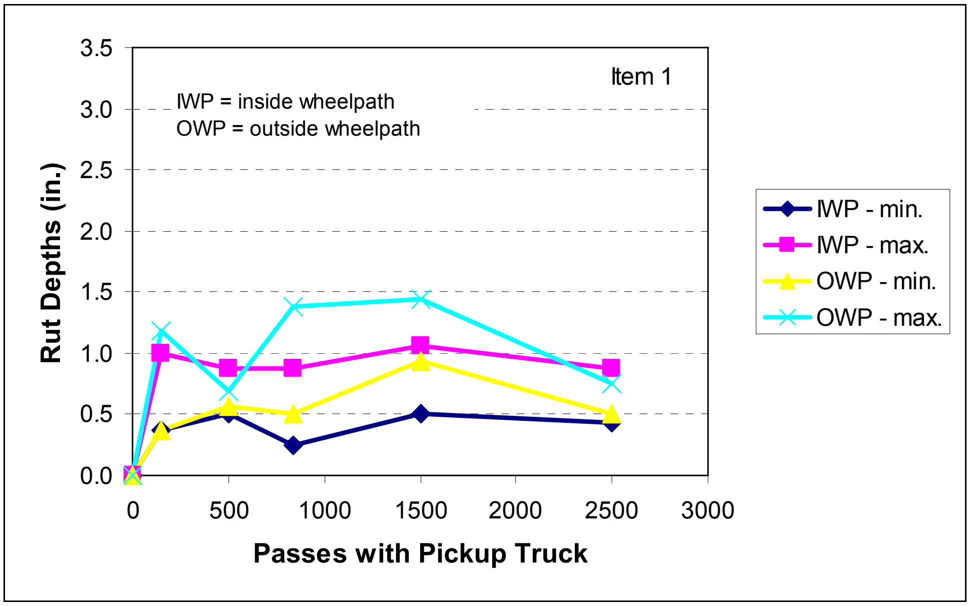

Figure 61. Rut depths for Item 1 (SCG), maintenance test section, dry lane, 2,500 passes with pickup truck

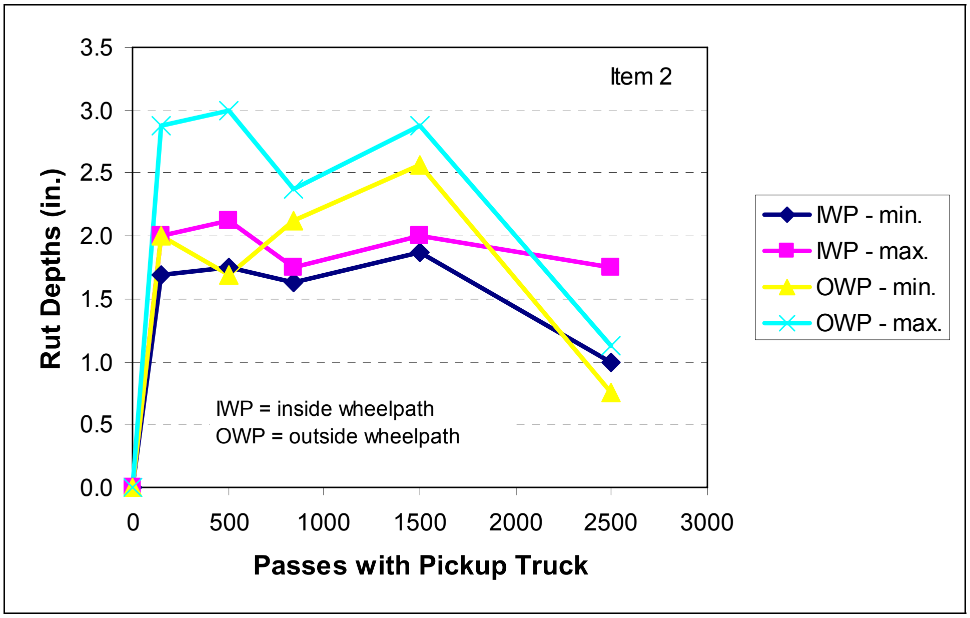

Figure 62. Rut depths for Item 2 (LST), maintenance test section, dry lane, 2,500 passes with pickup truck

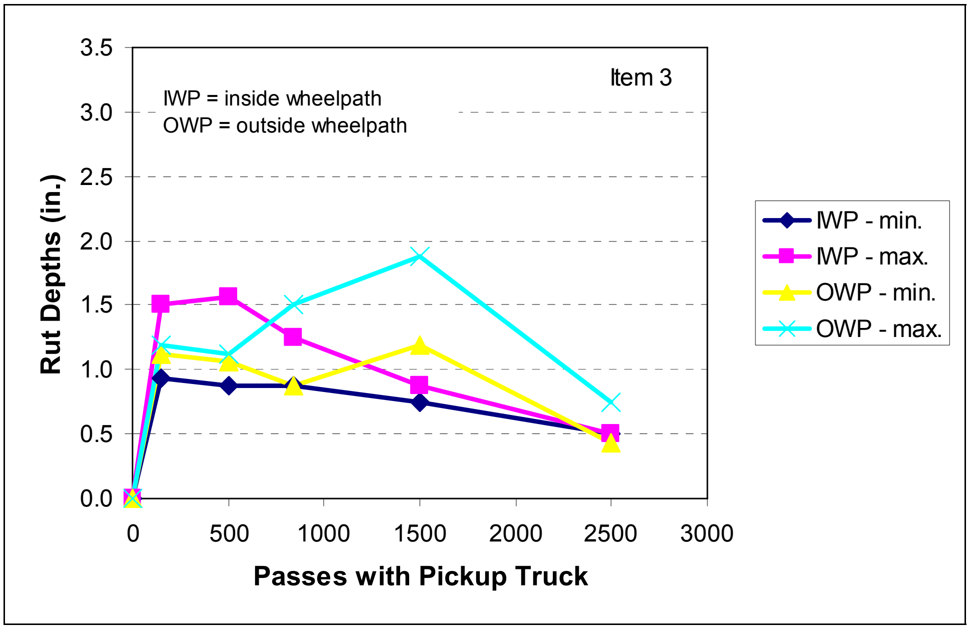

Figure 63. Rut depths for Item 3 (SST), maintenance test section, dry lane, 2,500 passes with pickup truck

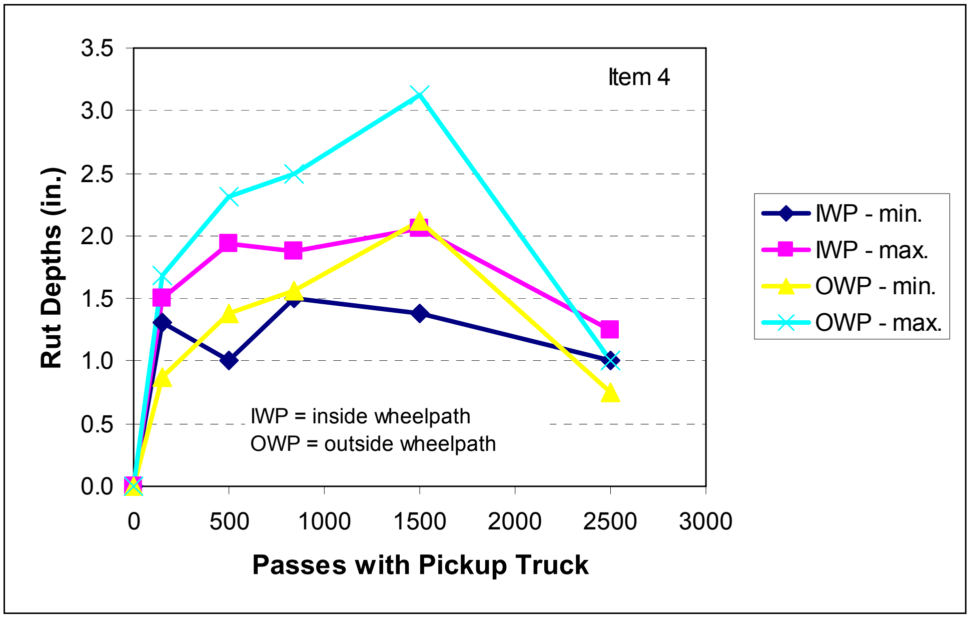

Figure 64. Rut depths for Item 4 (IGN), maintenance test section, dry lane, 2,500 passes with pickup truck

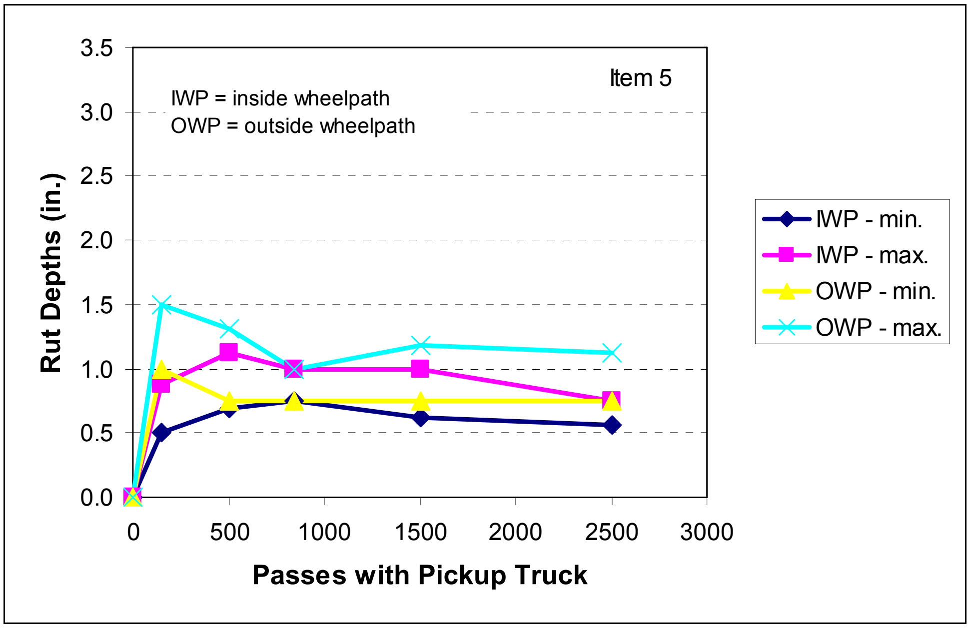

Figure 65. Rut depths for Item 5 (SSB), maintenance test section, dry lane, 2,500 passes with pickup truck

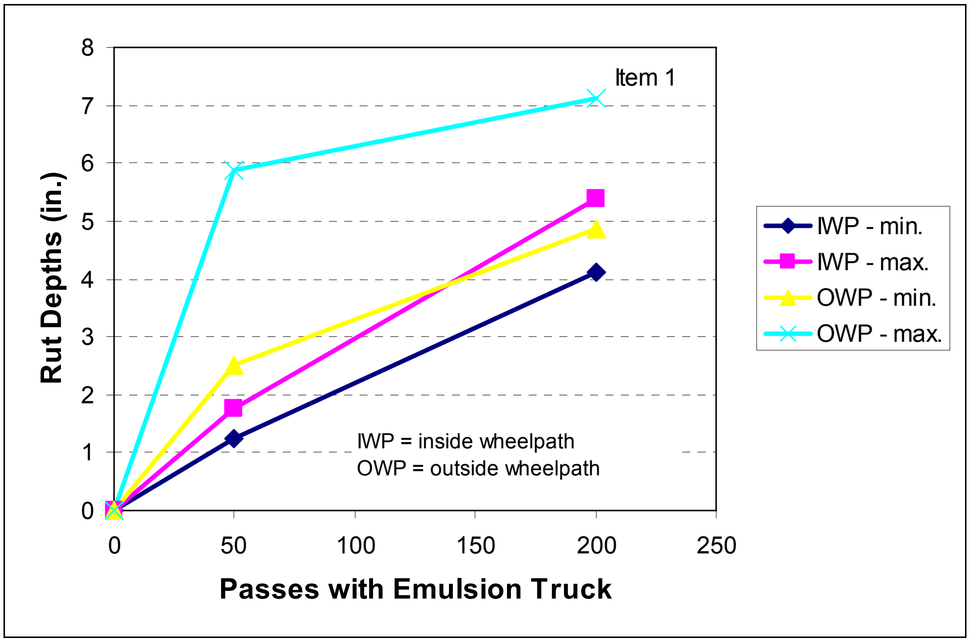

Figure 66. Rut depths for Item 1 (SCG), maintenance test section, dry lane, 200 passes with emulsion truck

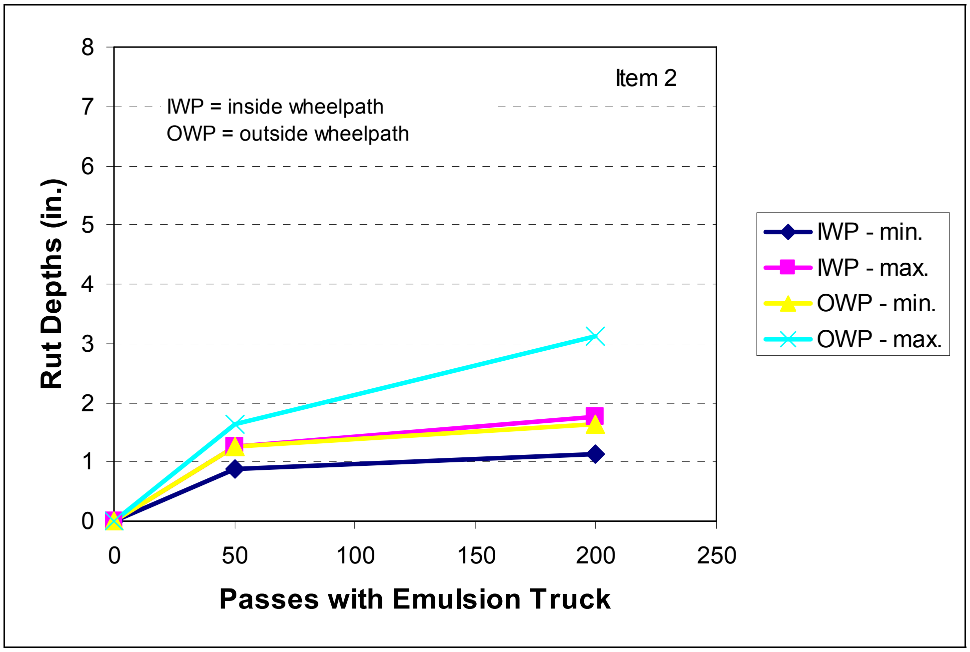

Figure 67. Rut depths for Item 2 (LST), maintenance test section, dry lane, 200 passes with emulsion truck

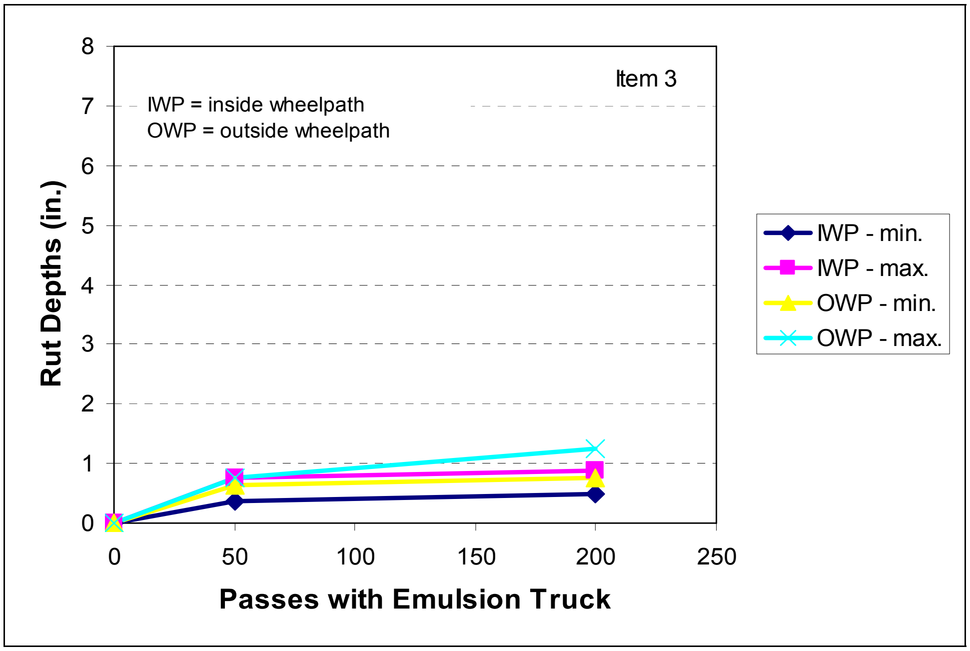

Figure 68. Rut depths for Item 3 (SST), maintenance test section, dry lane, 200 passes with emulsion truck

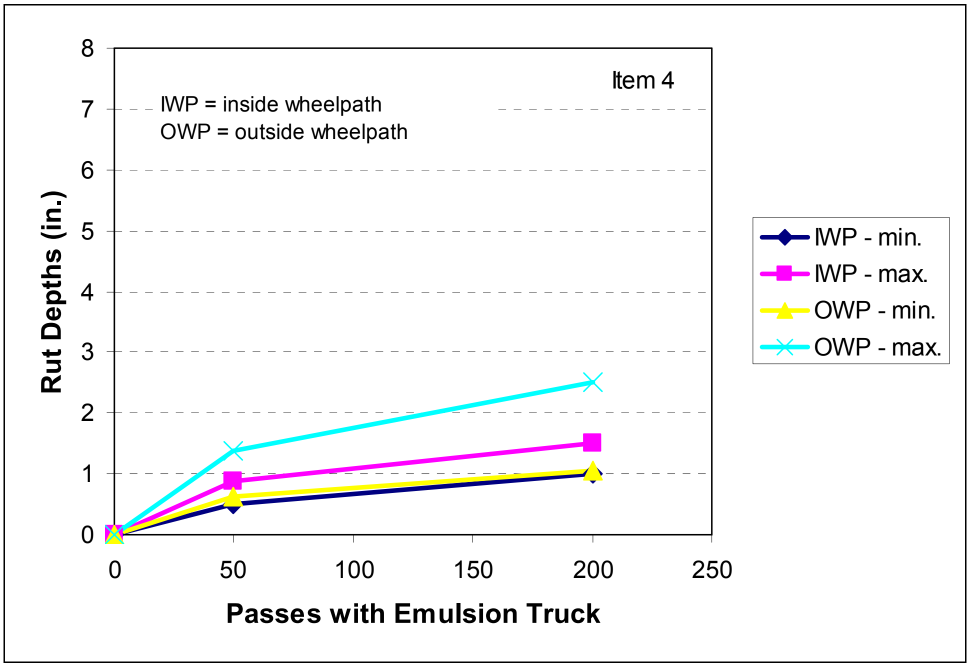

Figure 69. Rut depths for Item 4 (IGN), maintenance test section, dry lane, 200 passes with emulsion truck

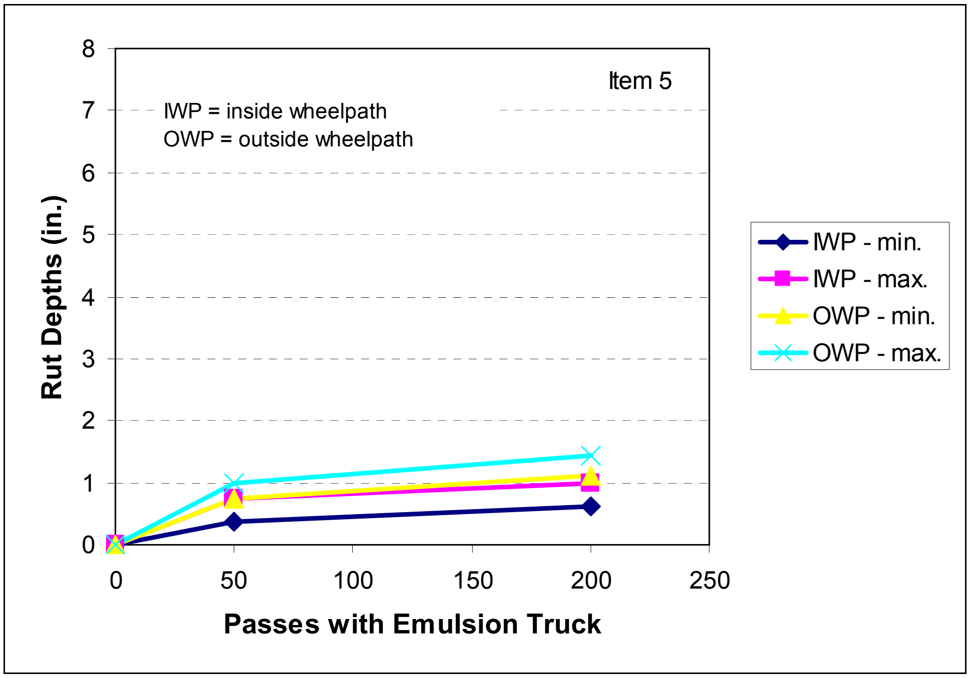

Figure 70. Rut depths for Item 5 (SSB), maintenance test section, dry lane, 200 passes with emulsion truck

6 Maintenance Test Section, Wet Lane

Description

The chronology of trafficking events for this lane is shown in Table 35. In August 2004, the pickup truck was driven over the wet lanes for both the Maintenance and the New Construction test sections. The pickup truck had only passed 10 times when trafficking was stopped. Rutting was particularly excessive in the New Construction test section, but rutting was also easily visible in the Maintenance test section, Item 1 (SCG). Trafficking for this lane did not resume until winter and spring of 2005, when traffic was applied independently of the New Construction test section. This was made possible by building a by-pass lane around the New Construction test section. Pickup truck and dump truck traffic were applied in February 2005. Pickup truck traffic was applied again in March 2005 under conditions that were believed to be very wet and deserving of another light traffic performance evaluation. In April 2005, the CBR truck was driven on the lane for only 50 passes when rutting in Item 1 (SCG) warranted measurement.

Table 35
Chronology of Trafficking Events for Maintenance Test Section, Wet Lane

Date(s)	Event
11-Aug-04	50 seating[1] passes with pickup truck.
12-Aug-04	Smoothed lane by backblading.
25-Aug-04	10 passes with pickup truck.
01-Sep-04	Smoothed lane by backblading.
28-Sep-04	50 seating passes with pickup truck.
03-Feb-05	200 passes with pickup truck.
07-Feb-05	Smoothed lane by backblading.
16-Feb-05	200 passes with dump truck
17-Feb-05	Smoothed lane by backblading.
08-Mar-05	150 passes with pickup truck.
11-Mar-05	Smoothed lane by backblading.
01-Apr-05	50 passes with CBR truck

[1] Seating passes were followed by smoothing or blading; ruts were not measured; they were accomplished to “seat” the test section.

The first application of traffic to wet lanes was conducted after 3.7 in. of rain fell over a 5-day period in August 2004. Moisture contents shown in Table 36 are on the order of 50 percent higher than those measured for previous trafficking in the dry lane. Dry unit weights, however, are similar to those measured previously. The DCP measurements (Table 37) were commensurate with strengths measured prior to previous dry trafficking with exception for SST, which appeared to be in a weakened state. As shown in Figures 71-87, rutting was severe in Items 1 (SCG) and 3 (SST) and, in the other items, was limited to 1 in. or less.

Table 36
Nuclear Density Gage Data Prior to 10 Passes with Pickup Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
1 (SCG)	9.1	127.1
2 (LST)	4.3	126.5
3 (SST)	6.8	129.3
4 (IGN)	3.7	130.6
5 (SSB)	7.2	130.4

Table 37
Dynamic Cone Penetrometer Data Prior to 10 Passes with Pickup Truck

Item	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	20 to 30	100	No data
2 (LST)	8 to 10	50 to 60	No data
3 (SST)	8 to 10	80 to 90	No data
4 (IGN)	6 to 10	50	No data
5 (SSB)	10 to 20	50 to 60	No data

The next application of traffic to this lane occurred 6 months later, after 2.3 in. of rain over a 4-day period. Relative to the previous wet trafficking, moisture contents in SCG and SSB were elevated slightly and dry unit weights were all lower than measured the previous fall (see Table 38). DCP measurements for the strength of surface materials were similar to those measured during dry trafficking (see Table 39). The CBR of the weakest underlying layer was lower than measured previously, but the depths of weak layers were still on the order of 2 ft.

Items 2 and 4 (LST and IGN) performed the best, with maximum rutting less than 1-1/2 in. Items 3 and 5 (SST and SSB) showed maximum rutting of approximately 3 in. Item 1 (SCG) showed the worst performance with maximum rutting of 4-1/2 in. All rutting was shallow in nature (see Photos C31 to C40).

Table 38
Nuclear Density Gage Data Prior to 200 Passes with Pickup Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
1 (SCG)	10.5	124.7
2 (LST)	4.3	123.5
3 (SST)	6.0	122.6
4 (IGN)	3.8	125.3
5 (SSB)	8.7	126.9

Table 39
Dynamic Cone Penetrometer Data Prior to 200 Passes with Pickup Truck

Item	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	20 to 30	60 to 70	10 at 25 in.
2 (LST)	10 to 15	80 to 90	15 at 23 in.
3 (SST)	10 to 15	60	6 to 7 at 20 in.
4 (IGN)	10 to 15	60	6 to 7 at 25 in.
5 (SSB)	15 to 20	80 to 100	20 at 20 in.

In February 2005, after a 0.6-in. rain and generally wet winter conditions, dump truck traffic was applied to the Maintenance test section wet lane. Moisture, density, and strengths did not show anything unusual (see Tables 40 and 41). The granular materials (LST, SST, and IGN) performed the best with maximum rutting of less than 2 in. (see Figures 78, 79, and 80). Item 5 (SSB) had maximum rutting of 5 in. and Item 1 (SCG) had maximum rutting of 9 in. See also Photos C41 to C50.

Table 40
Nuclear Density Gage Data Prior to 200 Passes with Dump Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
1 (SCG)	7.7	129.2
2 (LST)	3.8	124.3
3 (SST)	6.0	127.1
4 (IGN)	3.9	128.6
5 (SSB)	7.3	128.1

Table 41
Dynamic Cone Penetrometer Data Prior to 200 Passes with Dump Truck

Item	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	20 to 30	30 to 40	10 at 20 in.
2 (LST)	10 to 15	50 to 60	10 at 20 in.
3 (SST)	8 to 10	60 to 80	10 at 25 in.
4 (IGN)	6 to 8	50 to 60	10 at 25 in.
5 (SSB)	20 to 30	70 to 80	15 at 20 in.

In March 2005, another application of light pickup truck traffic was believed to be warranted after a particularly severe rain event of 1.25 in. in 1 day. Moisture, density, and strength information (Tables 42 and 43), however, were commensurate with previous measurements. Only Item 1 (SCG) showed poor performance with maximum rutting of 6 in. (Figure 82). All other items had maximum rutting of 2 in. (Figures 83 through 86). Rutting in Item 1 (SCG) was shallow in nature (Photos C51 and C52). Rutting in the granular materials (LST, SST, and IGN) was caused merely by movement of surface particles (Photos C53 through C58). Drying of materials during trafficking was evident by color changes in the wheelpaths (Photos C59 and C60).

Table 42
Nuclear Density Gage Data Prior to 150 Passes with Pickup Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
1 (SCG)	8.6	132.2
2 (LST)	5.7	124.6
3 (SST)	5.8	128.0
4 (IGN)	3.7	130.1
5 (SSB)	7.8	131.5

Table 43
Dynamic Cone Penetrometer Data Prior to 150 Passes with Pickup Truck

Item	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	20	50	6 to 7 at 20 in.
2 (LST)	8 to 10	50	8 to 10 at 25 in.
3 (SST)	50 to 60	80 to 90	8 to 10 at 25 in.
4 (IGN)	8 to 15	15 to 20	2 at 15 in.
5 (SSB)	50 to 60	80 to 90	15 at 20 in.

This lane was next trafficked with the CBR truck at the beginning of April 2005, after a 1.3-in. rain event. Moisture, density, and strength measurements were commensurate with previous data (Tables 44 and 45). Rutting was excessive only in Item 1 (SCG), (see Figure 87 and Photos C61 and C62). All other items held up under traffic very well.

Table 44
Nuclear Density Gage Data Prior to 50 Passes with CBR Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
1 (SCG)	9.4	130.6
2 (LST)	5.7	124.6
3 (SST)	5.0	123.4
4 (IGN)	4.0	128.0
5 (SSB)	8.1	130.3

Table 45
Dynamic Cone Penetrometer Data Prior to 50 Passes with CBR Truck

Item	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
1 (SCG)	30	100	No data
2 (LST)	10 to 20	100	No data
3 (SST)	20 to 30	100	No data
4 (IGN)	15	50	No data
5 (SSB)	40 to 50	100	No data

Summary for Wet Lane, Maintenance Test Section

The SCG material rutted under all traffic scenarios. This material was unstable when wet. Rutting was always shallow, however, and easily repairable due to the stiff nature of the underlying pavement structure.

The sandstone materials (SST and SSB) experienced surficial rutting under traffic during the early trafficking scenarios. However, during later trafficking scenarios they performed well, possibly as the result of densification under traffic, which either caused stiffening or improved efficiency at shedding rain water.

The LST and IGN granular materials performed well under traffic in all cases.

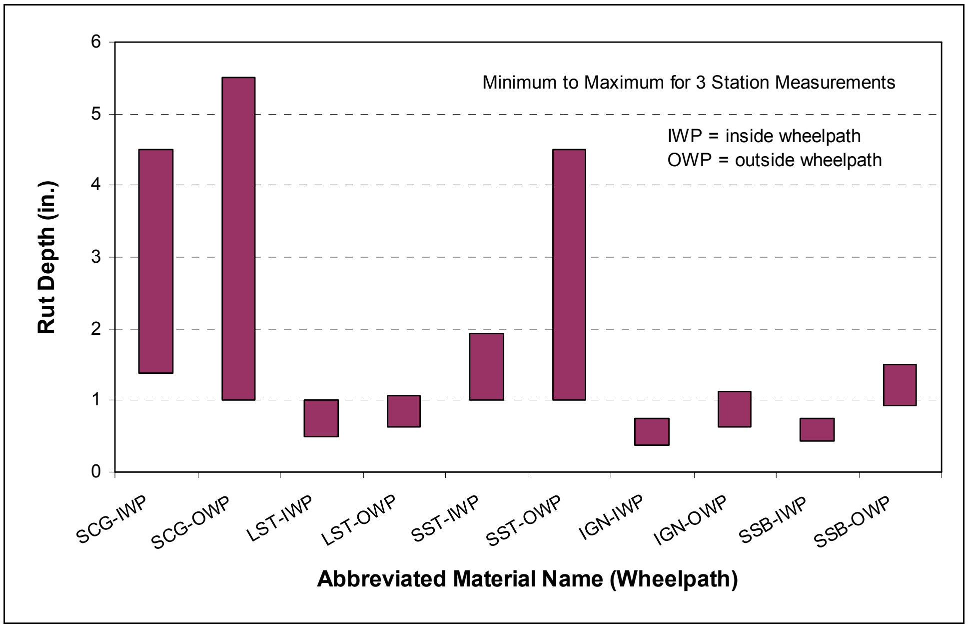

Figure 71. Rut depths for all items, maintenance test section, wet lane, 10 passes with pickup truck

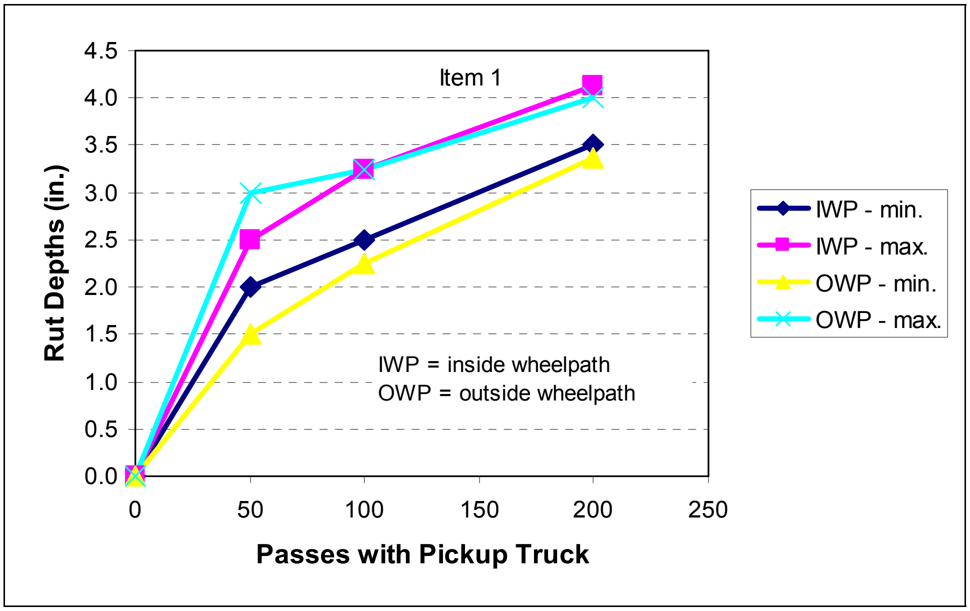

Figure 72. Rut depths for Item 1 (SCG), maintenance test section, wet lane, 200 passes with pickup truck

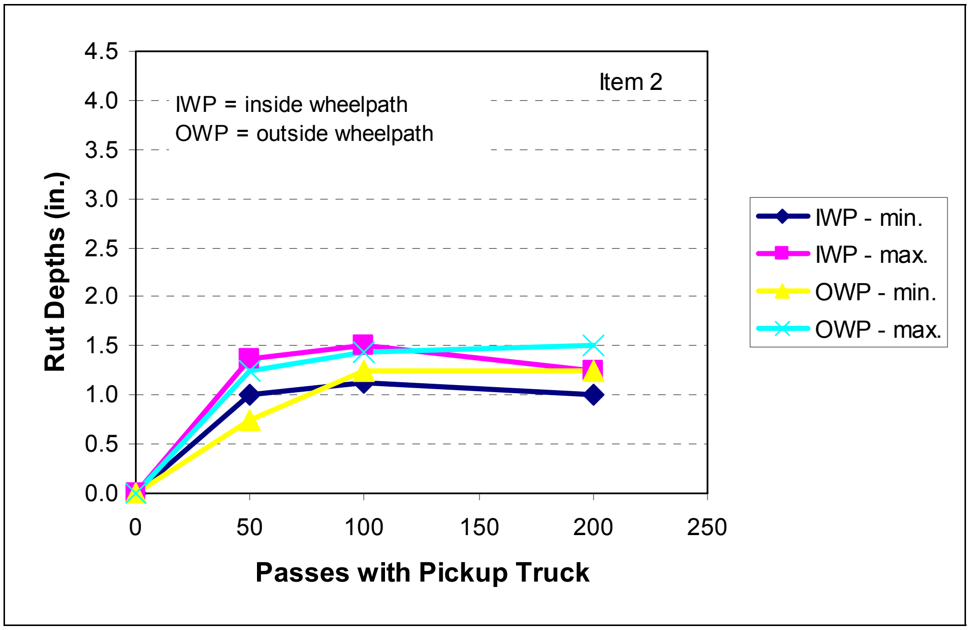

Figure 73. Rut depths for Item 2 (LST), maintenance test section, wet lane, 200 passes with pickup truck

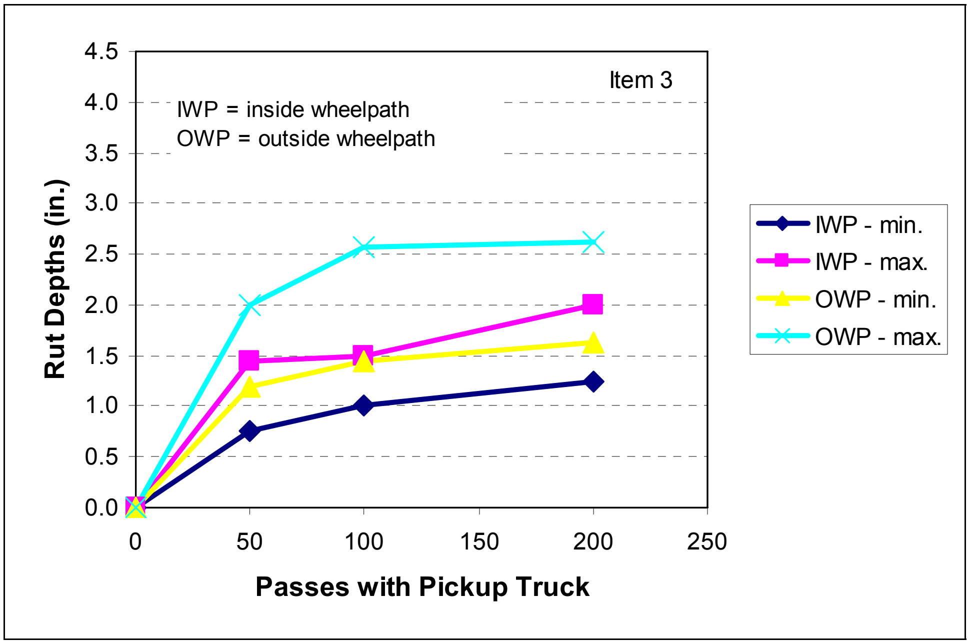

Figure 74. Rut depths for Item 3 (SST), maintenance test section, wet lane, 200 passes with pickup truck

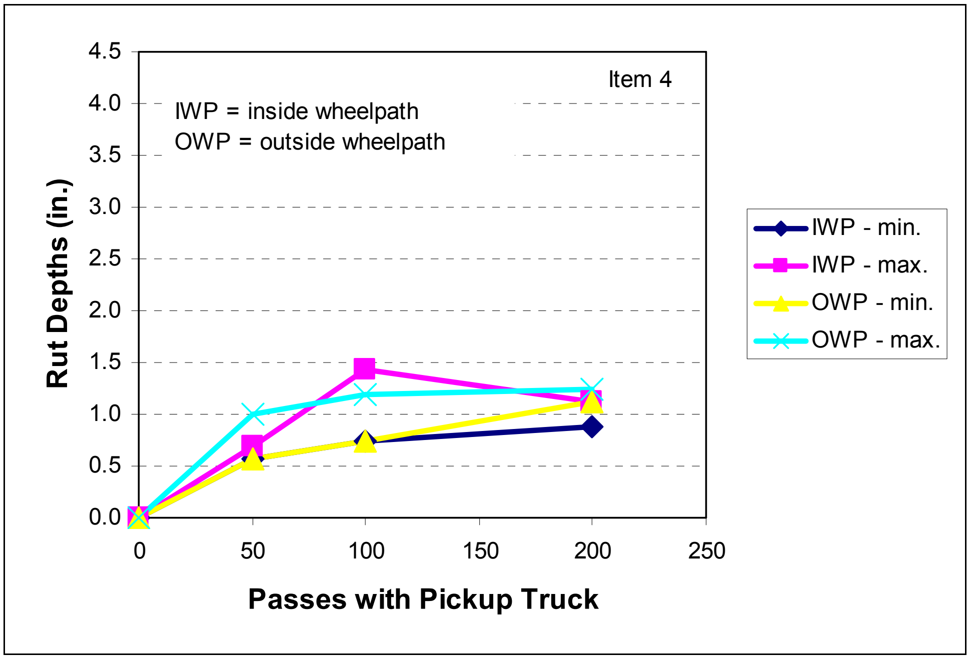

Figure 75. Rut depths for Item 4 (IGN), maintenance test section, wet lane, 200 passes with pickup truck

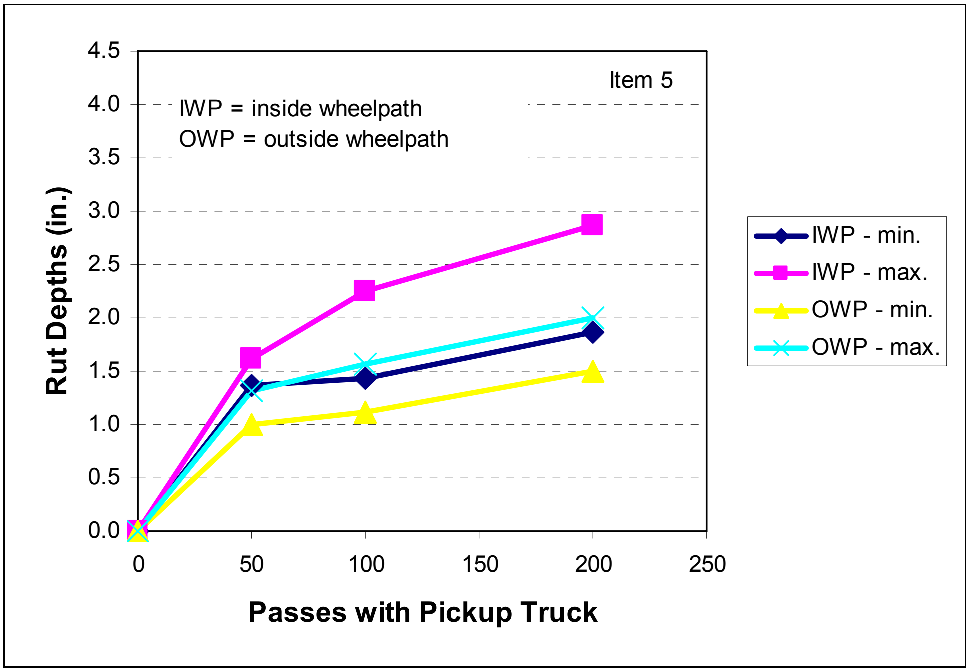

Figure 76. Rut depths for Item 5 (SSB), maintenance test section, wet lane, 200 passes with pickup truck

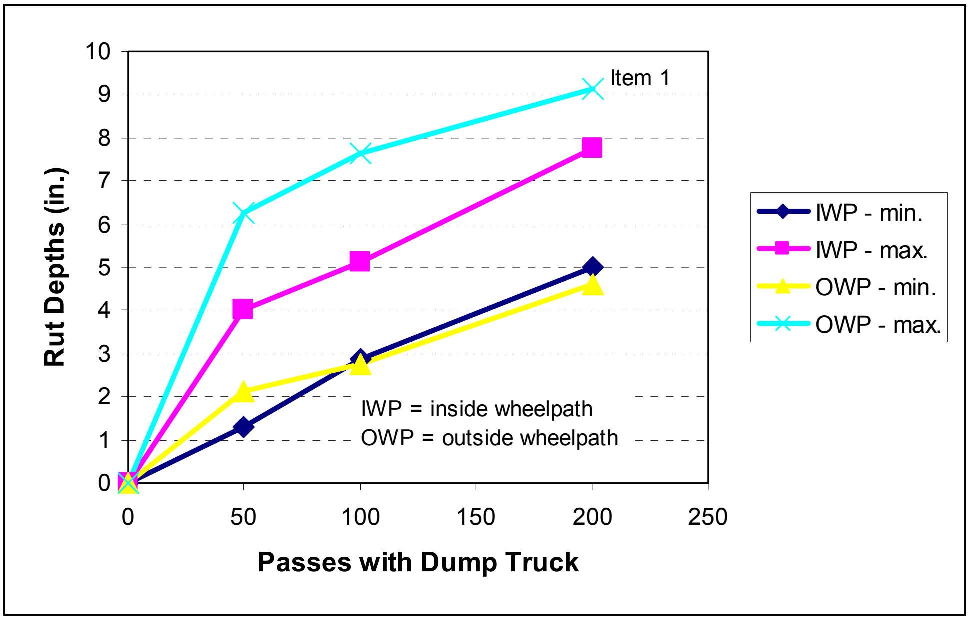

Figure 77. Rut depths for Item 1 (SCG), maintenance test section, wet lane, 200 passes with dump truck

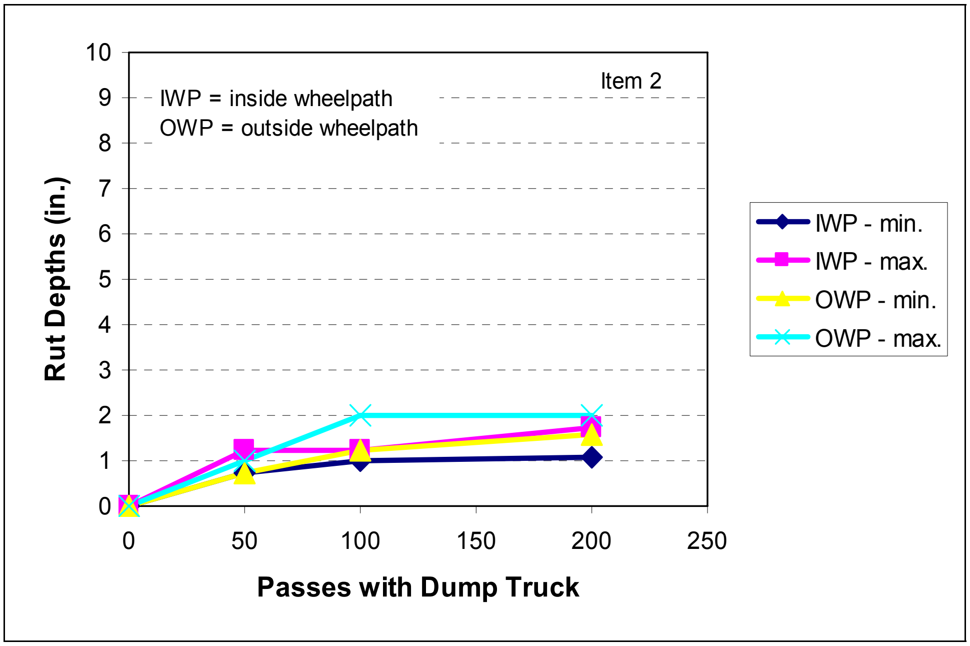

Figure 78. Rut depths for Item 2 (LST), maintenance test section, wet lane, 200 passes with dump truck

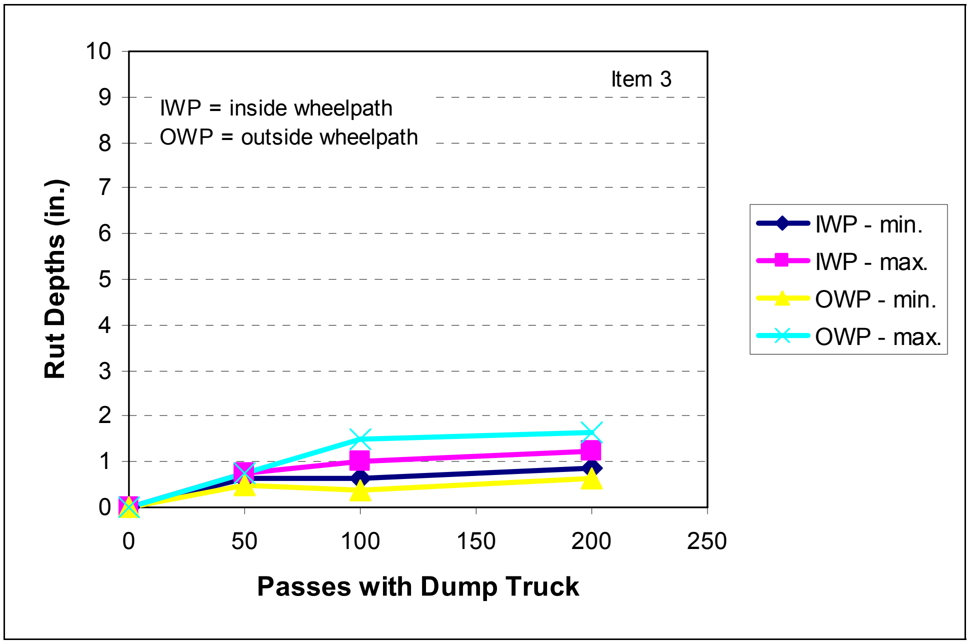

Figure 79. Rut depths for Item 3 (SST), maintenance test section, wet lane, 200 passes with dump truck

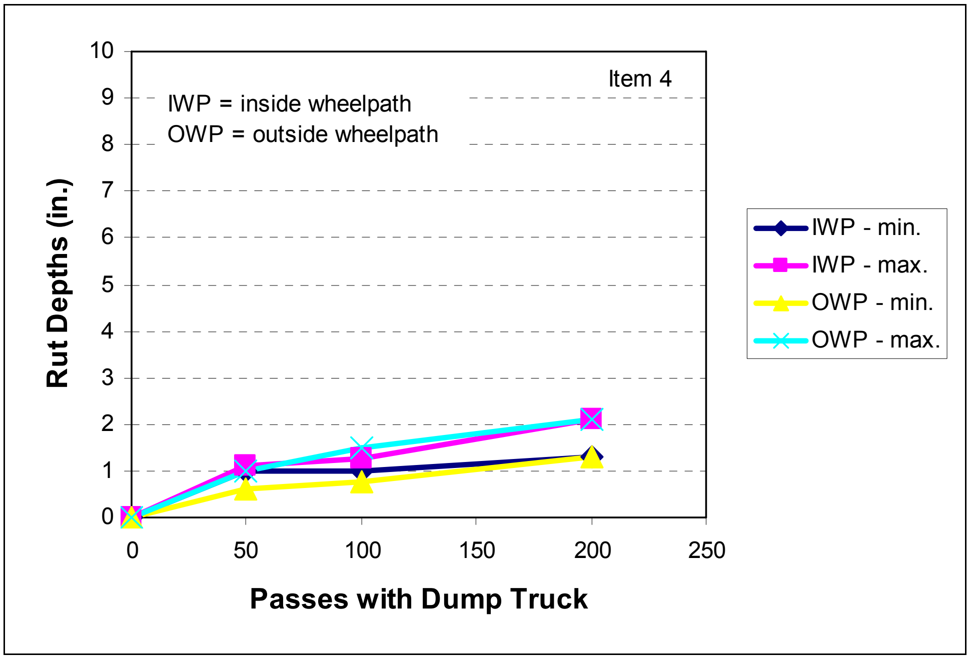

Figure 80. Rut depths for Item 4 (IGN), maintenance test section, wet lane, 200 passes with dump truck

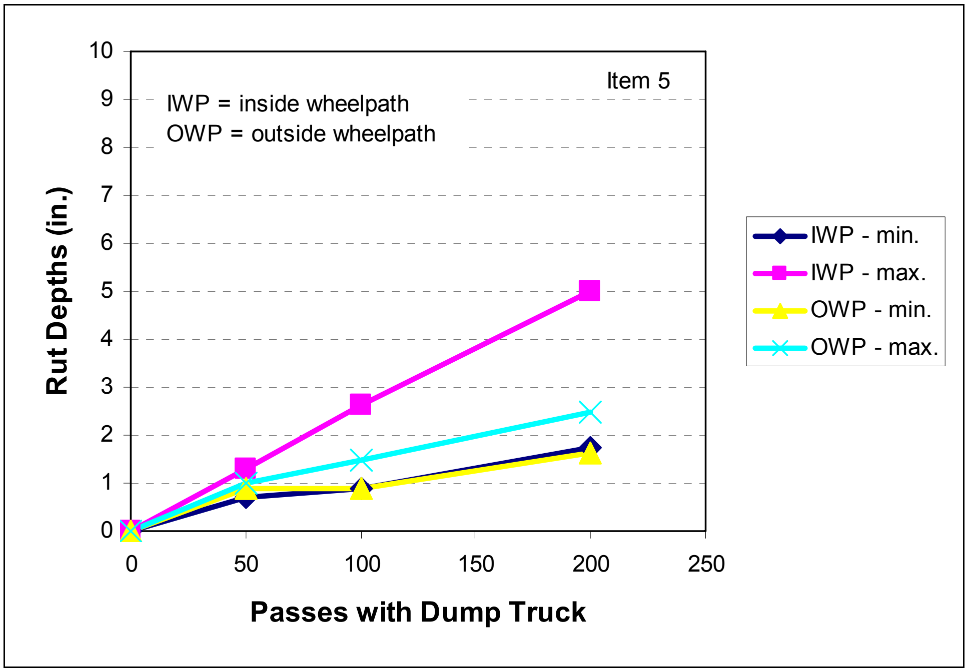

Figure 81. Rut Depths for Item 5 (SSB), maintenance test section, wet lane, 200 passes with dump truck

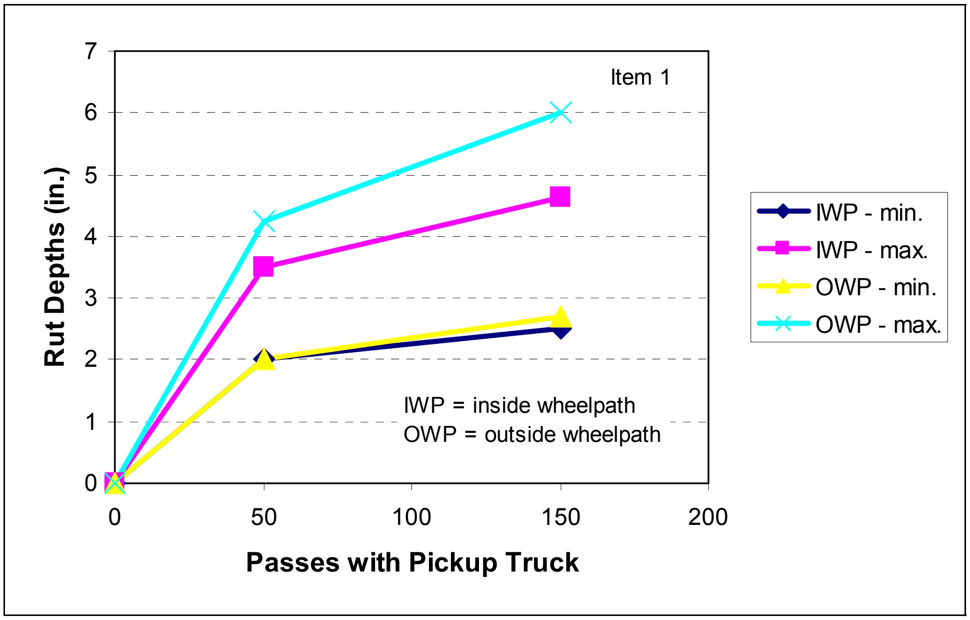

Figure 82. Rut depths for Item 1 (SCG), maintenance test section, wet lane, 150 passes with pickup truck

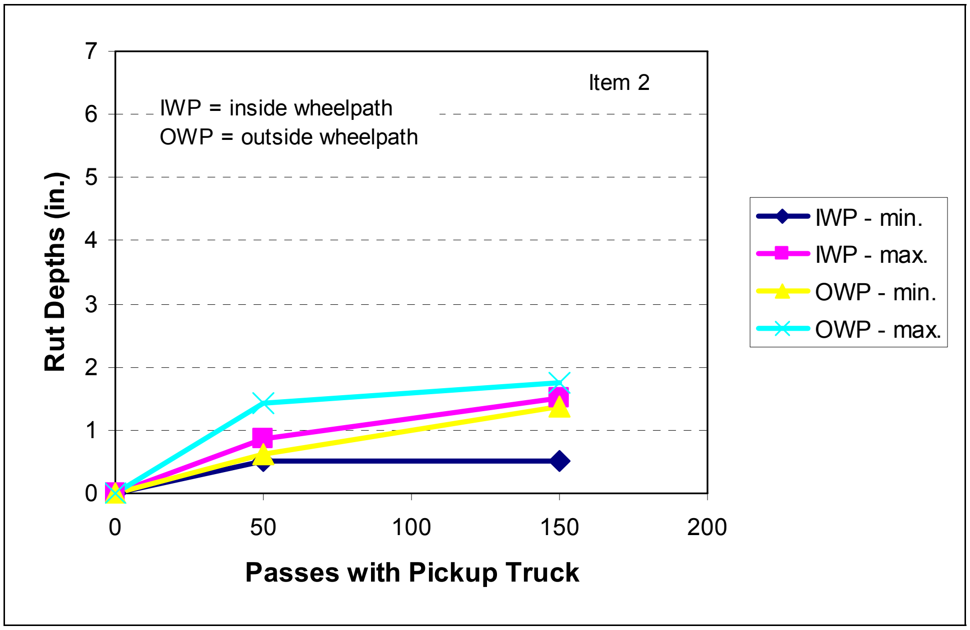

Figure 83. Rut Depths for Item 2 (LST), maintenance test section, wet lane, 150 passes with pickup truck

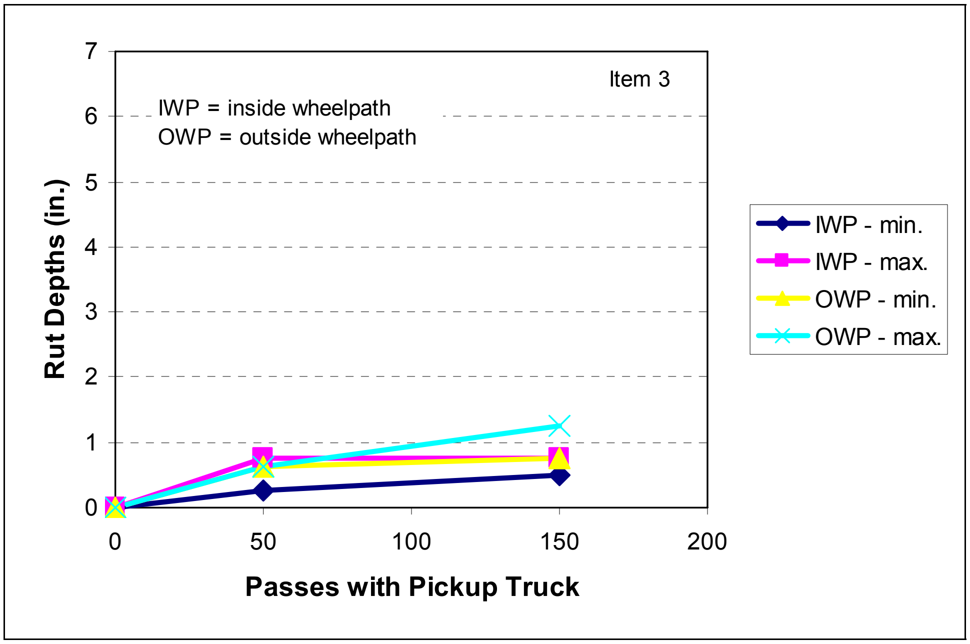

Figure 84. Rut depths for Item 3 (SST), maintenance test section, wet lane, 150 passes with pickup truck

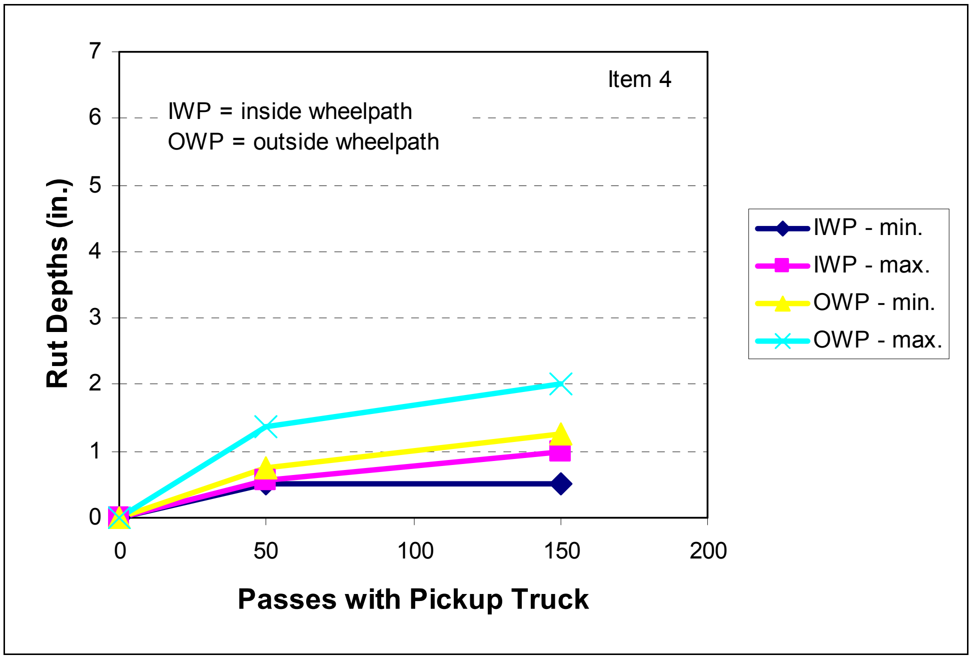

Figure 85. Rut depths for Item 4 (IGN), maintenance test section, wet lane, 150 passes with pickup truck

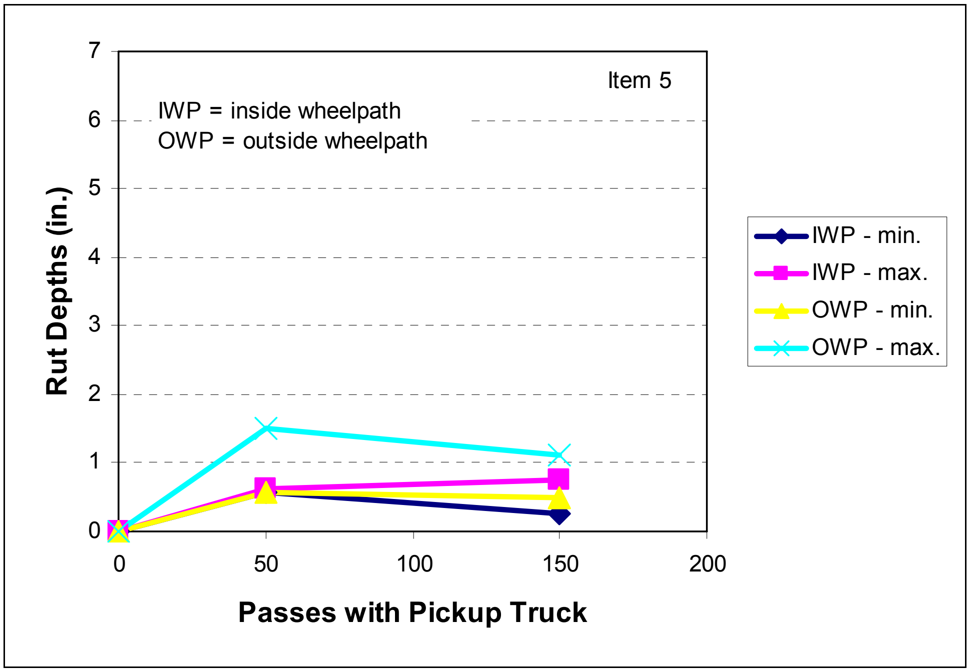

Figure 86. Rut depths for Item 5 (SSB), maintenance test section, wet lane, 150 passes with pickup truck

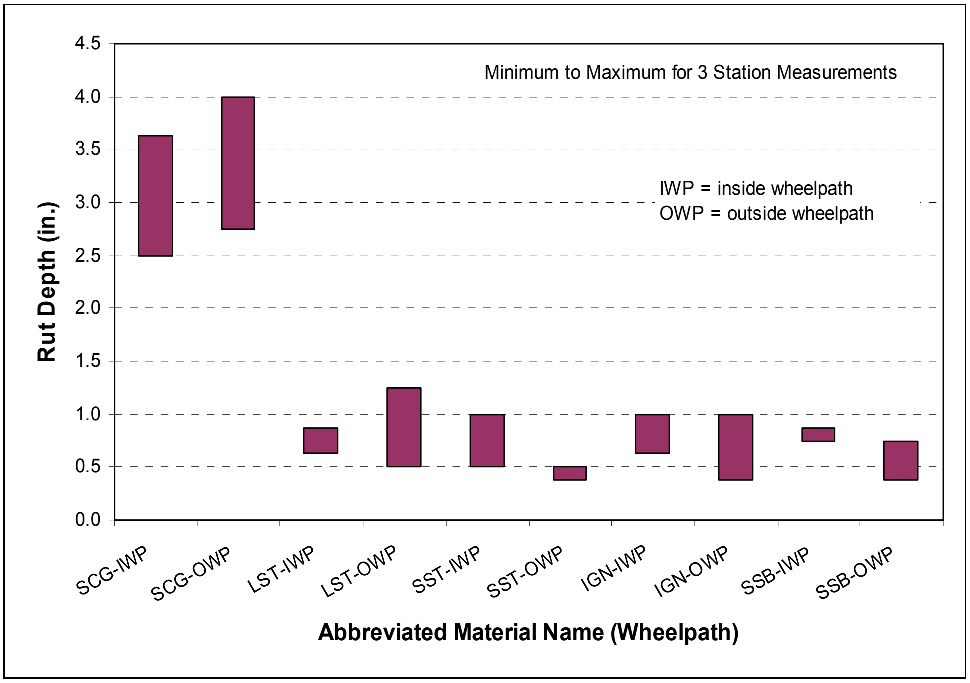

Figure 87. Rut depths for all items, maintenance test section, wet lane, 50 passes with CBR truck

7 New Construction Test Section, Dry Lane

Description

The chronology of trafficking events for this lane is shown in Table 46. All trafficking for this lane was performed as a full loop, with concurrent trafficking on the Maintenance test section, Dry Lane. The pickup truck was driven over the lane for 2,500 passes over a period of 2.5 months (August to October 2004). During November 2004, the dump truck traveled over the lane only 15 times when trafficking had to be stopped. Rutting in Item 7 (LST) was excessive.

Table 46
Chronology of Trafficking Events for New Construction Test Section, Dry Lane

Date(s)	Event
11-Aug-04	50 seating[1] passes with pickup truck.
12-Aug-04	Smoothed lane by backblading.
13-Aug-04	150 passes with pickup truck.
17-Aug-04	500 cumulative passes with pickup truck.
23-Sep-04	1,500 cumulative passes with pickup truck.
27-Oct-04	2,500 cumulative passes with pickup truck.
10-Nov-04	Smoothed lane by hand raking.
17-Nov-04	15 passes with dump truck.

[1] Seating passes were followed by smoothing or blading; ruts were not measured; they were accomplished to “seat” the test section.

Moisture contents for the surface aggregates stayed relatively constant during the application of pickup truck traffic (see Figure 88). Because of their higher proportions of fines, the moisture content for SCG and SSB remained about 1.5 to 2 times that for LST, SST, and IGN. Dry unit weights for surface aggregates started relatively low and in the range of 120 to 125 pcf (see Figure 89). This resulted from the minimal compaction during construction and because the materials were placed in a moisture condition less than optimum. The dry unit weights of surface aggregates all increased during trafficking (see Figure 89), leveling off in the range of 125 to 130 pcf.

The confined strengths for most surface aggregates remained relatively constant, as can be ascertained from Tables 47 through 48, column 3. Confined strengths are those achieved near the bottom of the 6-in. lift, away from the unconfined surface. The exception was SSB, which demonstrated hardening over time, improving from 25 to 40 CBR to 80 to 100 CBR. Subgrade weakening was apparent for the center three items (LST, SST, and IGN), as seen in the fourth column of Table 47. Water would have been nearly constantly available for percolation up into the constructed subgrade. Water was seen ponding in the woods, along the outside shoulder (Photo 3). Although ponding was evident adjacent to all items, water may have accessed the middle items more effectively for reasons related to water table or materials underlying the roadway.

Table 47
Dynamic Cone Penetrometer Data for Pickup Truck Traffic at 0 Passes

Item	Station	Confined CBR for Surface Material	CBR and Depth of Shallow Underlying Weak Layer	CBR and Depth of Weakest Underlying Layer
6 (SCG)	0 + 12.5	30 to 50	10 at 10 in.	8 at 15 in.
	0 + 25	80 to 100	10 at 10 in.	---
	0 + 37.5	20 to 30	10 at 15 in.	---
7 (LST)	0 + 62.5	20	6 to 7 at 10 in.	---
	0 + 75	20 to 30	8 at 10 in.	---
	0 + 87.5	20	6 to 7 at 8 in.	---
8 (SST)	1 + 12.5	30	15 at 10 in.	---
	1 + 25	50	8 at 8 in.	---
	1 + 37.5	50	10 at 10 in.	---
9 (IGN)	1 + 62.5	15	8 at 10 in.	---
	1 + 75	15	8 at 7 in.	---
	1 + 87.5	15	8 at 10 in.	---
10 (SSB)	2 + 12.5	25	10 at 10 in.	---
	2 + 25	30 to 40	15 at 10 in.	6 at 25 in.
	2 + 37.5	25	8 at 10 in.	---

In terms of rutting, the SCG, SST, and SSB materials performed the best under the pickup truck traffic (see Figures 90 through 94). The LST, SST, and IGN materials all showed surface particle movement that contributed to some rutting (see Photos C73 through C78). The LST and IGN materials also formed corrugations, although the corrugations eventually smoothed out under wandering traffic. The LST was showing signs of structural rutting at 2,500 passes (see Photo C84). The SCG rutting was concentrated only at the transition with incoming roadway (Photo C81), so it was not considered in rut calculations.

The only other attempt to traffic this lane was accomplished in November 2004, with the dump truck, after a dry spell of 2 weeks. Because the perpetual wetness of the underlying subgrade continued into 2005, all future trafficking on the New Construction test section was considered "wet." Moisture and density for the surface materials were typical for dry conditions (Table 49), as was the

Table 48
Dynamic Cone Penetrometer Data for Pickup Truck Traffic at 1,500 Passes

Item	Station	Confined CBR for Surface Material	CBR and Depth of Shallow Underlying Weak Layer	CBR and Depth of Weakest Underlying Layer
6 (SCG)	0 + 12.5	10	6 to 7 at 10 in.	5 at 15 in.
	0 + 25	80	10 at 10 in.	5 to 6 at 20 in.
	0 + 37.5	50 to 60	8 to 9 at 10 in.	6 to 7 at 20 in.
7 (LST)	0 + 62.5	15	5 at 10 in.	---
	0 + 75	15	5 at 10 in.	---
	0 + 87.5	10 to 15	5 at 10 in.	---
8 (SST)	1 + 12.5	30	10 at 10 in.	---
	1 + 25	60	10 at 12 in.	---
	1 + 37.5	50 to 60	10 at 12 in.	---
9 (IGN)	1 + 62.5	40	8 at 10 in.	---
	1 + 75	20	6 at 10 in.	---
	1 + 87.5	15	8 at 10 in.	---
10 (SSB)	2 + 12.5	80	15 at 15 in.	6 at 25 in.
	2 + 25	100	10 at 15 in.	6 to 7 at 20 in.
	2 + 37.5	100	20 at 10 in.	10 at 25 in.

Table 49
Dynamic Cone Penetrometer Data for Pickup Truck Traffic at 2,500 Passes

Item	Station	Confined CBR for Surface Material	CBR and Depth of Shallow Underlying Weak Layer	CBR and Depth of Weakest Underlying Layer
6 (SCG)	0 + 12.5	15 to 20	5 at 7 in.	4 at 10 in.
	0 + 25	100	15 at 10 in.	8 at 20 in.
	0 + 37.5	100	15 at 10 in.	9 at 20 in.
7 (LST)	0 + 62.5	15	3 to 4 at 8 in.	---
	0 + 75	30	2 at 9 in.	---
	0 + 87.5	15	1 to 2 at 10 in.	---
8 (SST)	1 + 12.5	25	3 at 10 in.	---
	1 + 25	30 to 40	5 at 10 in.	---
	1 + 37.5	25	5 at 10 in.	---
9 (IGN)	1 + 62.5	15 to 20	2 to 3 at 10 in.	---
	1 + 75	15	2 at 10 in.	---
	1 + 87.5	15	2 at 10 in.	---
10 (SSB)	2 + 12.5	80 to 100	20 at 10 in.	8 at 20 in.
	2 + 25	100	15 at 10 in.	7 at 17 in.
	2 + 37.5	80 to 100	20 at 10 in.	15 at 20 in.

strength of surface materials (Table 50, column 2). The strengths of the subgrade materials, however, had become a concern (Table 51, column 3). The CBR of soil beneath in the LST and IGN test items had dropped to 1 and 4, respectively. It is surmised that these materials were most permeable, thus allowing the most rain water to penetrate down into the subgrade. This effect supplemented the availability of water from the shoulder.

Table 50
Nuclear Density Gage Data Prior to 15 Passes with Dump Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
6 (SCG)	6.2	131.7
7 (LST)	3.3	127.7
8 (SST)	2.9	129.7
9 (IGN)	1.9	129.2
10 (SSB)	4.6	128.9

Table 51
Dynamic Cone Penetrometer Data Prior to 15 Passes with Dump Truck

Item	Confined CBR for Surface Material	High CBR for Underlying Road Material	CBR of Weakest Underlying Layer and Depth
6 (SCG)	60	10 at 15 in.	---
7 (LST)	10 to 15	1 to 2 at 7 in.	---
8 (SST)	40 to 50	15 at 10 in.	---
9 (IGN)	25	4 at 10 in.	---
10 (SSB)	80 to 100	15 at 12 in.	---

After only 10 passes with the dump truck, rutting was becoming severe for the LST (Photos C91 through C94). The LST was bladed smooth and trafficking was attempted again. After only 5 additional passes, totaling 15, traffic was stopped because of excessive rutting in LST (Figure 95 and Photos C95 and C96). A forensic investigation involved removing surface aggregates to reveal the surface of the subgrade. Standing water was found on the subgrade, and the subgrade was found to have pumped up into the surface aggregate material (Photos 4 and 5).

Summary for Dry Lane, New Construction Test Section

Under pickup truck traffic, all unbonded surfacing materials performed adequately, but the materials with higher fine contents (SCG and SSB) and fewer large particles (SST) performed the best. These materials were less susceptible to loose aggregate movement at the road surface.

Under the heavy dump truck traffic, the LST failed rapidly because of a weakened subgrade condition. The LST and IGN materials appeared to be most apt to letting rain water penetrate through the surface layer, thus accessing and weakening the subgrade. This problem was exasperated in this test section by the availability of water from ponding in the outside shoulder.

After the fall of 2004, the subgrade did not ever dry out. All future trafficking for the New Construction test section was considered “wet.”

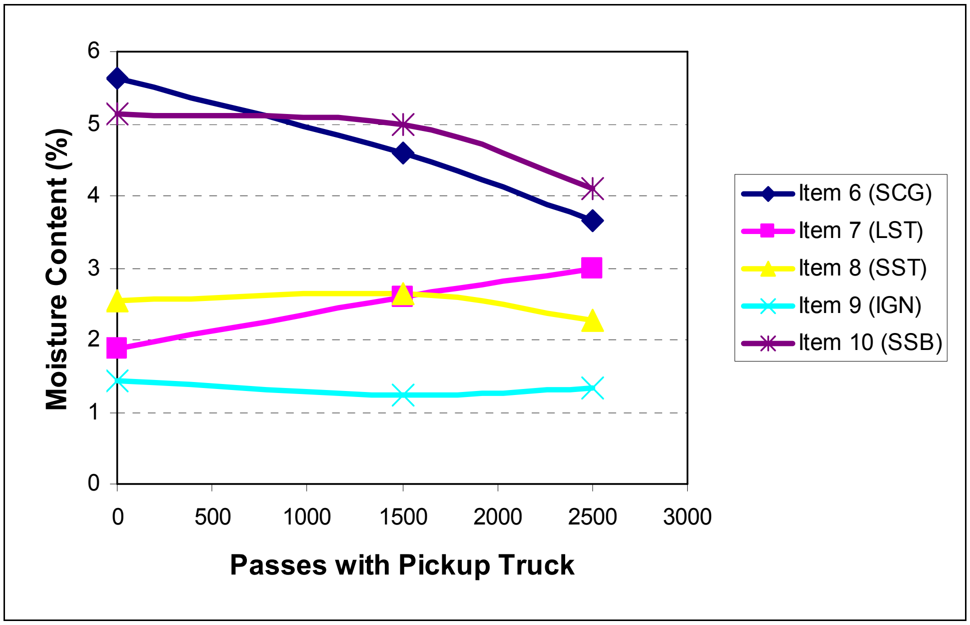

Figure 88. Moisture contents for surface aggregates on new construction test section, dry lane, 2,500 passes with pickup truck

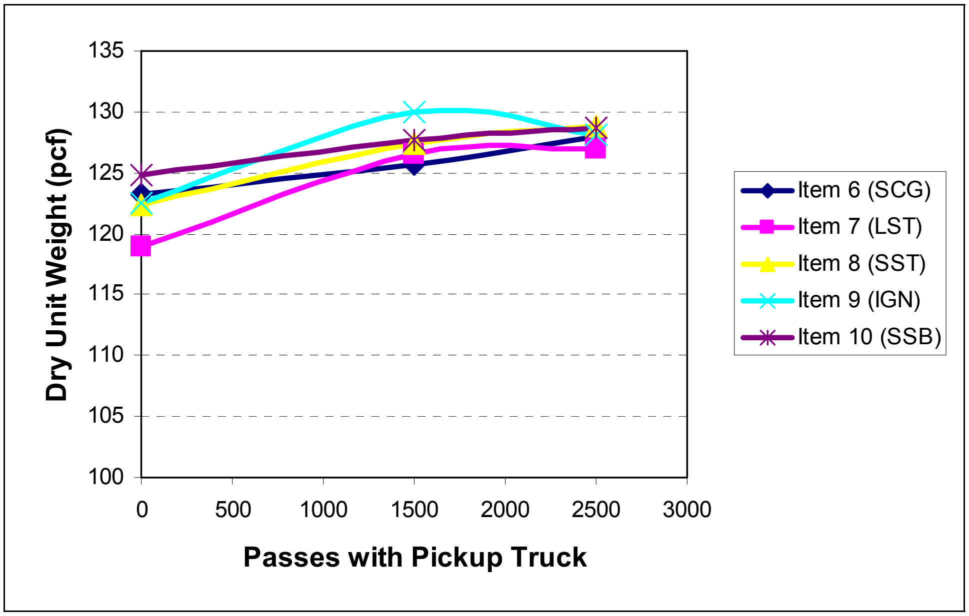

Figure 89. Dry unit weights for surface aggregates on new construction test section, dry lane, 2,500 passes with pickup truck

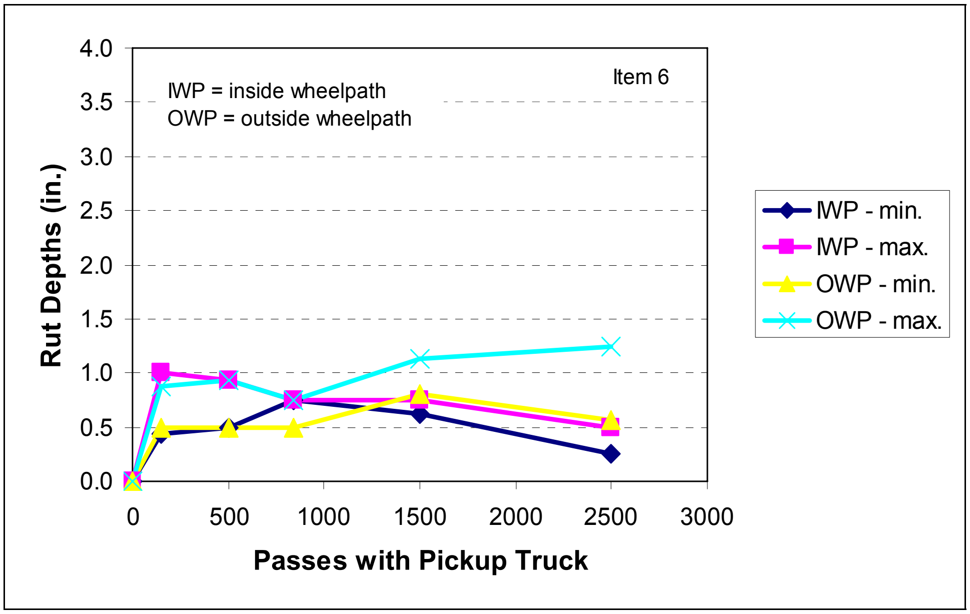

Figure 90. Rut depths for Item 6 (SCG), new construction test section, dry lane, 2,500 passes with pickup truck

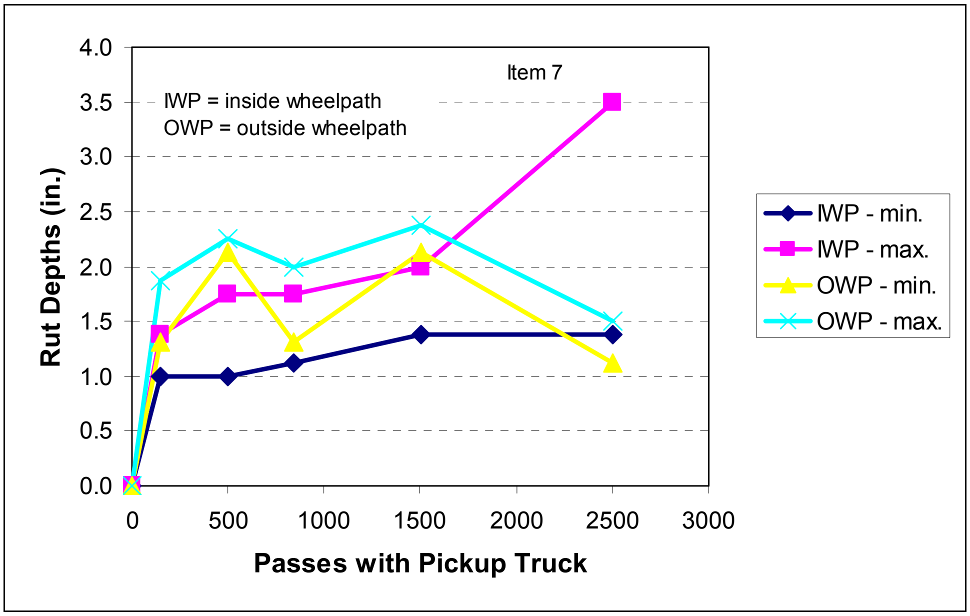

Figure 91. Rut depths for Item 7 (LST), new construction test section, dry lane, 2,500 passes with pickup truck

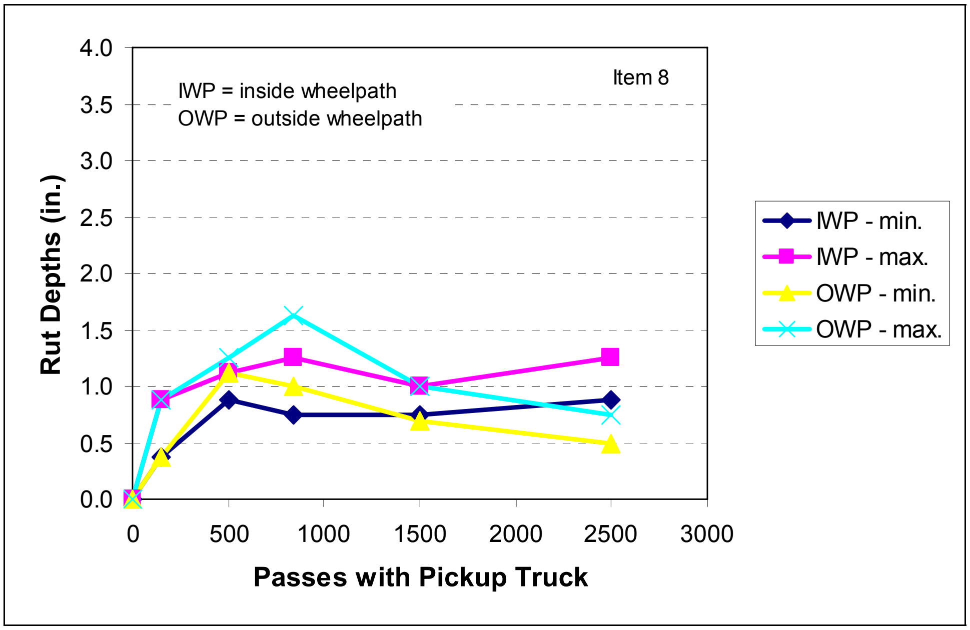

Figure 92. Rut depths for Item 8 (SST), new construction test section, dry lane, 2,500 passes with pickup truck

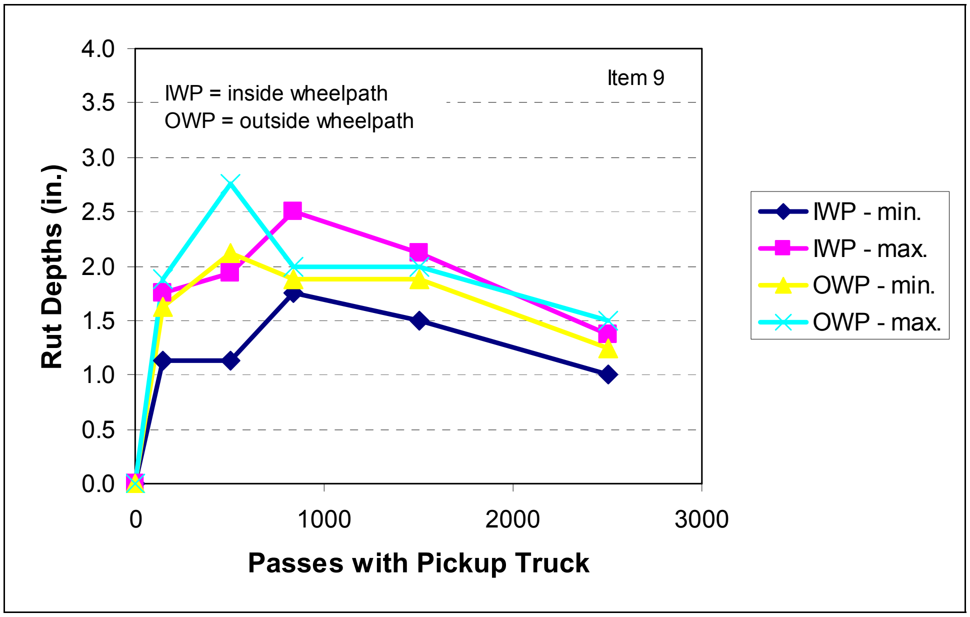

Figure 93. Rut depths for Item 9 (IGN), new construction test section, dry lane, 2,500 passes with pickup truck

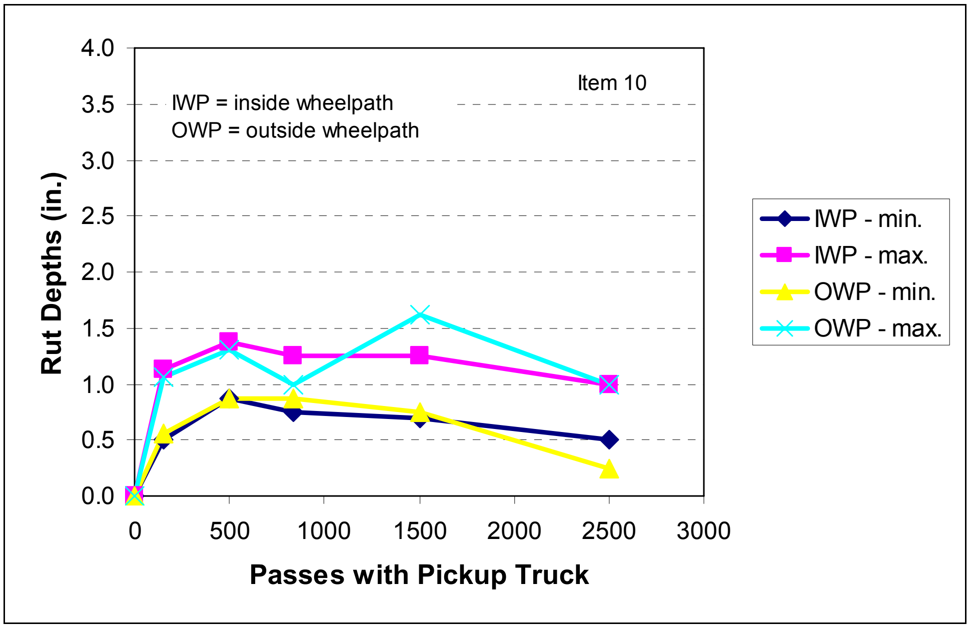

Figure 94. Rut depths for Item 10 (SSB), new construction test section, dry lane, 2,500 passes with pickup truck

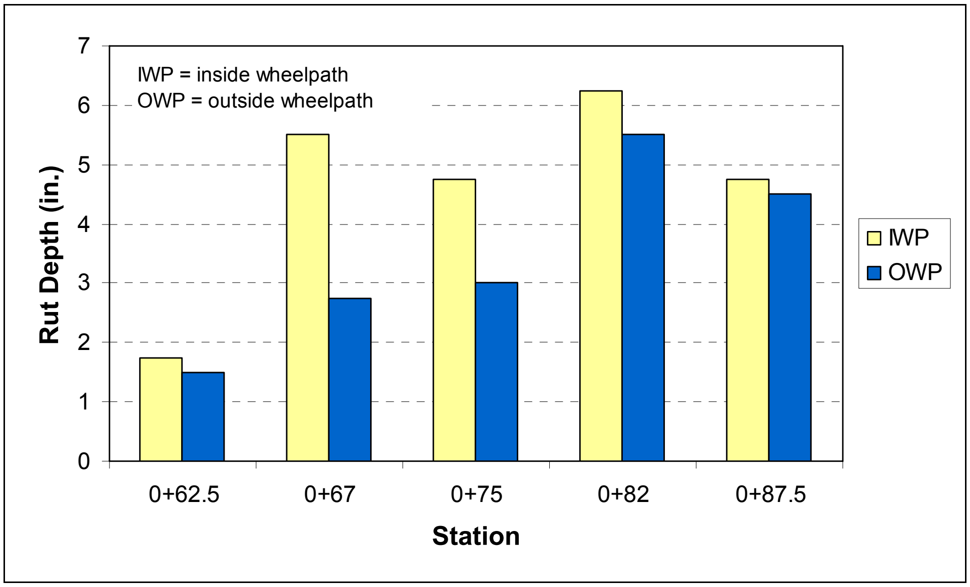

Figure 95. Rut depths for Item 7 (LST), new construction test section, dry lane, 15 passes with dump truck

Photo 3. Ponding of water along outside shoulder

Photo 4. Wet subgrade under Item 7 (LST) surface aggregate

Photo 5. Subgrade pumping up into surface aggregate for Item 7 (LST)

8 New Construction Test Section, Wet Lane

Description

The chronology of trafficking events for this lane is shown in Table 52. In August 2004, the pickup truck was driven over the wet lanes for both the New Construction and the Maintenance test sections (Figure 96). The pickup truck had only passed 10 times when trafficking was stopped. Rutting was particularly excessive in Item 7 (LST). Trafficking for this lane did not resume until April 2005. The subgrade in this lane became wet and weak soon after construction and it never dried out. April trafficking for this lane was accomplished independent of the Maintenance test section wet lane. Because of the wet subgrade in this lane, trafficking in April was short. After only 25 passes with the pickup truck, rutting in Item 9 (IGN) warranted measurement. After resmoothing all lanes, only 25 passes were possible for the CBR truck before the lane became impassable.

Table 52
Chronology of Trafficking Events for New Construction Test Section, Wet Lane

Date(s)	Event
11-Aug-04	50 seating[1] passes with pickup truck.
12-Aug-04	Smoothed lane by backblading.
25-Aug-04	10 passes with pickup truck.
01-Sep-04	Smoothed lane by backblading.
28-Sep-04	50 seating passes with pickup truck.
15-Apr-05	25 passes with pickup truck.
15-Apr-05	25 passes with CBR truck.

[1] Seating passes were followed by smoothing or blading; ruts were not measured; they were accomplished to “seat” the test section.

The first application of traffic to wet lanes was conducted after 3.7 in. of rain fell over a 5-day period in August 2004. Moisture contents and densities for the surface aggregates (Table 53) are commensurate with those measured for the companion items in the Maintenance test section. From DCP measurements

(Table 54), the strength of SCG and SSB seemed weakened by the rain. Also, the subgrades of LST, SST, and IGN test items were extremely weak (CBR = 1).

Table 53
Nuclear Density Gage Data Prior to 10 Passes with Pickup Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
6 (SCG)	7.8	124.8
7 (LST)	4.3	125.3
8 (SST)	5.1	126.5
9 (IGN)	3.6	128.1
10 (SSB)	7.3	126.7

Table 54
Dynamic Cone Penetrometer Data Prior to 10 Passes with Pickup Truck

Item	Confined CBR for Surface Material	CBR and Depth of Shallow Underlying Weak Layer	CBR and Depth of Weakest Underlying Layer
6 (SCG)	10	6 to 7 at 8 in.	5 to 6 at 17 in.
7 (LST)	6	1 at 10 in.	---
8 (SST)	8 to 10	1 at 10 in.	---
9 (IGN)	15 to 20	1 at 10 in.	---
10 (SSB)	15	8 at 8 in.	5 at 25 in.

After only 10 passes with a pickup truck, trafficking was stopped because of excessive rutting in Item 7 (Figure 97). Rutting in Items 8 and 9 (SST and IGN) had also reached 1-1/2 in.

The next application of traffic to this lane involved both the pickup truck and the CBR truck. Traffic was applied 3 days after a rain of 1.8 in. Surface aggregates were slightly drier than for previous “wet” trafficking (see Table 55). Contrary to the previous fall, now the subgrades beneath all the items had become weakened to CBRs of 4 or less (see Table 56).

Table 55
Nuclear Density Gage Data Prior to 25 Passes with Pickup Truck and 25 Passes with CBR Truck

Item	Moisture Contents (%) of Surface Aggregates	Dry Unit Weights (pcf) of Surface Aggregates
6 (SCG)	6.5	127.6
7 (LST)	4.0	129.9
8 (SST)	4.6	128.2
9 (IGN)	2.9	126.0
10 (SSB)	5.9	130.4

Table 56
Dynamic Cone Penetrometer Data Prior to 25 Passes with Pickup Truck and 25 Passes with CBR Truck

Item	Confined CBR for Surface Material	CBR and Depth of Shallow Underlying Weak Layer	CBR and Depth of Weakest Underlying Layer
6 (SCG)	20	1 to 2 at 12 in.	---
7 (LST)	15 to 20	4 at 10 in.	---
8 (SST)	30	2 at 10 in.	---
9 (IGN)	10 to 15	2 to 3 at 8 in.	---
10 (SSB)	20 to 30	2 at 8 in.	---

After 25 passes with the pickup truck, rut depths for Item 9 (IGN) had already become severe (Figure 97). See also Photos C100 to C102. Other items had only surface aggregate movement, with no structural rutting (Photos C97 to C99 and C103). All items were smoothed out in preparation for trafficking with the CBR truck. After 25 passes with the CBR truck, the lane was nearly impassable. Rutting in Items 6 (SCG), 8 (SST), and 9 (IGN) was particularly severe (Figure 98). Items 7 (LST) and 10 (SSB) performed the best, although maximum rutting was still on the order of 4-1/2 in. for these items (see Photos C104 to C112).

After CBR truck traffic, surface aggregates were removed and ruts were measured at the top of the subgrade. For all items, the subgrade rutting accounted for over one-half of the total rutting that was measured on the road surface. Subgrade properties were measured with a nuclear gage, for comparison with as-constructed properties. As mentioned in Chapter 4, the moisture content at the time of construction was 11 percent and the dry density was approximately 107 pcf. Table 57 shows that while dry unit weight decreased only slightly, moisture content increased substantially. This was as expected, given the decreases in strength, as measured by the DCP.

Table 57
Nuclear Density Gage Data for the Subgrades after Pickup and CBR Truck Trafficking

Item	Moisture Contents (%) of Top of Subgrade	Dry Unit Weights (pcf) of Top of Subgrade
6 (SCG)	20.9	104.3
7 (LST)	18.7	107.0
8 (SST)	17.4	107.4
9 (IGN)	20.1	105.0
10 (SSB)	19.0	106.4

Summary for Wet Lane, New Construction Test Section

Subgrade weakening due to the availability of moisture controlled the performance of test items in this lane. Under pickup truck traffic, Items 7 (LST) and 9 (IGN) showed the worst deterioration, in the form of structural rutting. Water was available from shoulder ponding for all items. Water was also available from surface infiltration, particularly for the coarsely graded LST and IGN aggregates.

The only item that held up relatively well under all trafficking scenarios (pickup truck and CBR truck) was Item 10 (SSB). Because of its high fines content, the SSB was able to resist surface infiltration of water. Also, because of its dense gradation, in combination with angularity, the SSB provided good load spreading capability and resisted movement of particles at the road surface.

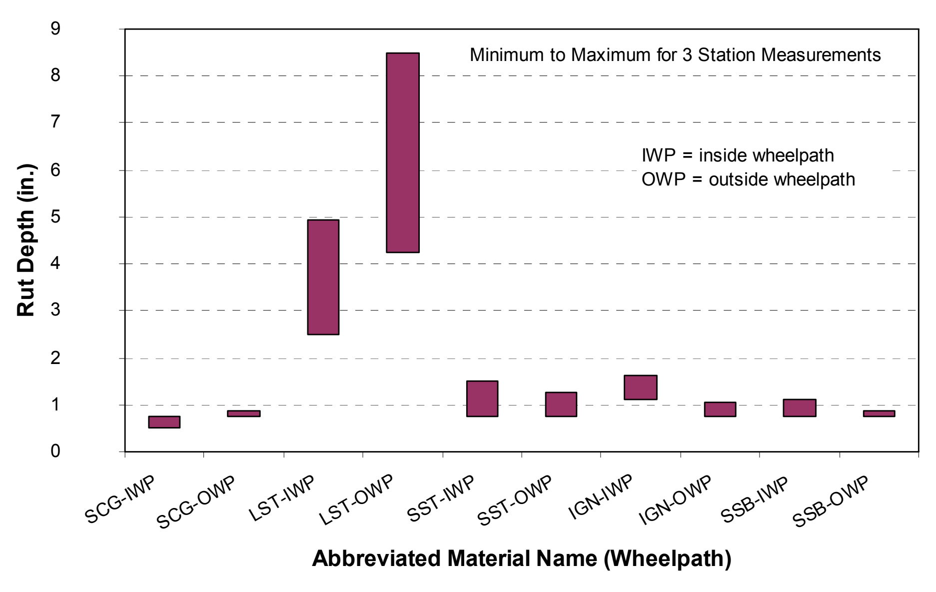

Figure 96. Rut depths for all items, new construction test section, wet lane, 10 passes with pickup truck (August 2004)

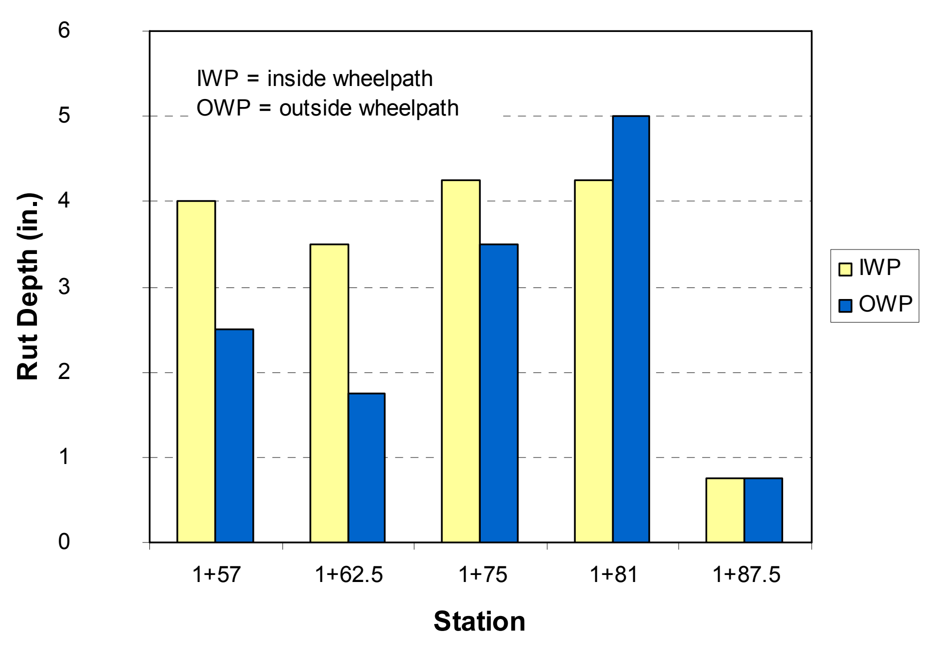

Figure 97. Rut depths for Item 9 (IGN), new construction test section, wet lane, 25 passes with pickup truck (April 2005)

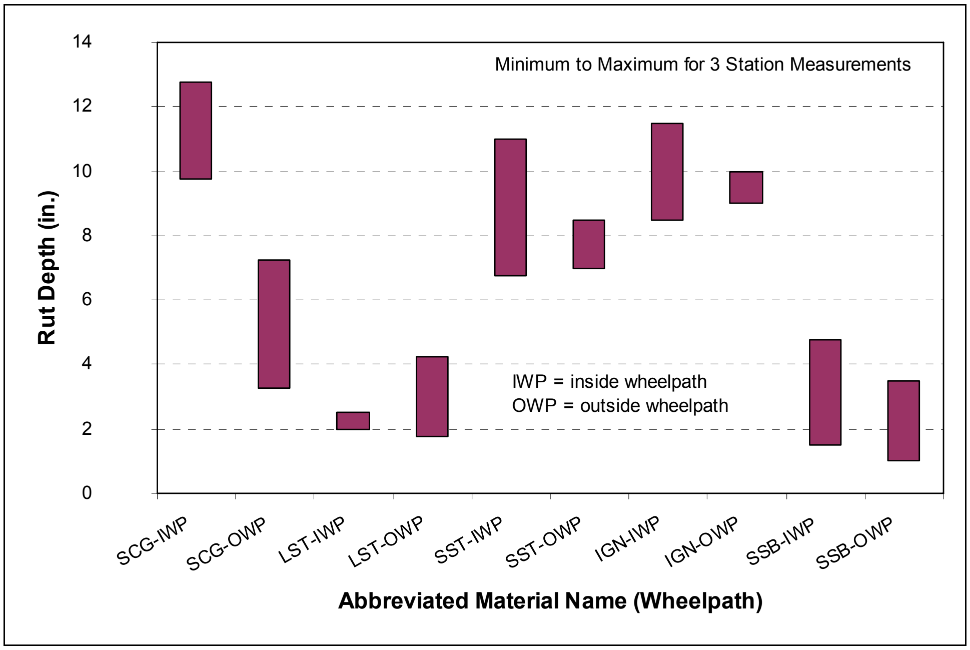

Figure 98. Rut depths for all items, new construction test section, wet lane, 25 passes with CBR truck (April 2005)

9 Summary, Conclusions, and Recommendations

Engineers at the Vicksburg District (MVK), Mississippi Valley Division (MVD), U.S. Army Corps of Engineers (USACE), design and construct levees all along the Mississippi River and its tributaries within the District's boundaries. The MVD is also responsible for maintaining approximately 390 miles of unpaved roads that reside on top of the levees. The roads are necessary for providing easy vehicular access for the purposes of levee maintenance and emergency operations. Surfacing the unbonded roads had traditionally been accomplished with sand clay gravel, but the reliable sources of this material were becoming depleted. Therefore, engineers from the MVK and MVD needed an experimental investigation on a broad range of aggregate types that could be used for surfacing unbonded roads. Specifically, they required a comparison between the effectiveness of different aggregate types, and they needed recommendations for improvements to their specifications on surfacing aggregate.

Engineers from the MVK consulted with the U.S. Army Engineer Research and Development Center (ERDC), and these agencies collectively decided that the best approach to the investigation would involve the construction of simulated levee roads on a test track where environmental conditions, traffic, and roadway performance could be monitored closely. The test track was located at the ERDC's Waterways Experiment Station (WES) in Vicksburg, MS. The levee construction on the track included two test sections, one intending to simulate new levee road construction and one intending to simulate levee road maintenance, which would involve an overlay-type situation. For the "New Construction" test section, 6 in. of experimental aggregate was placed directly on a lean clay (CL) subgrade. For the "Maintenance" test section, 6 in. of experimental aggregate was placed on top of a road structure that simulated an "existing road," that is, a road that required maintenance. The "existing road" included 6 in. of sand clay gravel on top of a mixture of aggregate and soil, which were materials remaining from an old roadbed.

Five aggregate types were included in this study: sand clay gravel (SCG), limestone (LST), sandstone (SST), igneous rock (IGN), and sandstone with binder (SSB). The SCG was the only natural gravel; all others were produced from crushing operations. The SSB included crushed sandstone that was blended with lean clay to produce a material that had plasticity characteristics similar to the SCG.

The aggregates were delivered to WES by dump trucks. Timing and distances to some sources did not permit material quality checks prior to delivery. Consequently, some aggregates did not conform to USACE specifications and/or specifications produced by the MVK. The non-conformances will be summarized here. Relative to the Unified Facilities Guide Specification UFGS-02731, the SCG and SSB materials had plasticity indices (PI) that exceeded the upper limit. Also relative to the UFGS, the IGN was too coarse and the SSB had an excessive proportion of fines. Relative to the MVK specification for aggregate grading, both the SCG and SSB materials were too fine.

The two test sections were trafficked with several vehicle types: pickup truck, dump truck, CBR (flatbed) truck, and an emulsion (dual-tandem) truck. Dry lanes were trafficked during dry weather, and wet lanes were trafficked soon after rain events. Road performance was monitored visually, by measuring rut depths, and by surveying transverse surface profiles. Material properties in the test sections were monitored for moisture, density, and strength by dynamic cone penetrometer (DCP).

Summary of Roadway Performance

On the Maintenance test section and under dry conditions, all unbonded surfacing materials performed adequately under pickup truck traffic. The materials with higher fine contents (SCG and SSB) performed best because they were less susceptible to loose aggregate movement at the road surface. Under heavy emulsion truck traffic, the aggregate with rounded particles (SCG) performed the worst and the two sandstone aggregates (SST and SSB) performed the best, possibly because of their combination of angularity and sufficient proportion of finer particles, relative to LST and IGN.

When trafficking the Maintenance test section under wet conditions, the SCG material rutted under all traffic scenarios. This material was unstable when wet. Rutting was always shallow, however, and easily repairable because of the stiff nature of the underlying pavement structure. The sandstone materials (SST and SSB) experienced surficial rutting under traffic during the early trafficking scenarios (i.e., soon after construction). However, during later trafficking scenarios they performed well, possibly because of densification under traffic, which caused either stiffening or improved efficiency at shedding rain water. The LST and IGN granular materials performed well under traffic in all cases.

On the New Construction test section and under dry conditions, all unbonded surfacing materials performed adequately under pickup truck traffic, but the materials with higher fine contents (SCG and SSB) and fewer large particles (SST) performed the best. These materials were less susceptible to loose aggregate movement at the road surface. Under the heavy CBR truck traffic, the LST failed rapidly because of a weakened subgrade condition. The LST and IGN materials appeared to be most apt to letting rainwater penetrate through the surface layer, thus accessing and weakening the subgrade. This problem was aggravated in this test section by the availability of water from ponding in the outside shoulder.

On the New Construction test section and under wet conditions, subgrade weakening controlled the performance of test items. Under pickup truck traffic, Items 7 (LST) and 9 (IGN) showed the worst deterioration, in the form of structural rutting. While water was available from shoulder ponding for all test items, surface infiltration of water was particularly severe for the coarsely graded LST and IGN aggregates. The only item that held up relatively well under all trafficking scenarios (pickup truck and heavy CBR truck) was Item 10 (SSB). Because of its high fines content, the SSB was able to resist surface infiltration of water. Also, because of its dense gradation, in combination with angularity, the SSB provided good load spreading capability (subgrade protection) and resisted movement of particles at the road surface.

The performances of roadway surface aggregates under traffic are summarized in terms of relative qualitative rankings in Tables 58 and 59.

Table 58
Relative Performance of Surface Aggregates for Maintenance Test Sections[1]

Abbreviated Common Name	Dry Conditions		Wet Conditions
	Light Traffic	Heavy Traffic	Light and Heavy Traffic
SCG	Best	Poor	Poor
LST	Good	Good	Best
SST	Good	Best	Good
IGN	Good	Good	Best
SSB	Best	Best	Good

[1] Aggregates (6 in. thick) were placed over 6 in. of existing SCG.

Table 59
Relative Performance of Surface Aggregates for New Construction Test Sections[1]

Abbreviated Common Name	Dry Conditions	Wet Conditions	
	Light Traffic[2]	Light Traffic	Heavy Traffic
SCG	Best	Fair	Poor
LST	Good	Poor	Poor
SST	Best	Fair	Poor
IGN	Good	Poor	Poor
SSB	Best	Good	Fair

[1] Aggregates (6 in. thick) were placed directly on top of lean clay subgrade.
[2] Performance under heavy traffic was difficult to compare because the subgrade became wet soon after construction and it was never able to dry out.

Conclusions

The results of this investigation support that a wide range of crushed materials would be well suited for use in levee road maintenance (i.e., overlay) situations. In these situations, the sand clay gravel residing under the surface course would serve as a subbase. If coarsely graded materials such as the LST and IGN aggregates used herein were placed as the surface course, they would offer the advantage of providing a stable surface during wet weather. If materials with more fines such as the SSB used herein were placed as the surface course, they would offer the advantage of a smoother riding surface with less loose aggregate movement. The SST behaved in a manner intermediate between LST/IGN and SSB. The SCG, which was the only natural (i.e., not crushed) aggregate used herein, was susceptible to rutting under heavy traffic, even in a dry condition. The SCG would be the worst choice in a road maintenance situation.

The results of this investigation support that aggregate grading is critical when building a new levee road, that is, when the aggregate is to be placed directly on top of fine-grained soil. Coarsely graded materials, such as the LST, SST, and IGN aggregates, do not provide any protection from the infiltration of rain water. With water accessing the subgrade surface, the subgrade becomes weak and the road becomes susceptible to structural failure. For construction of new levee roads, the SSB would provide much better protection for the soil and would provide a relatively smooth riding surface. The SSB is the best choice for new construction situations. If a coarsely graded material (such as the LST, SST, or IGN) must be used as the surface course, it should be placed on top of a well-graded subbase-type material. The subbase material would have sufficient fines to provide some protection against intrusion of moisture from the surface to the subgrade. It would also help prevent migration of subgrade fines into the surface aggregate. Cost-effective subbase materials include sand clay gravel as defined in this report or any soil/aggregate blends that meet the requirements of Unified Facilities Guide Specification UFGS-02721A.

There was no indication in this study that the limestone had an advantage over sandstone and igneous aggregates, because of its ability for developing natural cementation between particles over time. The limestone test items did not form any hard crust surfaces and the dynamic cone penetrometer did not detect any increases in strength over time. The limestone, sandstone, and igneous aggregates were all equally capable of maintaining pavement cross-slope. The absence of cementation in this study likely resulted because the limestone was relatively coarsely graded and included only about 6 percent fines (particles passing the No. 200 sieve).

Recommendations for Road Construction

For the purpose of presenting recommendations, levee road construction will be classified into three types of structures.

a. Two-layer structures constructed with crushed aggregates in the surface course and either crushed or natural aggregates in the underlying layer.

b. Natural aggregate surface layers to be used for maintenance (i.e., overlay) operations.

c. Single layer structures consisting of crushed aggregate placed directly on natural soil.

Structure (a) is used when traffic is expected to include heavy truck traffic (e.g., 3+ axles) and/or when good road performance during wet weather is important. Structure (b) is used only when traffic is known to be almost entirely passenger cars and pickup trucks. Structure (c) is used when funding prevents the use of structure (a) or the road is not so critical during wet weather that it warrants structure (a).

The material to be used for the surface course in structure (a) above should be similar to either the “crushed aggregates” or the “crushed aggregate with binder” currently specified by the MVK. The underlying layer for structure (a) could be a material meeting the “sand clay gravel” requirements, a material meeting “crushed aggregate with binder requirements,” or a material that meets subbase requirements, as specified in UFGS-02721A. The material to be used for structure (b) above should be similar to the “sand clay gravel” currently specified by the MVK. The material to be used for structure (c) above should be similar to the “crushed aggregate with binder” currently specified by the MVK.

The MVK material requirements (reviewed in Chapter 1) will now be presented along with a few recommended changes, beginning with particle size distributions.

a. There is no evidence from this project to support changing the MVK grading requirements for the natural aggregate (i.e., sand clay gravel). The delivered product was finer than that allowed by MVK; it had insufficient sand-sized particles. The sand clay gravel used in this study would likely have performed better if it met the MVK requirements.

b. While the LST aggregate met MVK requirements for “crushed stone,” it had insufficient particles smaller than 1 mm to meet the USACE guide specification (UFGS 02731A) requirements for Grading No. 1. The LST aggregate in this study would likely have performed better if it had been finer in grading. Therefore, Grading No. 1 is recommended as a replacement for the current MVK requirement for crushed stone (see Table 60). Grading No. 1 also happens to be similar to the FHWA grading requirement.

c. The crushed aggregate with binder used in this study (i.e., the SSB) benefited from its fines content and its plasticity of fines in a manner similar to the way these physical properties benefit sand clay gravel. Therefore, it is recommended that the percent passing the No. 200 sieve be similar for these two aggregate types. It is recommended that the range of allowable percent passing No. 200 for crushed stone with binder be increased from 3 to 12 percent to 5 to 15 percent (as shown in Table 60).

Table 60
Recommended MVK Grading Requirements for Surface Aggregates

Sieve Size	Sand Clay Gravel	Crushed Stone	Crushed Stone with Binder
50.0 mm (2 in.)	100	---	---
37.5 mm (1-1/2 in.)	95 – 100	100	100
25.0 mm (1 in.)	75 – 100	---	---
19.0 mm (3/4 in.)	---	97 – 100	50 – 100
12.5 mm (1/2 in.)	45 – 90	---	42 – 85
4.75 mm (No. 4)	30 – 65	41 – 71	25 – 65
2.00 mm (No. 10)	20 – 50	---	20 – 50
0.425 mm (No. 40)	10 – 30	12 – 28	10 – 32
0.075 mm (No. 200)	5 – 15	9 – 16	5 – 15

Currently, the MVK specifies the following durability requirements for the coarse fraction (retained on No. 4 sieve) of all three MVK materials.

a. LA abrasion (AASHTO T 96) ≤40 percent after 500 revolutions.

b. Magnesium sulfate soundness loss (AASHTO T 104) ≤15 percent after 5 cycles.

There is no evidence in this study to support changing these requirements, so they should remain unchanged.

The MVK specification does not include a requirement for flat and/or elongated particles. It is recommended that the following USACE (UFGS-02731A) requirement be adopted for all three types of MVK materials. Minimizing flat and/or elongated particles will facilitate compaction and will help to minimize the movement of loose surface particles.

- Particles with length/width ratios and/or width/thickness ratios of 3:1 or more must account for no more than 20 percent by mass of particles retained on the No. 4 sieve and larger (measured according to ASTM D 4791).

The MVK specification does not include a requirement for fractured faces. It is recommended that the MVK adopt the following requirement from the

Washington State DOT. This requirement would apply to the MVK "crushed stone" and "crushed stone with binder" materials.

- At least 75 percent of the particles on each of the sieves No. 4 and larger must have at least one fractured face (counted in according with ASTM D 5821). This Washington State DOT requirement is increased relative to the FHWA requirement for at least 50 percent fractured particles.

Currently, the MVK specifies a maximum liquid limit (AASHTO T 89) of 30 percent for the minus No. 40 fraction for both "sand clay gravel" and "crushed stone with binder." Both the SCG and the SSB had liquid limits near the allowable maximum. Given that the UFGS specification and the FHWA both specify a maximum allowable LL of 35 percent, it is suggested that the MVK adopt a similar limit for both "sand clay gravel" and "crushed stone with binder":

- Liquid Limit ≤ 35 percent.

Currently, the MVK requires a plasticity index (AASHTO T 90) = 5 to 15 percent for "sand clay gravel" and a plasticity index of 4 to 9 percent for "crushed stone with binder." Given that the SSB used in this study had a PI of 14 and that the high PI did not cause problems, it is recommended that the limits for plasticity index be the same for both "sand clay gravel" and "crushed stone with binder":

- Plasticity Index = 5 to 15 percent.

Currently, the MVK has no requirements for plasticity of "crushed stone" fines; these fines are assumed to be non-plastic. However, fractured faces are not specified for the fine fraction, so soil blending could produce fines with plasticity. A small amount of plasticity would not be harmful as long as gradation requirements are met. The following plasticity requirements are recommended for "crushed stone" materials, as a precaution. The liquid limit requirement is consist with the other MVK materials and the plasticity index limit matches the UFGS 02731A upper limit.

a. Liquid Limit ≤ 35 percent and

b. Plasticity Index ≤ 9 percent

Although the South African specification was effective in differentiating between the performances of coarse granular materials (LST, SST, and IGN) and aggregates with fines (SCG and SSB), the South African specification is not recommended for adoption. This specification requires the use of a British Standard test, which measures linear shrinkage of particles passing the No. 40 sieve. It would be difficult to find consulting firms that could perform this test. Also, correlations between linear shrinkage and Atterberg limits were not found to be strong enough to allow for a practical substitution.

Several additional tests were conducted in this study and are not recommended for adoption by the MVK, including the uncompacted voids test and the sand equivalent test.

Finally, a precaution for compaction is recommended for adoption by the MVK. Although MVK stated that compaction equipment would not be available at levee construction sites and that compaction would continue to be provided only by trucks that are hauling aggregate, a precaution could still be implemented in terms of moisture content. The aggregates in this study were compacted after a long period of drying in stockpiles. Although the SCG and the SSB retained some moisture, the other aggregates were very dry. This made compaction difficult. It is recommended that the MVK require moisture contents to be within 2 percent of optimum, as determined by ASTM D 698 (standard Proctor compaction).

Recommendations for Further Research

The aggregates received for this project did not permit documentation of the benefits related to self-cementation of crushed limestone. Further study of this phenomenon, including the development of laboratory test methods for quantifying potential for self-cementation is warranted.

All the aggregates met all the LA abrasion requirements for USACE and the various other agencies. However, the abrasion values for IGN, SST, and SSB were higher than for SCG and LST: 27 to 34 percent versus 18 to 19 percent. This study did not provide a good opportunity for quantifying changes in gradation under traffic. A study for this purpose, as well as for quantifying the plasticity of fines produced by particle degradation, is warranted. Some degradation could be beneficial to roadway performance, while excessive degradation could be detrimental.

Refinement of the MVK specifications for the three types of aggregates (natural, crushed, and crushed with binder), in terms of gradings, plasticity, and durability requirements would be best accomplished with a laboratory study where material characteristics could be altered in a systematic manner.

Complaints from private citizens who have suffered flat tires seem to indicate that aggregate type can affect tire wear. The pickup truck used in this study had at least two flat tires, but the truck traveled over all aggregate types with each pass over the test sections. Therefore, the effect of aggregate type could not be discerned. A tire wear study could be readily accomplished with the use of the heavy vehicle simulator (HVS) that is located at the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, MS.

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Appendix A
Climatic Records

Table A1
Climatic Data During Test Section Trafficking and Performance Monitoring

Date	Temperature (°F)		Precipitation (in.)	
	Low	High	Daily	Cumulative
04-Aug-04	69	94	0	0
05-Aug-04	73	96	0	0
06-Aug-04	66	88	0	0
07-Aug-04	62	87	0	0
08-Aug-04	66	92	0	0
09-Aug-04	67	92	0	0
10-Aug-04	72	92	0	0
11-Aug-04	68	91	0.06	0.06
12-Aug-04	61	83	0	0.06
13-Aug-04	59	80	0	0.06
14-Aug-04	53	82	0	0.06
15-Aug-04	53	86	0	0.06
16-Aug-04	56	86	0	0.06
17-Aug-04	55	87	0	0.06
18-Aug-04	61	91	0	0.06
19-Aug-04	67	93	0	0.06
20-Aug-04	72	86	0	0.06
21-Aug-04	69	86	3.13	3.19
22-Aug-04	71	88	0	3.19
23-Aug-04	71	90	0.18	3.37
24-Aug-04	74	91	0.33	3.7
25-Aug-04	74	92	0.05	3.75
26-Aug-04	75	91	0	3.75
27-Aug-04	75	92	0	3.75
28-Aug-04	72	92	0	3.75
29-Aug-04	70	87	0	3.75
30-Aug-04	66	85	0	3.75
31-Aug-04	63	86	0	3.75
01-Sep-04	66	88	0	3.75
02-Sep-04	64	89	0	3.75
03-Sep-04	73	86	0	3.75
04-Sep-04			0	3.75
05-Sep-04			0	3.75
06-Sep-04	70	91	0	3.75
07-Sep-04	70	88	0.42	4.17
08-Sep-04	61	85	0	4.17
09-Sep-04	63	87	0	4.17
10-Sep-04	68	89	0	4.17
11-Sep-04	66	90	0	4.17
12-Sep-04	65	90	0	4.17
13-Sep-04	69	94	0.01	4.18

(Sheet 1 of 7)

Table A1 (Continued)

Date	Temperature (°F)		Precipitation (in.)	
	Low	High	Daily	Cumulative
14-Sep-04	70	86	0	4.18
15-Sep-04	69	90	0	4.18
16-Sep-04	67	92	0	4.18
17-Sep-04	65	92	0	4.18
18-Sep-04	58	90	0	4.18
19-Sep-04	59	85	0	4.18
20-Sep-04	62	85	0	4.18
21-Sep-04			0	4.18
22-Sep-04	66	87	0	4.18
23-Sep-04	71	82	0	4.18
24-Sep-04	70	86	0	4.18
25-Sep-04	70	83	0	4.18
26-Sep-04	66	88	0	4.18
27-Sep-04	57	85	0	4.18
28-Sep-04	53	84	0	4.18
29-Sep-04			0	4.18
30-Sep-04	60	84	0	4.18
01-Oct-04	57	87	0	4.18
02-Oct-04	63	86	0	4.18
03-Oct-04	60	85	0	4.18
04-Oct-04	59	86	0	4.18
05-Oct-04	60	82	0	4.18
06-Oct-04	60	88	0	4.18
07-Oct-04	68	82	0	4.18
08-Oct-04	68	72	0.05	4.23
09-Oct-04	65	69	0	4.23
10-Oct-04	66	71	0	4.23
11-Oct-04	67	82	6.88	11.06
12-Oct-04	54	72	0	11.06
13-Oct-04	50	77	0	11.06
14-Oct-04	46	68	0	11.06
15-Oct-04	41	72	0	11.06
16-Oct-04	48	79	0	11.06
17-Oct-04	57	85	0	11.06
18-Oct-04	70	86	0	11.06
19-Oct-04	73	89	0	11.06
20-Oct-04	69	90	0	11.06
21-Oct-04	65	79	0	11.06
22-Oct-04	64	87	0.01	11.07
23-Oct-04	70	84	0	11.07
24-Oct-04	66	86	0.28	11.35

(Sheet 2 of 7)

Table A1 (Continued)

Date	Temperature (°F)		Precipitation (in.)	
	Low	High	Daily	Cumulative
25-Oct-04	66	86	0	11.35
26-Oct-04	66	87	0	11.35
27-Oct-04	63	86	0	11.35
28-Oct-04	66	85	0	11.35
29-Oct-04	61	84	0	11.35
30-Oct-04	69	86	0	11.35
31-Oct-04	62	79	0	11.35
01-Nov-04	71	82	0.1	11.45
02-Nov-04	64	74	0	11.45
03-Nov-04	54	71	2.16	13.61
04-Nov-04	45	60	0	13.61
05-Nov-04	40	64	0	13.61
06-Nov-04	38	72	0	13.61
07-Nov-04	46	78	0	13.61
08-Nov-04	46	73	0	13.61
09-Nov-04	46	70	0	13.61
10-Nov-04	54	74	0	13.61
11-Nov-04	56	76	0	13.61
12-Nov-04	49	57	0.03	13.64
13-Nov-04	49	52	0	13.64
14-Nov-04	52	67	0	13.64
15-Nov-04	48	66	0.02	13.66
16-Nov-04	46	74	0	13.66
17-Nov-04	48	73	0	13.66
18-Nov-04	57	65	0.01	13.67
19-Nov-04	53	67	0	13.67
20-Nov-04	51	63	0	13.67
21-Nov-04	60	69	2.89	16.56
22-Nov-04	63	69	0	16.56
23-Nov-04	63	78	0	16.56
24-Nov-04	46	66	0	16.56
25-Nov-04	38	53	0	16.56
26-Nov-04	36	62	0	16.56
27-Nov-04	41	68	0	16.56
28-Nov-04	36	59	0	16.56
29-Nov-04	39	73	1	17.56
30-Nov-04	41	70	0	17.56
01-Dec-04	36	53	0.69	18.25
02-Dec-04	35	55	0.11	18.36
03-Dec-04	32	62	0	18.36
04-Dec-04	36	60	0	18.36

(Sheet 3 of 7)

Table A1 (Continued)

Date	Temperature (°F)		Precipitation (in.)	
	Low	**High**	**Daily**	**Cumulative**
05-Dec-04	50	69	0	18.36
06-Dec-04	62	73	0.36	18.72
07-Dec-04	46	72	2.07	20.79
08-Dec-04	41	65	0	20.79
09-Dec-04	59	73	2.5	23.29
10-Dec-04	46	64	0	23.29
11-Dec-04	38	53	0	23.29
12-Dec-04	37	68	0	23.29
13-Dec-04	35	54	0	23.29
14-Dec-04	28	41	0	23.29
15-Dec-04	27	48	0	23.29
16-Dec-04	29	55	0	23.29
17-Dec-04	32	58	0	23.29
18-Dec-04	28	61	0	23.29
19-Dec-04	29	50	0.01	23.3
20-Dec-04	26	59	0	23.3
21-Dec-04	48	71	0	23.3
22-Dec-04	28	65	0.77	24.07
23-Dec-04	24	30	0	24.07
24-Dec-04	23	30	0	24.07
25-Dec-04	21	35	0	24.07
26-Dec-04	21	51	0	24.07
27-Dec-04	23	56	0.01	24.08
28-Dec-04	30	64	0	24.08
29-Dec-04	40	70	0	24.08
30-Dec-04	54	72	0	24.08
31-Dec-04	53	69	0	24.08
01-Jan-05	53	67	0.52	24.6
02-Jan-05	61	72	0	24.6
03-Jan-05	57	74	0	24.6
04-Jan-05	58	74	0	24.6
05-Jan-05	56	75	0.13	24.73
06-Jan-05	44	66	0	24.73
07-Jan-05	43	58	0	24.73
08-Jan-05	39	51	0	24.73
09-Jan-05	34	61	0	24.73
10-Jan-05	48	72	2.37	27.1
11-Jan-05	57	76	0.18	27.28
12-Jan-05	62	75	0.7	27.98
13-Jan-05	44	68	0.36	28.34
14-Jan-05	36	49	0	28.34

(Sheet 4 of 7)

Table A1 (Continued)

Date	Temperature (°F)		Precipitation (in.)	
	Low	High	Daily	Cumulative
15-Jan-05	34	47	0	28.34
16-Jan-05	28	45	0	28.34
17-Jan-05	24	40	0	28.34
18-Jan-05	28	45	0	28.34
19-Jan-05	30	54	0	28.34
20-Jan-05	33	67	0	28.34
21-Jan-05	42	72	0	28.34
22-Jan-05	32	64	0	28.34
23-Jan-05	23	37	0	28.34
24-Jan-05	21	49	0	28.34
25-Jan-05	37	66	0	28.34
26-Jan-05	46	69	0	28.34
27-Jan-05	37	50	0	28.34
28-Jan-05	41	51	0.02	28.36
29-Jan-05	43	49	0	28.36
30-Jan-05	42	47	0	28.36
31-Jan-05	41	45	0.71	29.07
01-Feb-05	42	47	0.39	29.46
02-Feb-05	44	49	1.23	30.69
03-Feb-05	41	45	0.01	30.7
04-Feb-05	38	52	0	30.7
05-Feb-05	30	61	0	30.7
06-Feb-05	43	63	0	30.7
07-Feb-05	53	64	0	30.7
08-Feb-05	56	61	0.42	31.12
09-Feb-05	42	59	0.52	31.64
10-Feb-05	34	52	0	31.64
11-Feb-05	29	64	0	31.64
12-Feb-05	39	63	0	31.64
13-Feb-05	52	61	0	31.64
14-Feb-05	45	70	0.62	32.26
15-Feb-05	44	75	0	32.26
16-Feb-05	49	64	0.02	32.28
17-Feb-05	43	57	0	32.28
18-Feb-05	39	58	0	32.28
19-Feb-05	38	65	0	32.28
20-Feb-05	52	71	0	32.28
21-Feb-05	59	77	0	32.28
22-Feb-05	57	73	0.69	32.97
23-Feb-05	47	65	0	32.97
24-Feb-05	41	48	0.86	33.83

(Sheet 5 of 7)

Table A1 (Continued)

Date	Temperature (°F)		Precipitation (in.)	
	Low	High	Daily	Cumulative
25-Feb-05	36	54	0	33.83
26-Feb-05	36	61	0	33.83
27-Feb-05	48	61	0	33.83
28-Feb-05	44	61	0.11	33.94
01-Mar-05	38	53	0	33.94
02-Mar-05	39	52	0	33.94
03-Mar-05	41	61	0	33.94
04-Mar-05	35	68	0	33.94
05-Mar-05	47	69	0	33.94
06-Mar-05	47	70	0	33.94
07-Mar-05	47	68	0	33.94
08-Mar-05	43	55	1.25	35.19
09-Mar-05	41	55	0.08	35.27
10-Mar-05	35	59	0	35.27
11-Mar-05	49	66	0	35.27
12-Mar-05	48	80	0	35.27
13-Mar-05	45	78	0	35.27
14-Mar-05	41	60	0.59	35.86
15-Mar-05	44	60	0	35.86
16-Mar-05	41	45	0.56	36.42
17-Mar-05	38	58	0.01	36.43
18-Mar-05	35	64	0	36.43
19-Mar-05	47	71	0	36.43
20-Mar-05	54	58	0	36.43
21-Mar-05	55	68	0.78	37.21
22-Mar-05	55	79	0.58	37.79
23-Mar-05	49	62	0	37.79
24-Mar-05	43	75	0	37.79
25-Mar-05	51	81	0	37.79
26-Mar-05	57	82	0	37.79
27-Mar-05	46	57	0	37.79
28-Mar-05	43	69	0.55	38.34
29-Mar-05	44	76	0	38.34
30-Mar-05	58	80	0	38.34
31-Mar-05	63	82	0.02	38.36
01-Apr-05	50	69	1.32	39.68
02-Apr-05	43	67	0	39.68
03-Apr-05	40	76	0	39.68
04-Apr-05	48	74	0	39.68
05-Apr-05	55	79	0	39.68
06-Apr-05	56	72	0	39.68

(Sheet 6 of 7)

Table A1 (Concluded)

Date	Temperature (ºF)		Precipitation (in.)	
	Low	High	Daily	Cumulative
07-Apr-05	54	71	0.58	40.26
08-Apr-05	48	80	0	40.26
09-Apr-05	55	78	0	40.26
10-Apr-05	55	76	0	40.26
11-Apr-05	57	74	0	40.26
12-Apr-05	50	74	1.81	42.07
13-Apr-05	48	70	0	42.07
14-Apr-05	51	71	0	42.07
15-Apr-05	48	78	0.01	42.08
16-Apr-05	49	80	0	42.08
17-Apr-05	55	79	0	42.08
18-Apr-05	51	77	0	42.08
19-Apr-05	56	81	0	42.08

(Sheet 7 of 7)

Appendix B
Transverse Profiles

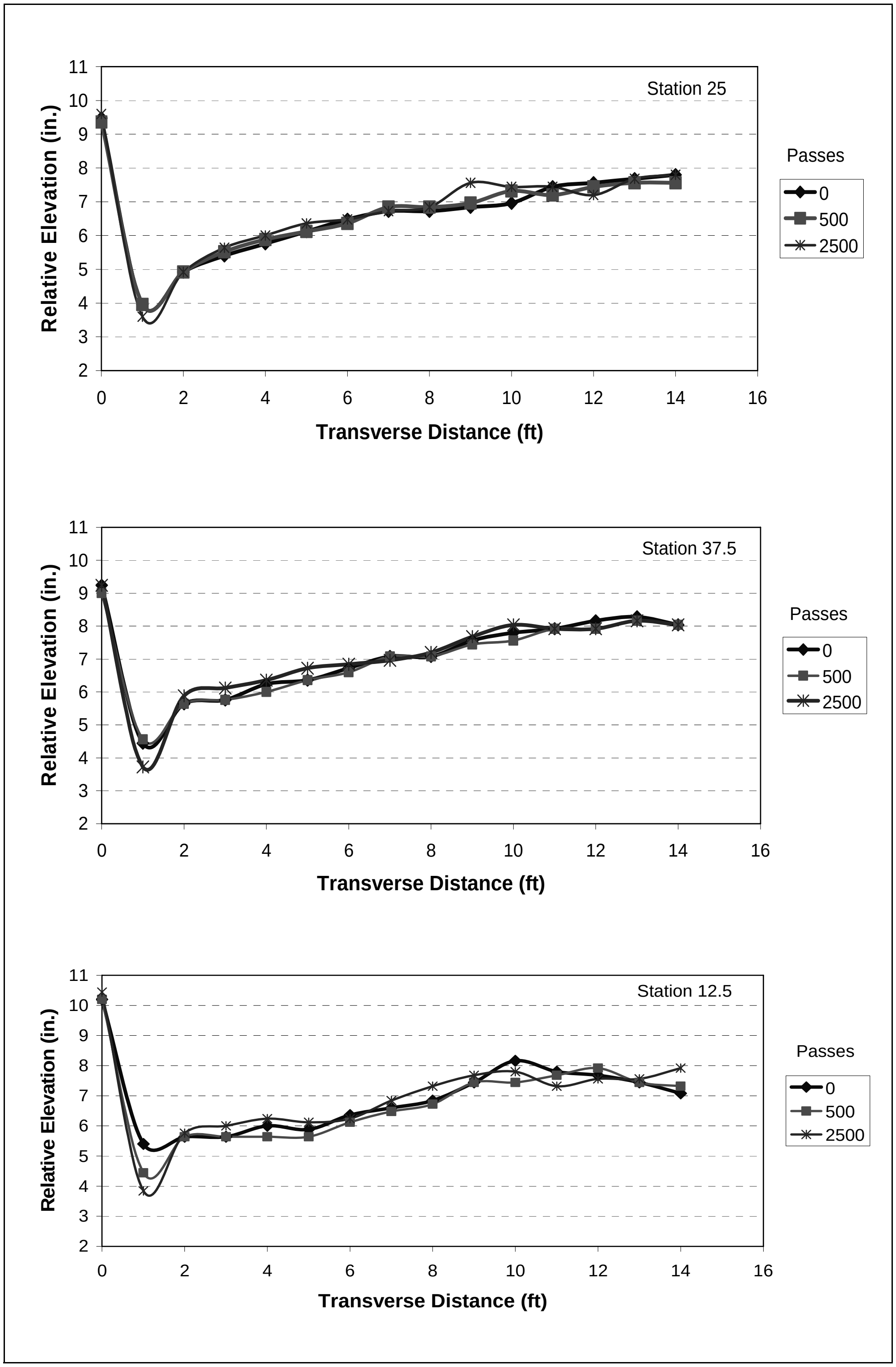


Figure B1. Transverse road surface profiles for Item 1 (SCG), maintenance test section, dry lane, 2500 passes with pickup truck

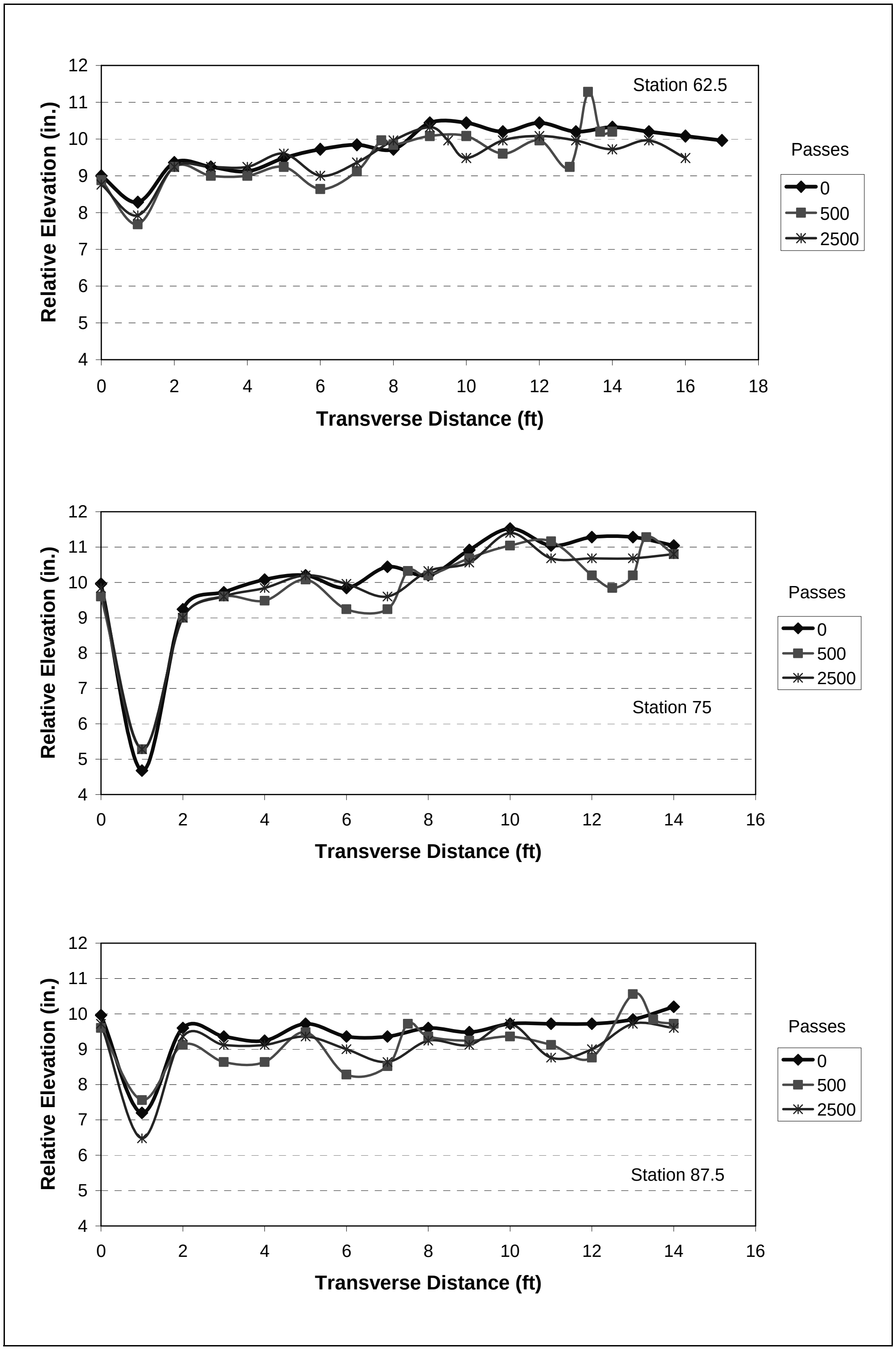


Figure B2. Transverse road surface profiles for Item 2 (LST), maintenance test section, dry lane, 2500 passes with pickup truck

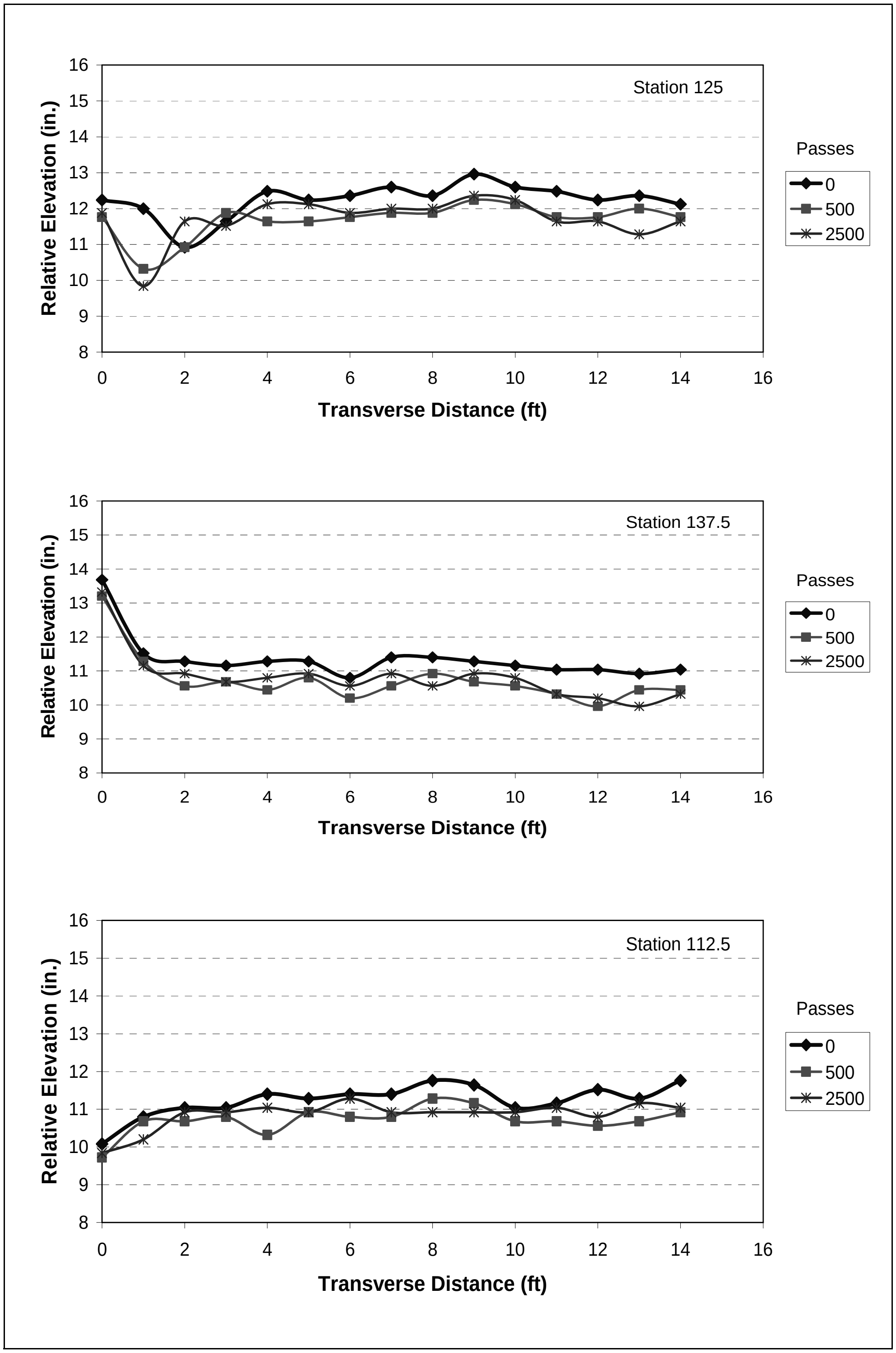


Figure B3. Transverse road surface profiles for Item 3 (SST), maintenance test section, dry lane, 2500 passes with pickup truck

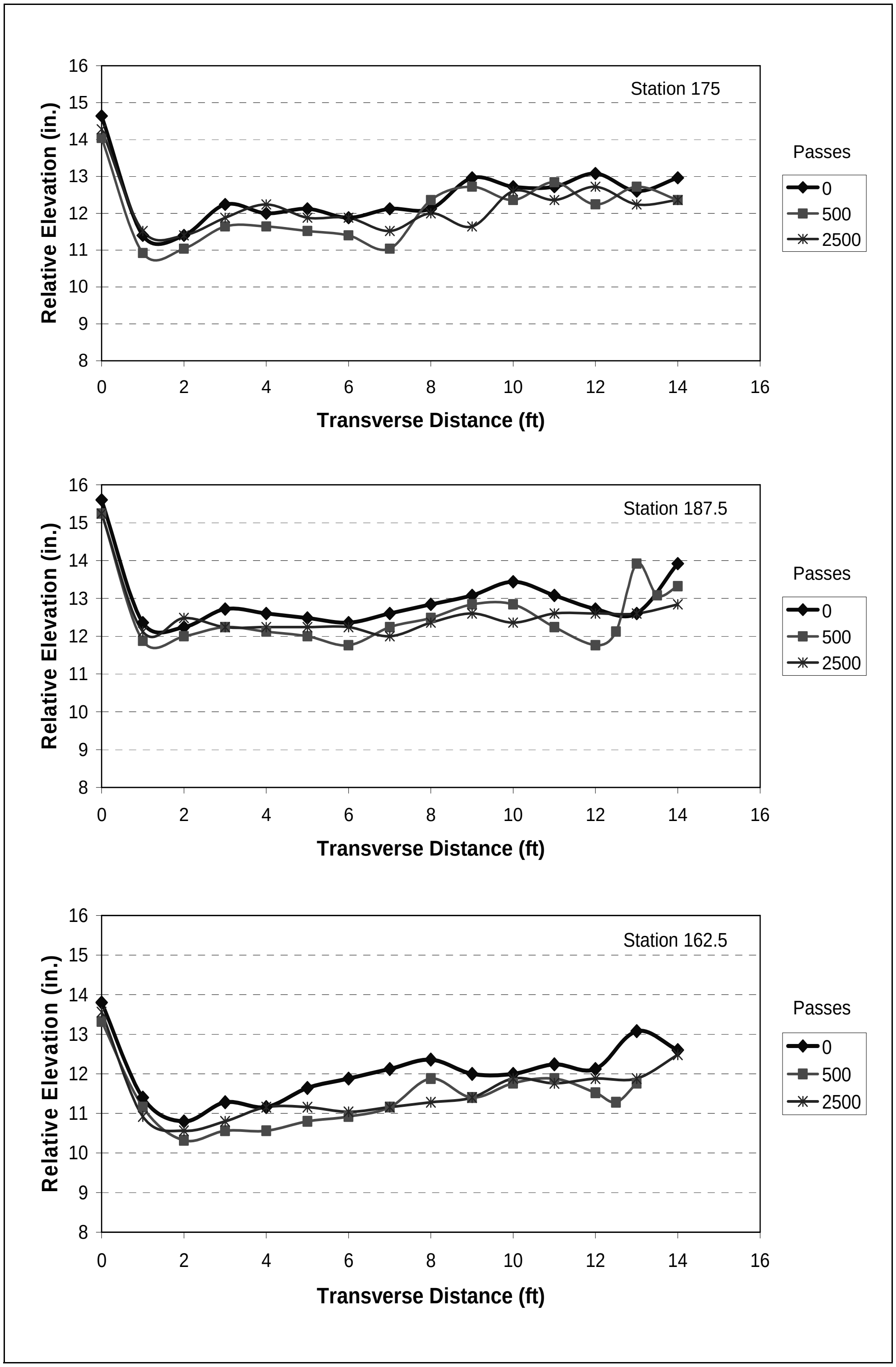
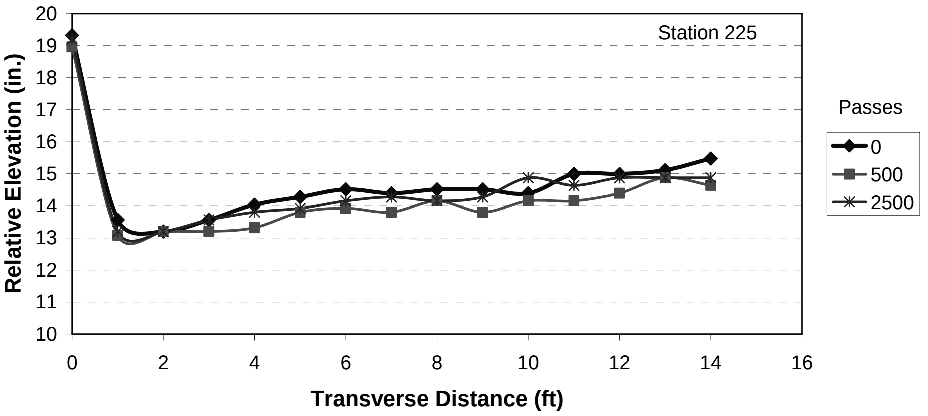
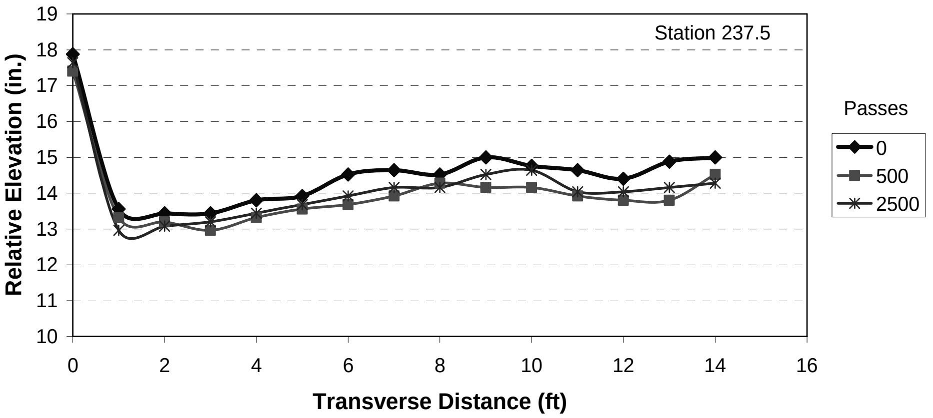


Figure B4. Transverse road surface profiles for Item 4 (IGN), maintenance test section, dry lane, 2500 passes with pickup truck





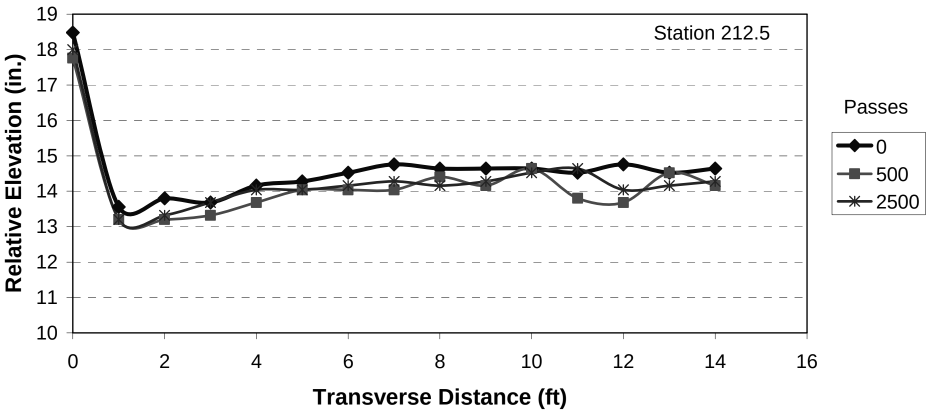


Figure B5. Transverse road surface profiles for Item 5 (SSB), maintenance test section, dry lane, 2500 passes with pickup truck

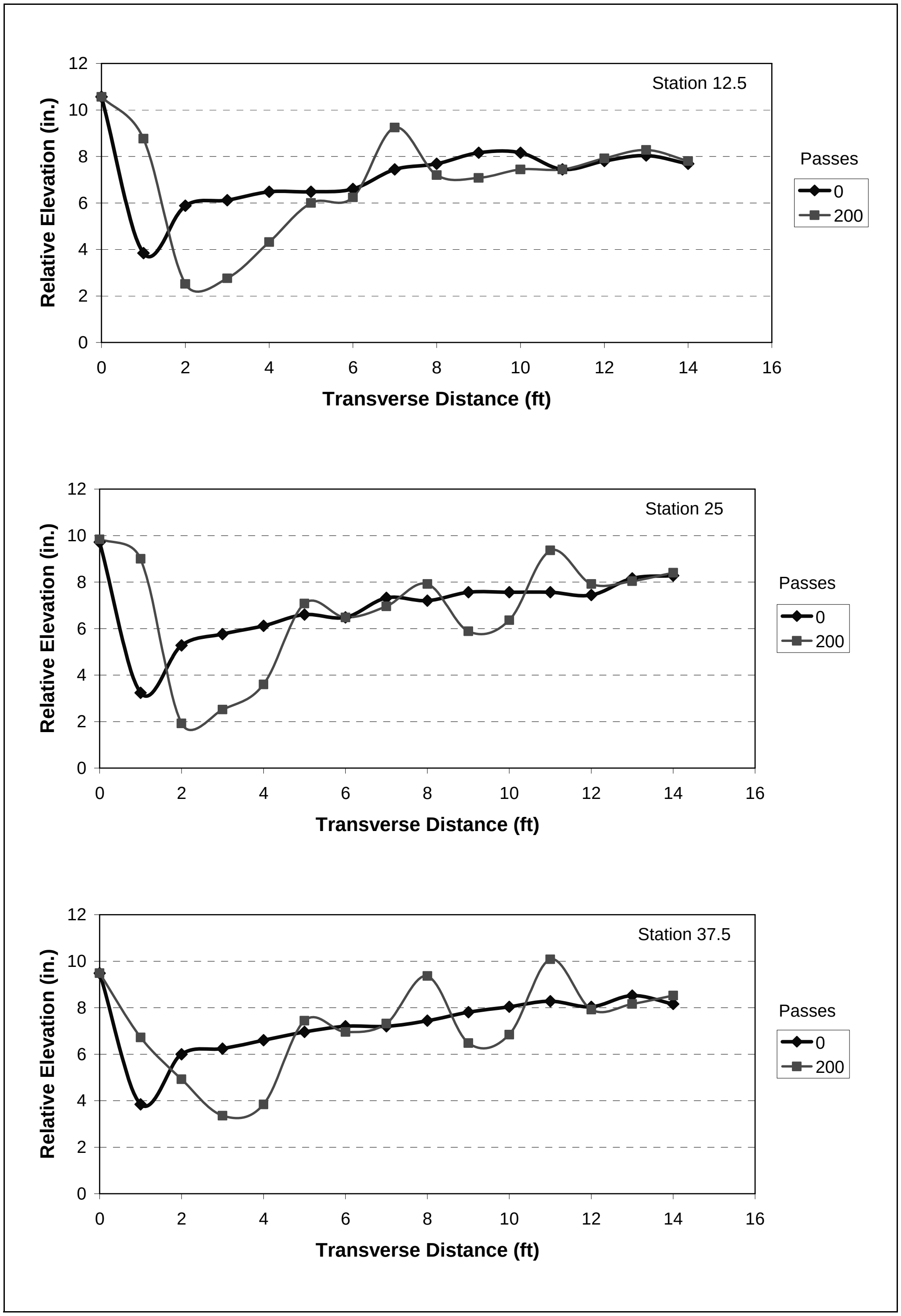


Figure B6. Transverse road surface profiles for Item 1 (SCG), maintenance test section, dry lane, 200 passes with emulsion truck

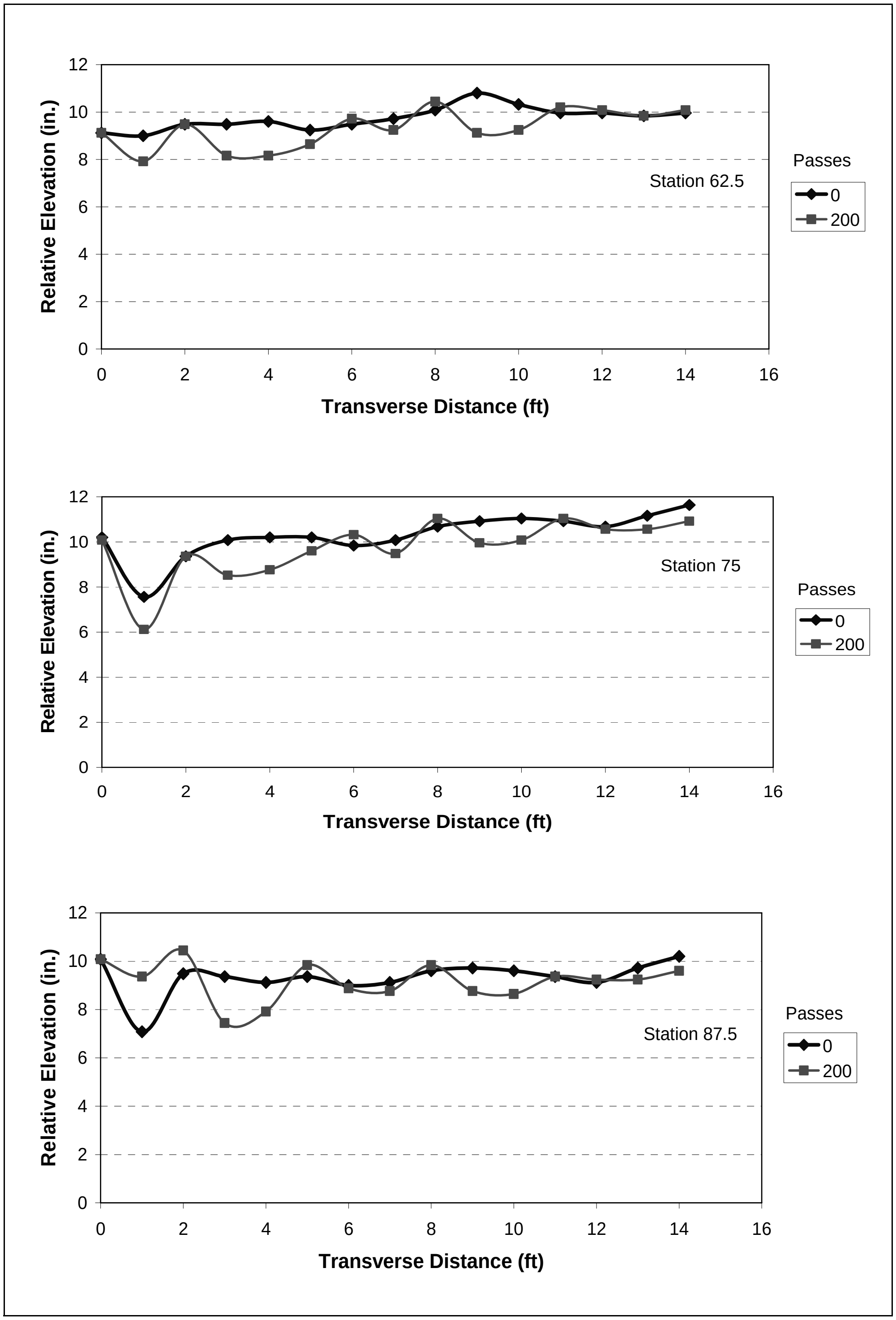


Figure B7. Transverse road surface profiles for Item 2 (LST), maintenance test section, dry lane, 200 passes with emulsion truck

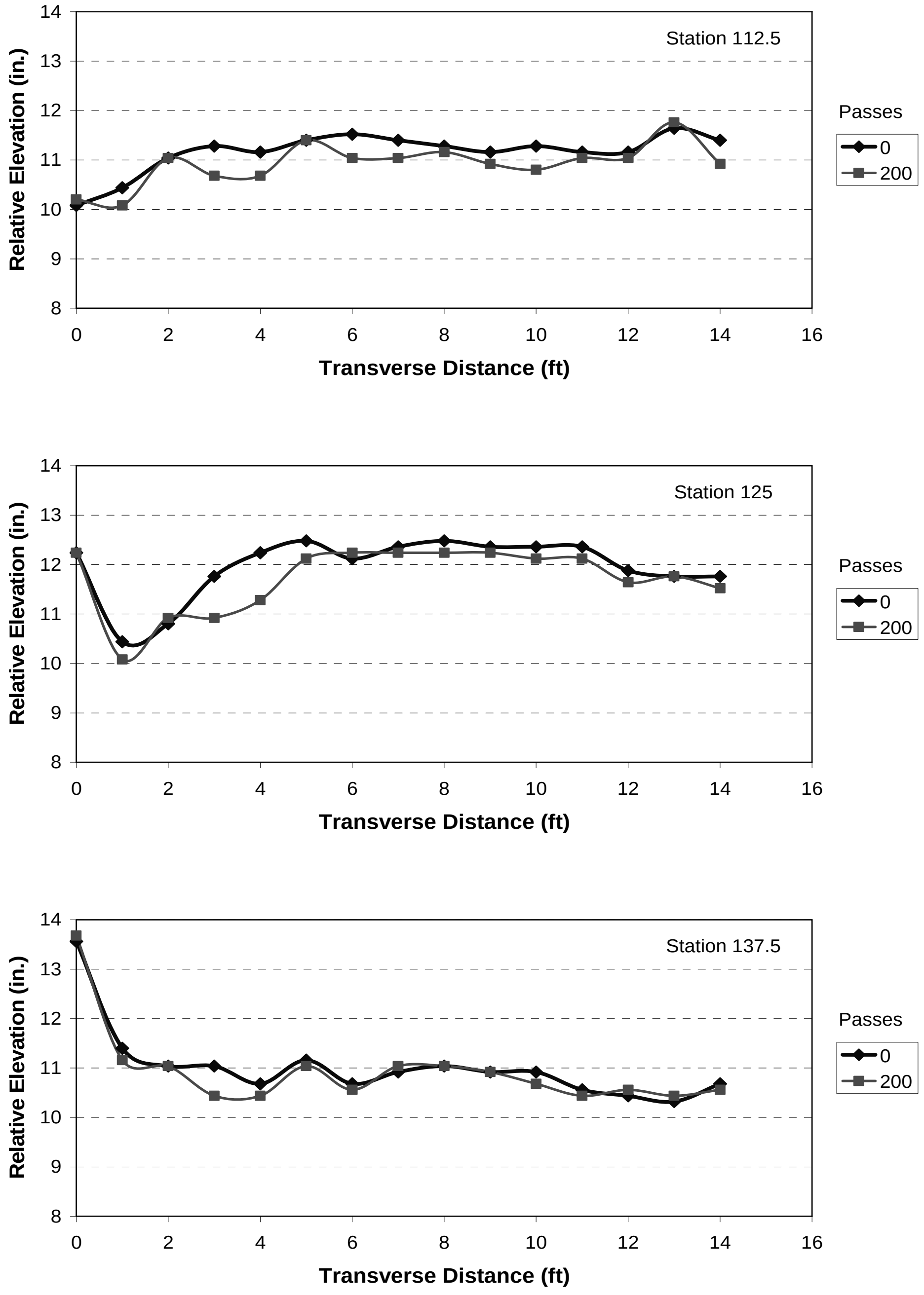


Figure B8. Transverse road surface profiles for Item 3 (SST), maintenance test section, dry lane, 200 passes with emulsion truck

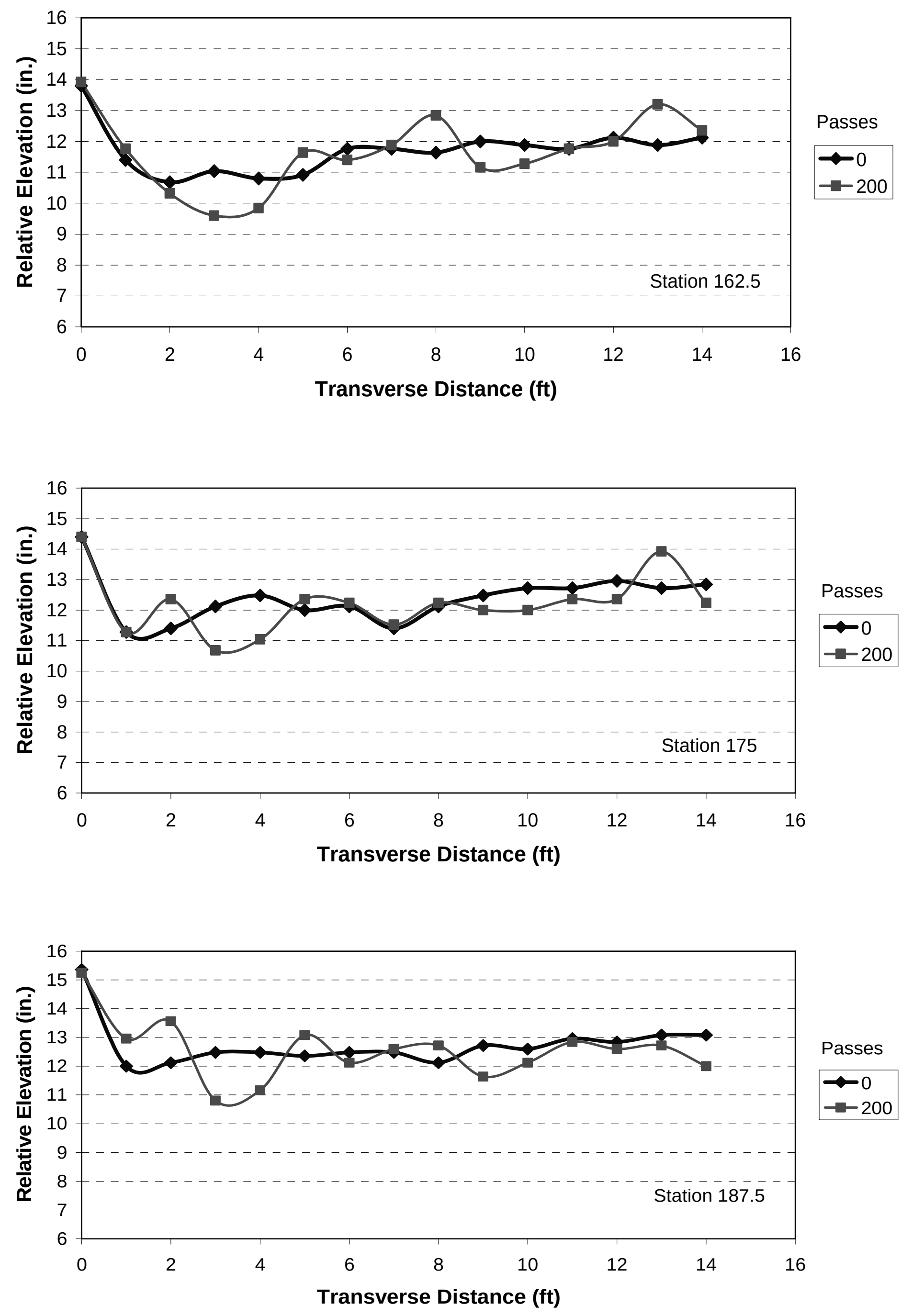


Figure B9. Transverse road surface profiles for Item 4 (IGN), maintenance test section, dry lane, 200 passes with emulsion truck

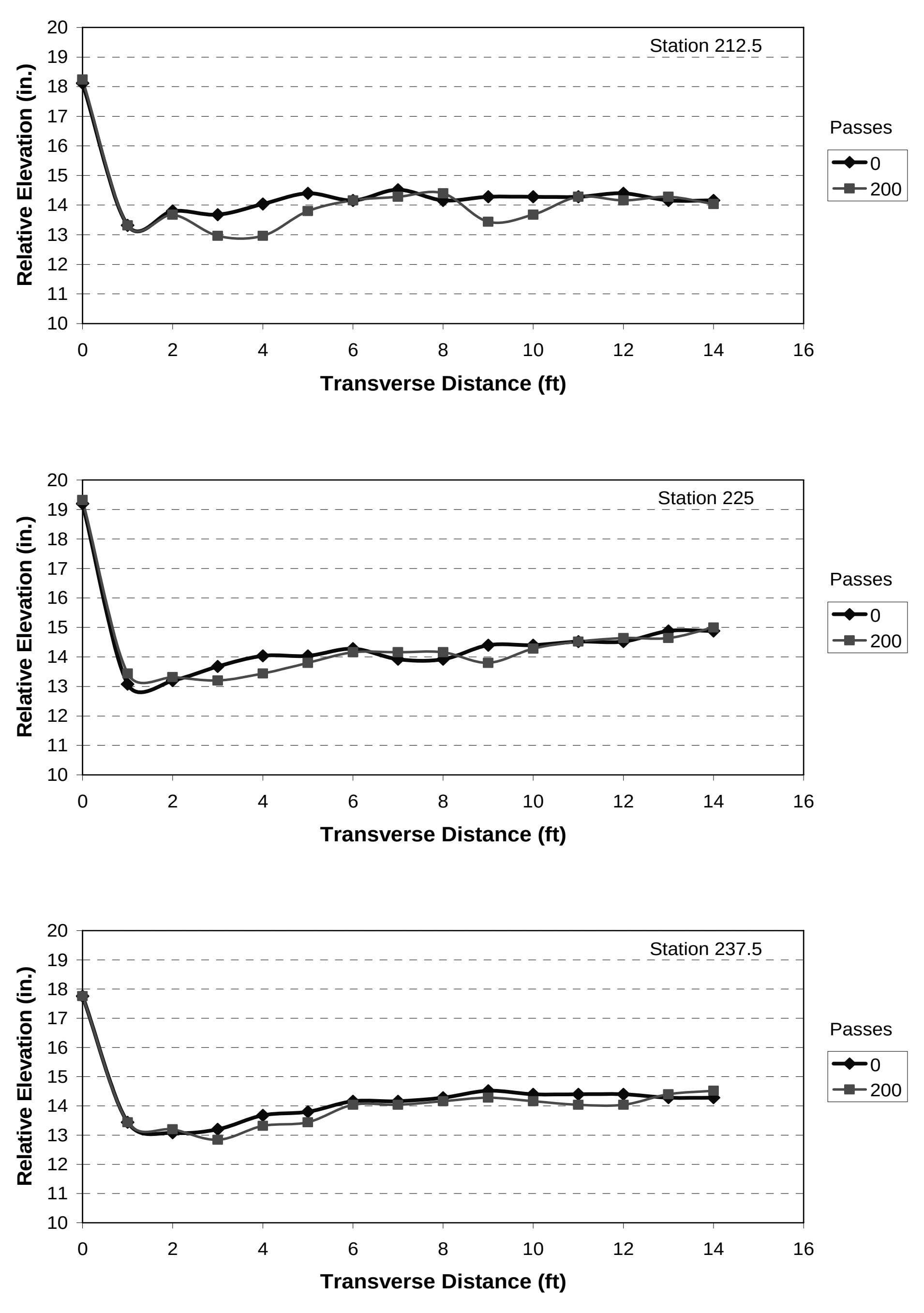


Figure B10. Transverse road surface profiles for Item 5 (SSB), maintenance test section, dry lane, 200 passes with emulsion truck

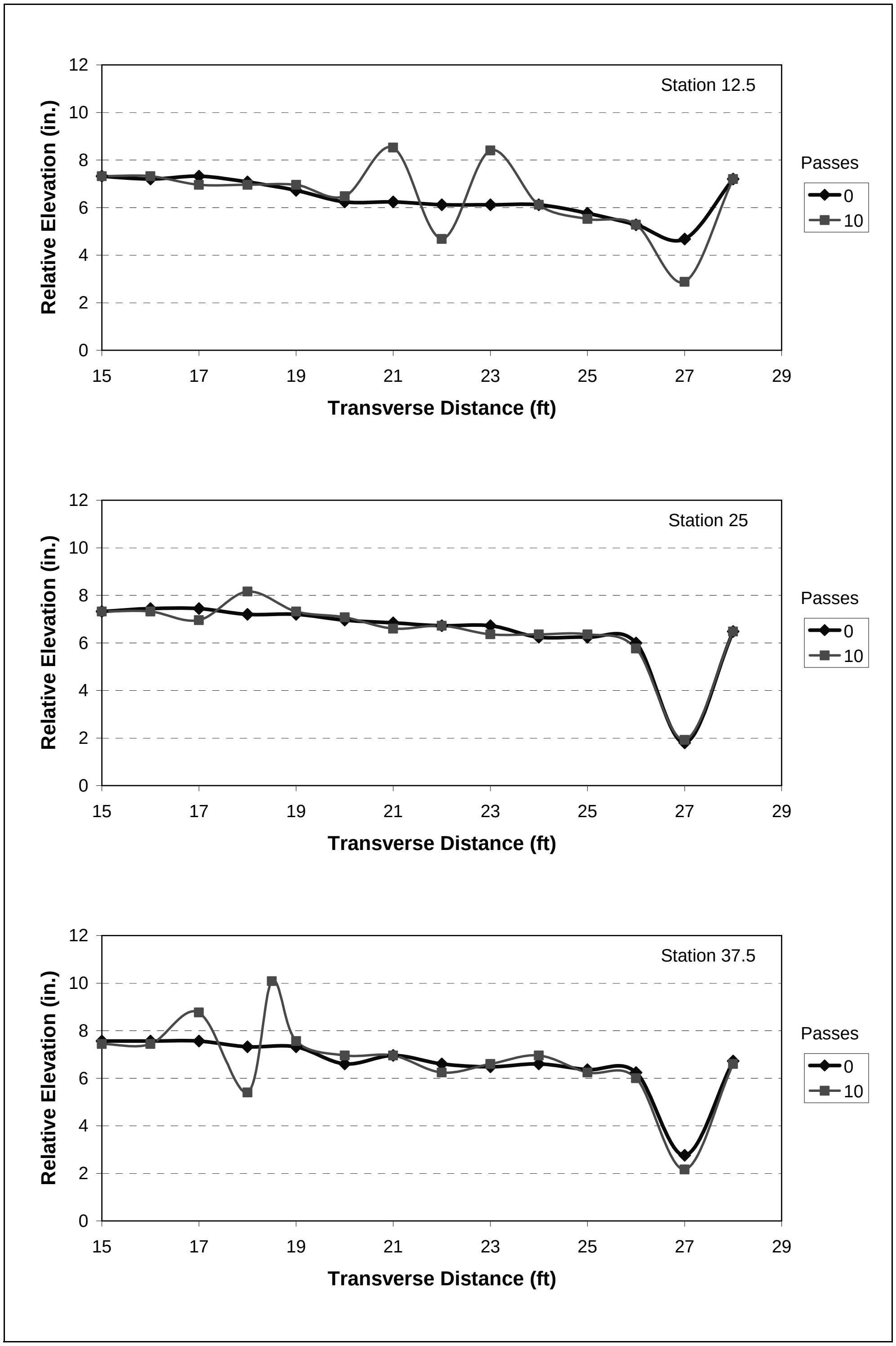


Figure B11. Transverse road surface profiles for Item 1 (SCG), maintenance test section, wet lane, 10 passes with pickup truck

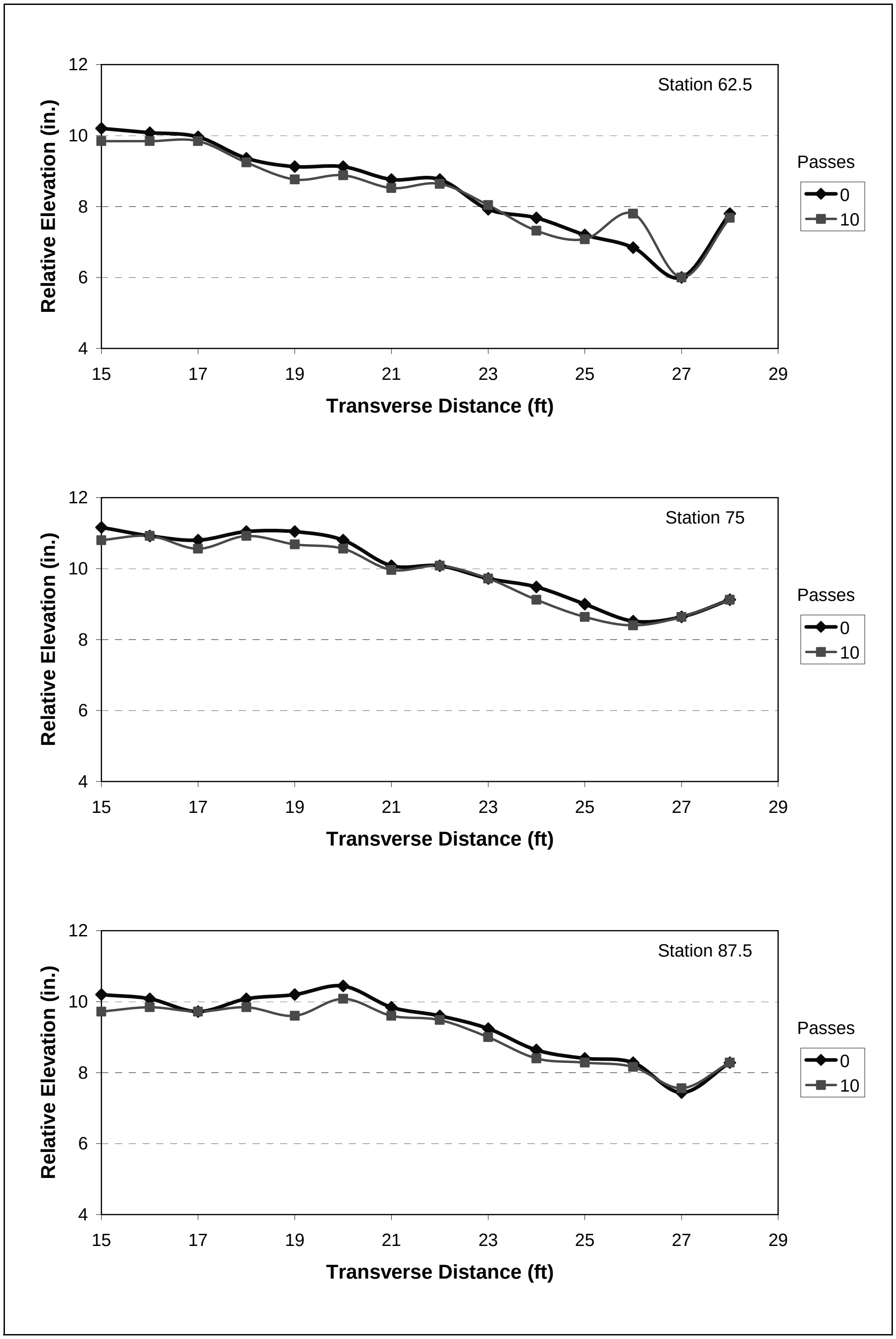


Figure B12. Transverse road surface profiles for Item 2 (LST), maintenance test section, wet lane, 10 passes with pickup truck

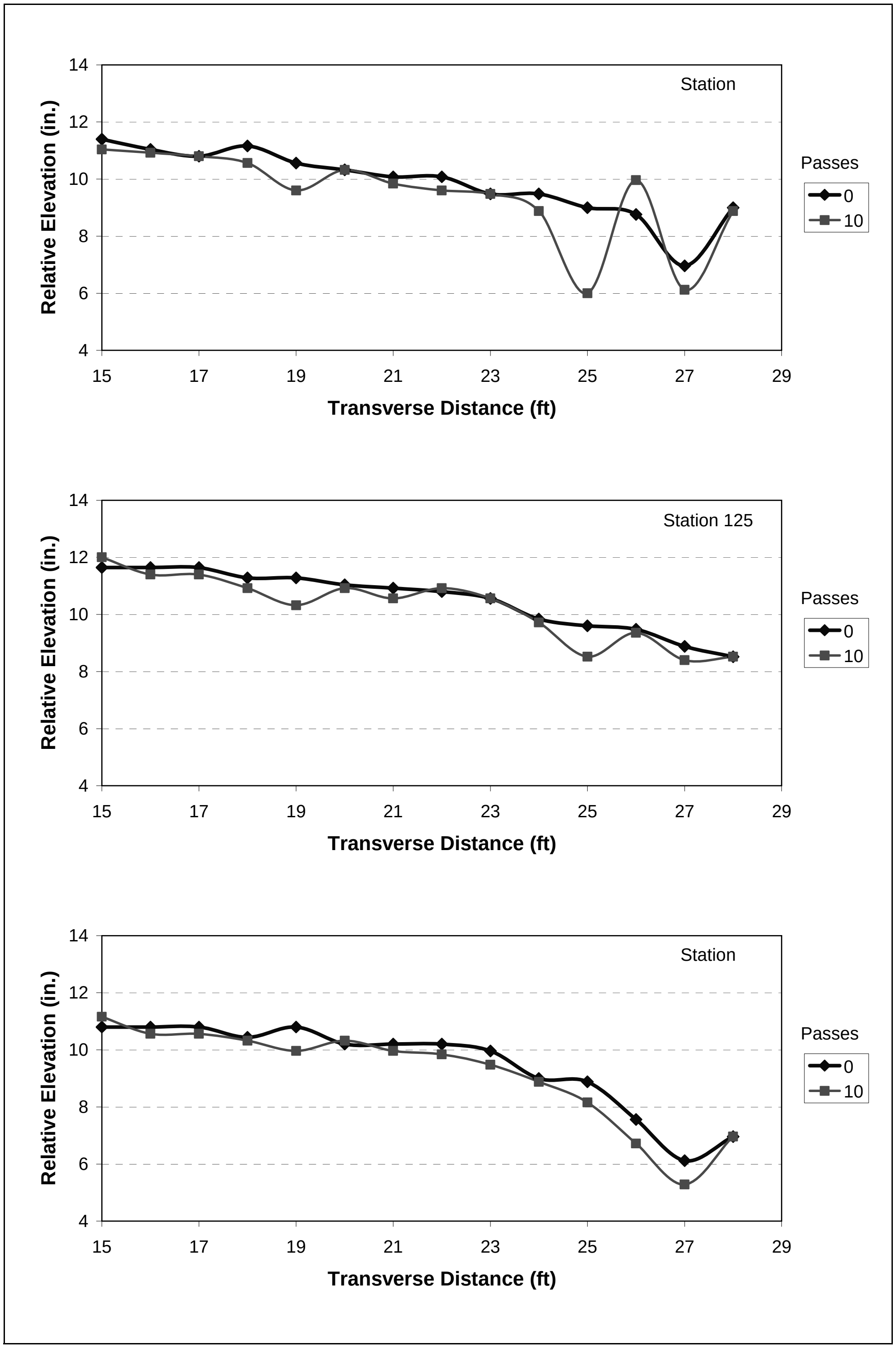


Figure B13. Transverse road surface profiles for Item 3 (SST), maintenance test section, wet lane, 10 passes with pickup truck

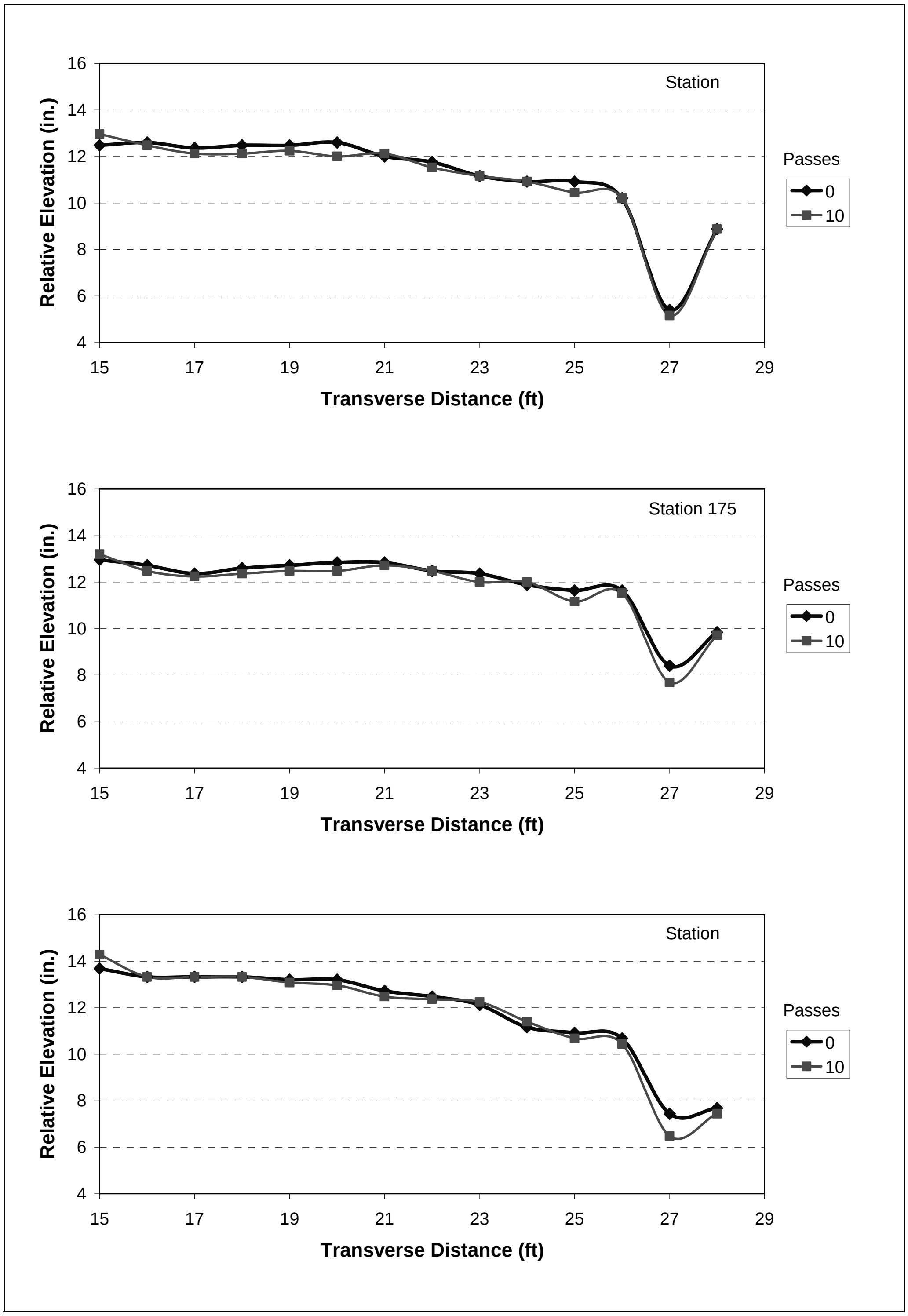


Figure B14. Transverse road surface profiles for Item 4 (IGN), maintenance test section, wet lane, 10 passes with pickup truck

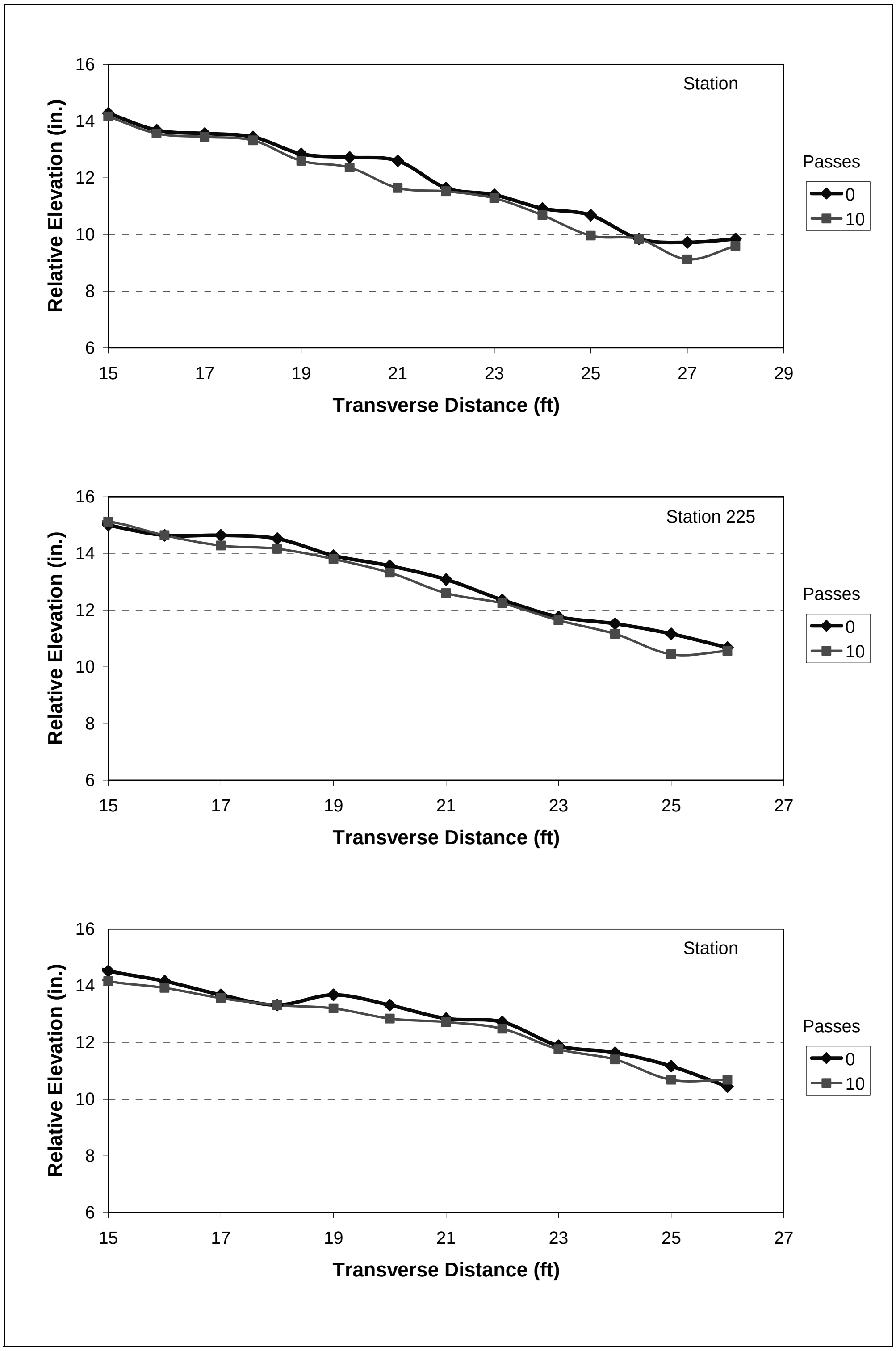


Figure B15. Transverse road surface profiles for Item 5 (SSB), maintenance test section, wet lane, 10 passes with pickup truck

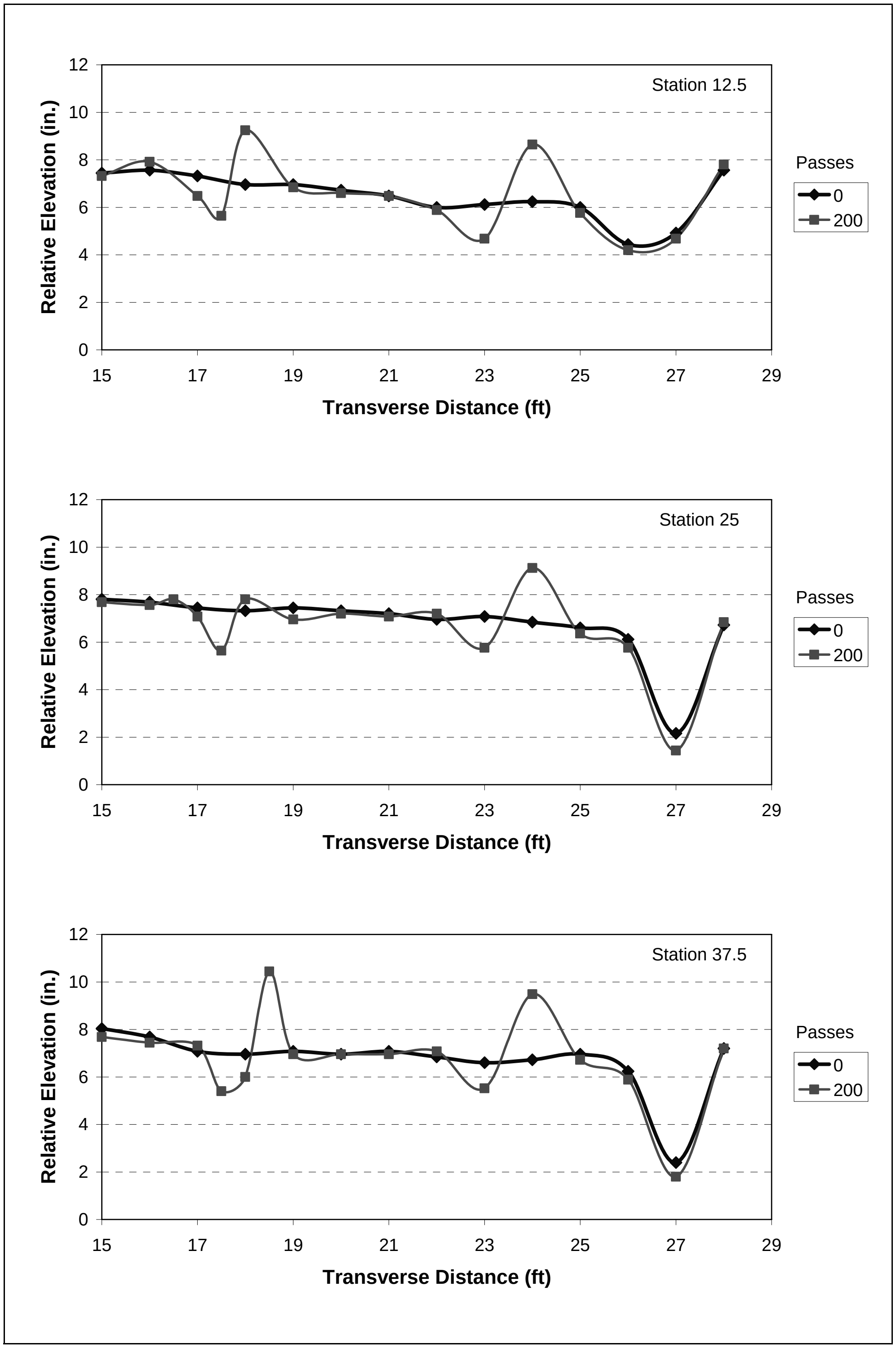


Figure B16. Transverse road surface profiles for Item 1 (SCG), maintenance test section, wet lane, 200 passes with pickup truck

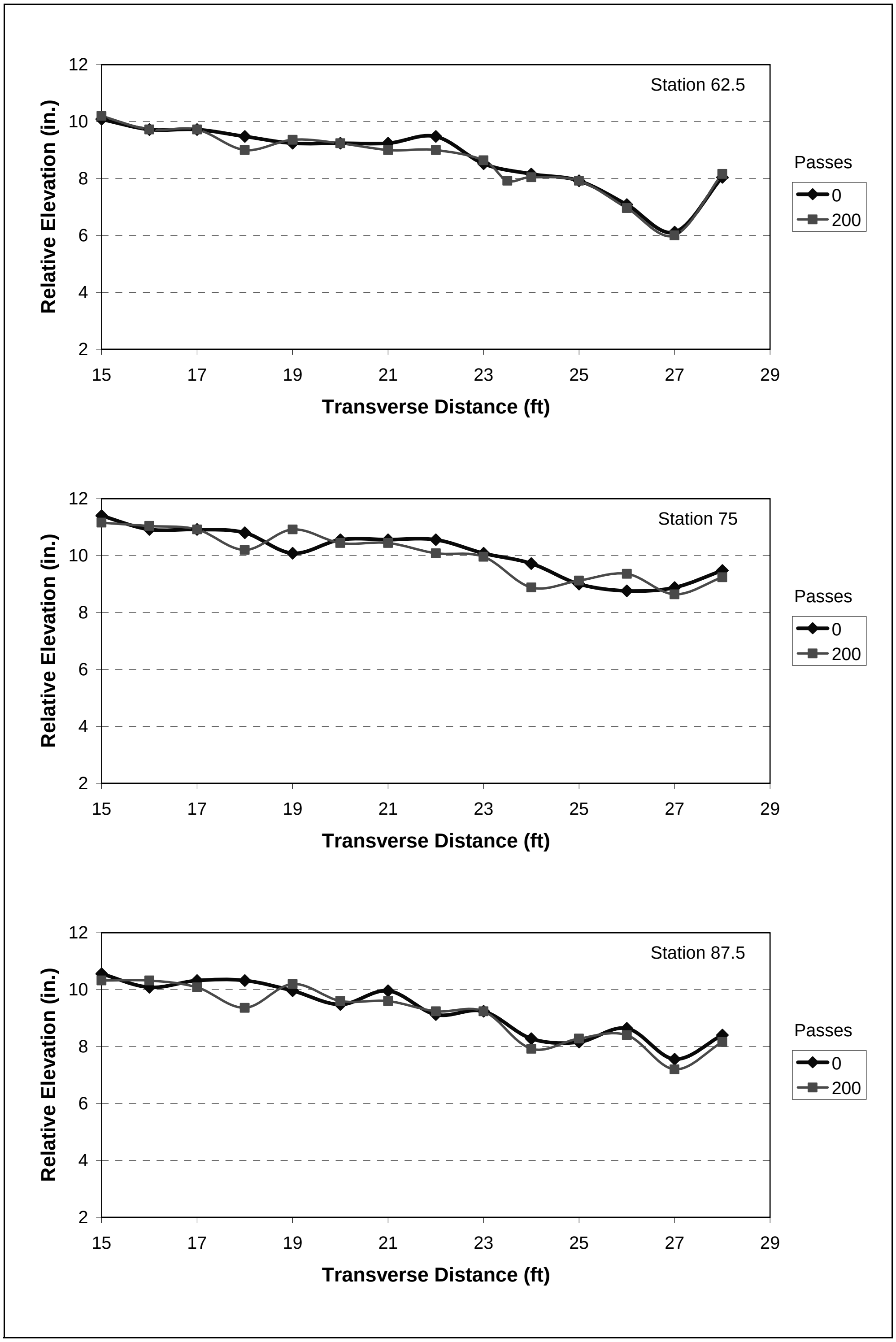


Figure B17. Transverse road surface profiles for Item 2 (LST), maintenance test section, wet lane, 200 passes with pickup truck

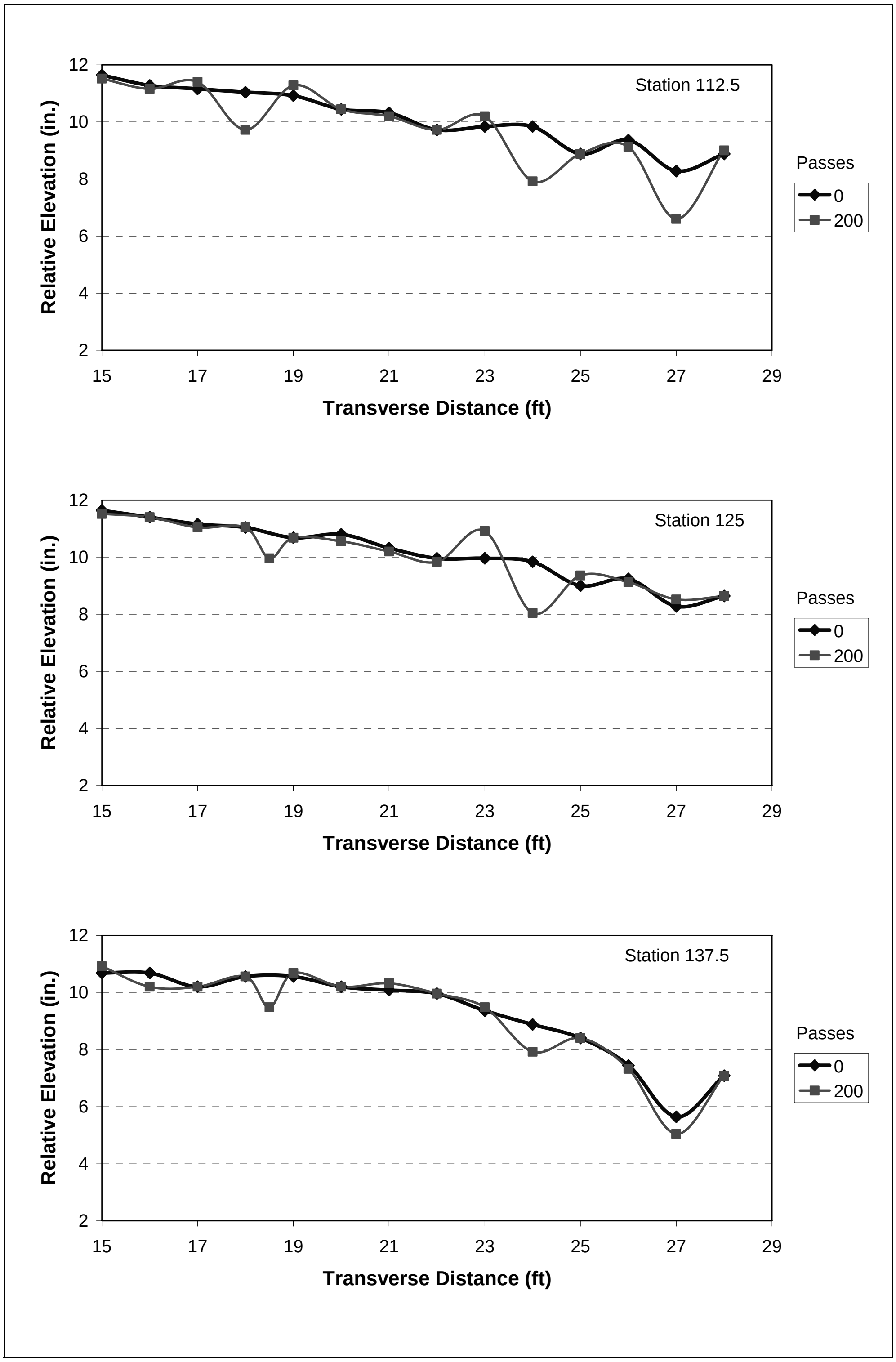


Figure B18. Transverse road surface profiles for Item 3 (SST), maintenance test section, wet lane, 200 passes with pickup truck

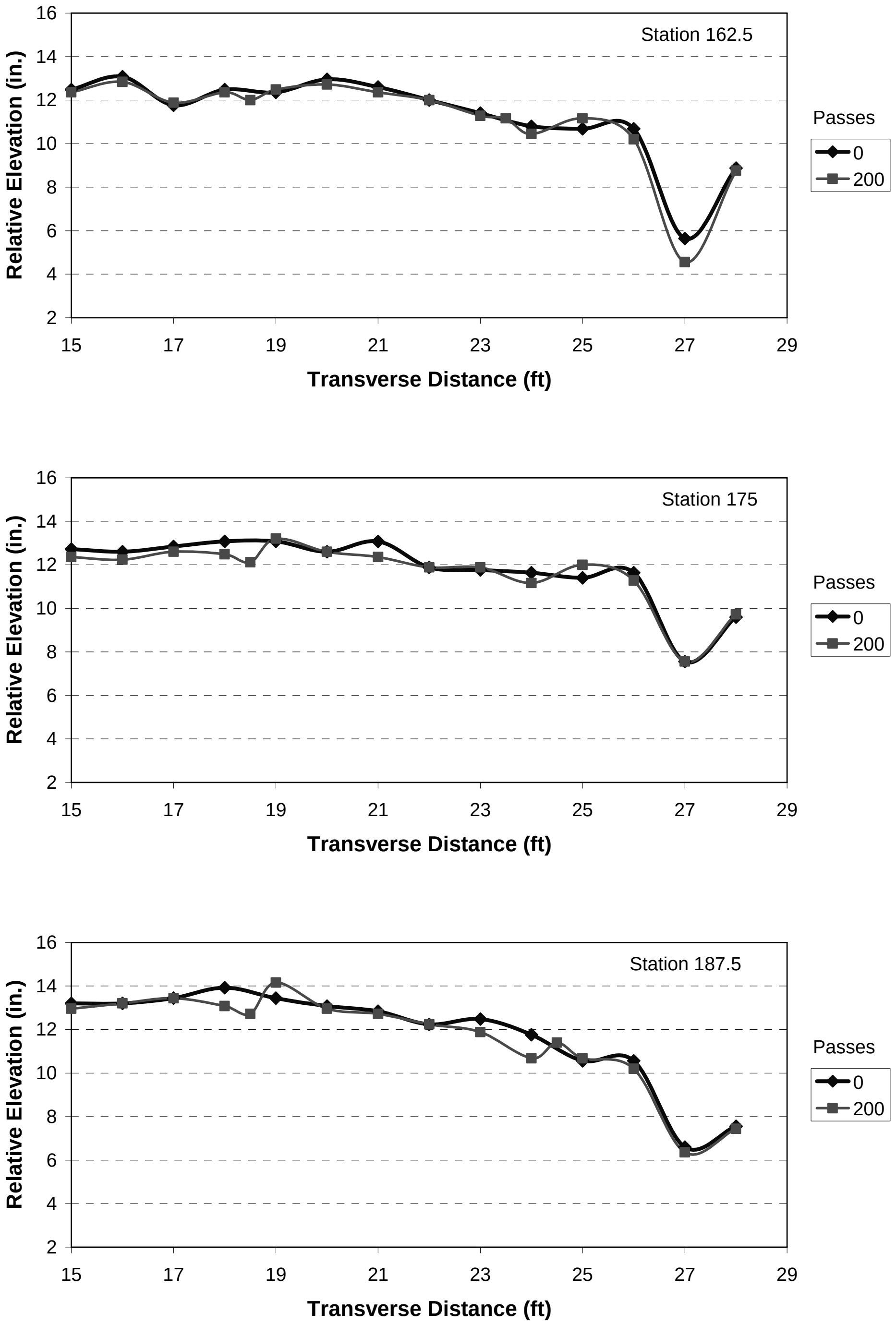


Figure B19. Transverse road surface profiles for Item 4 (IGN), maintenance test section, wet lane, 200 passes with pickup truck

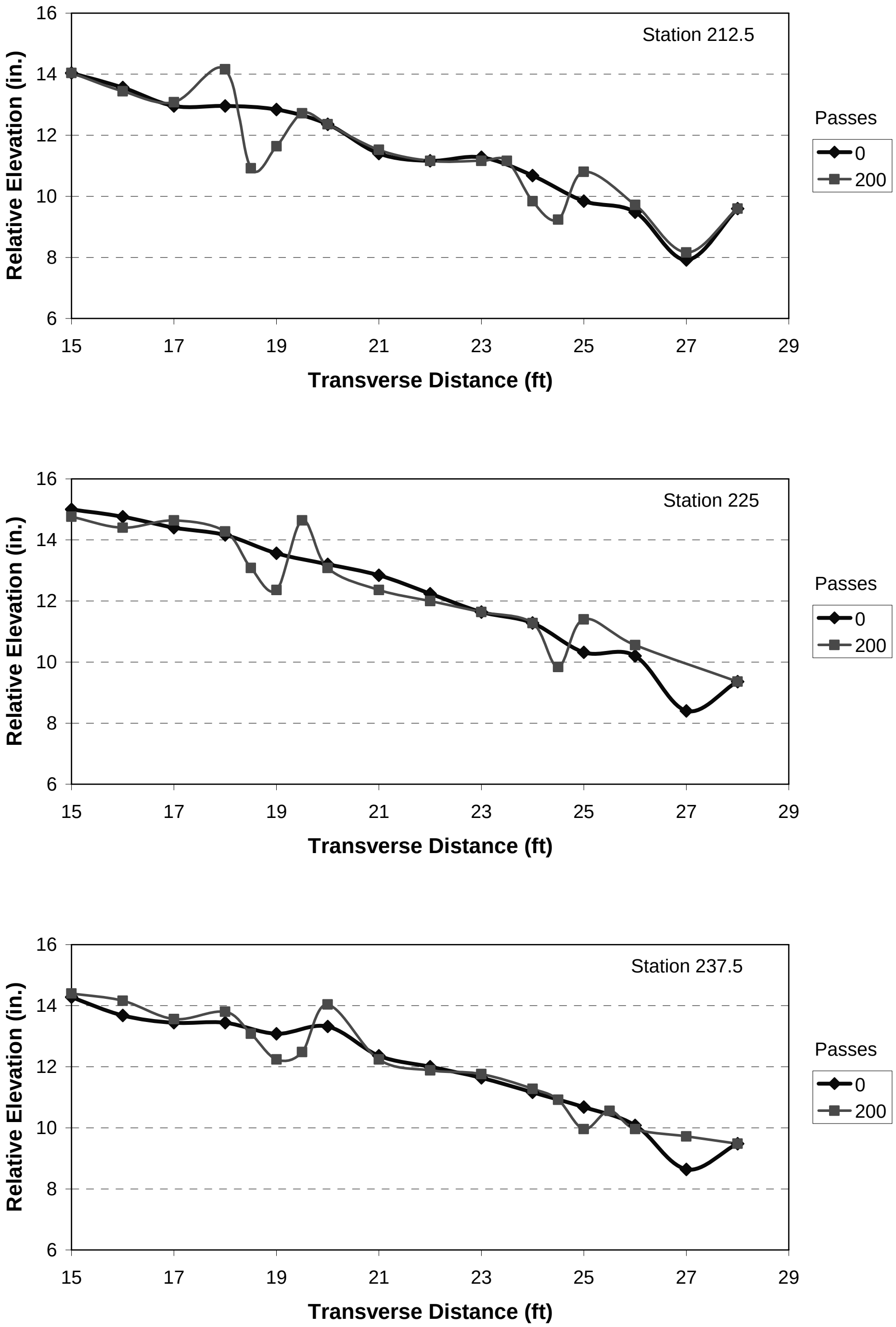


Figure B20. Transverse road surface profiles for Item 5 (SSB), maintenance test section, wet lane, 200 passes with pickup truck

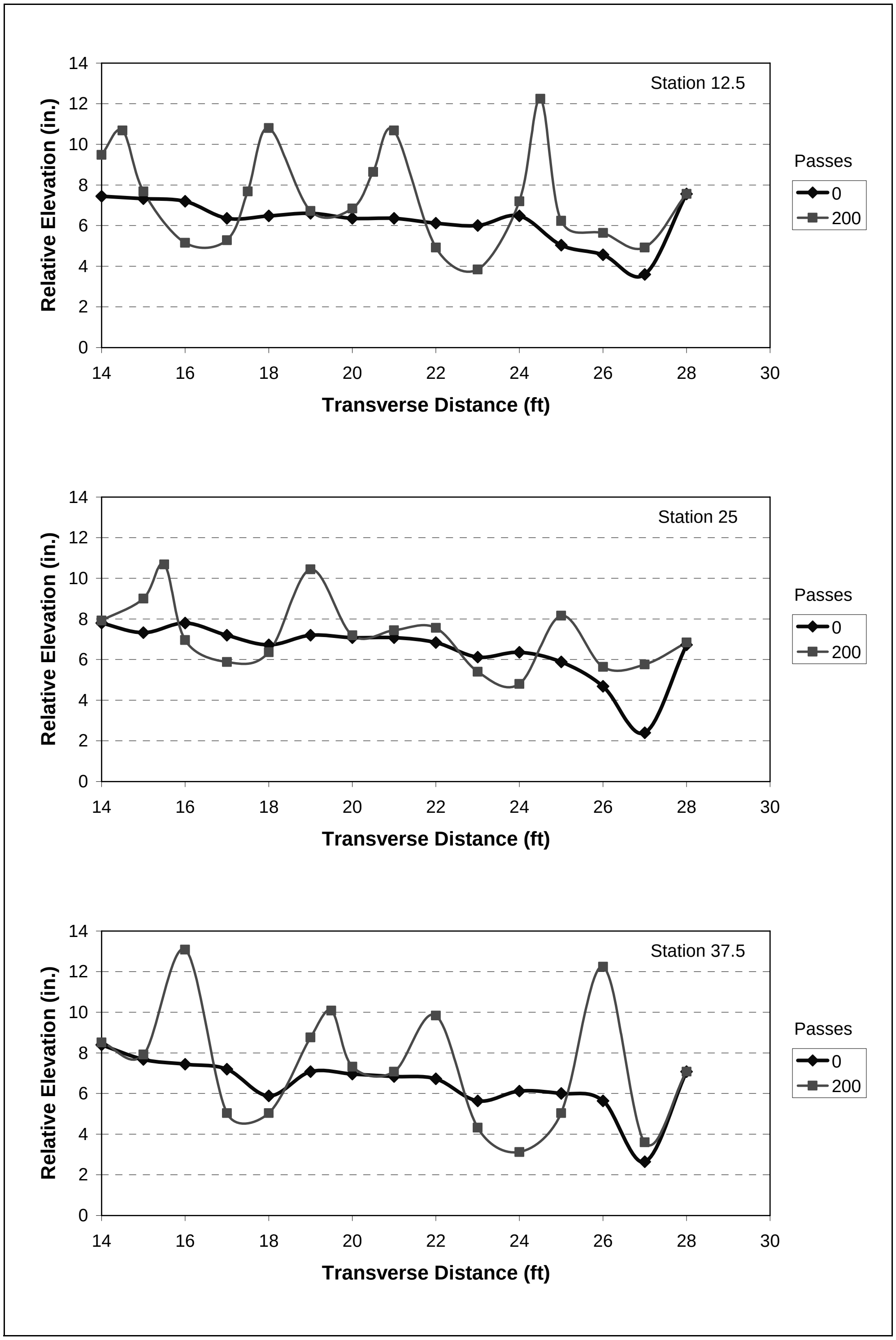


Figure B21. Transverse road surface profiles for Item 1 (SCG), maintenance test section, wet lane, 200 passes with dump truck

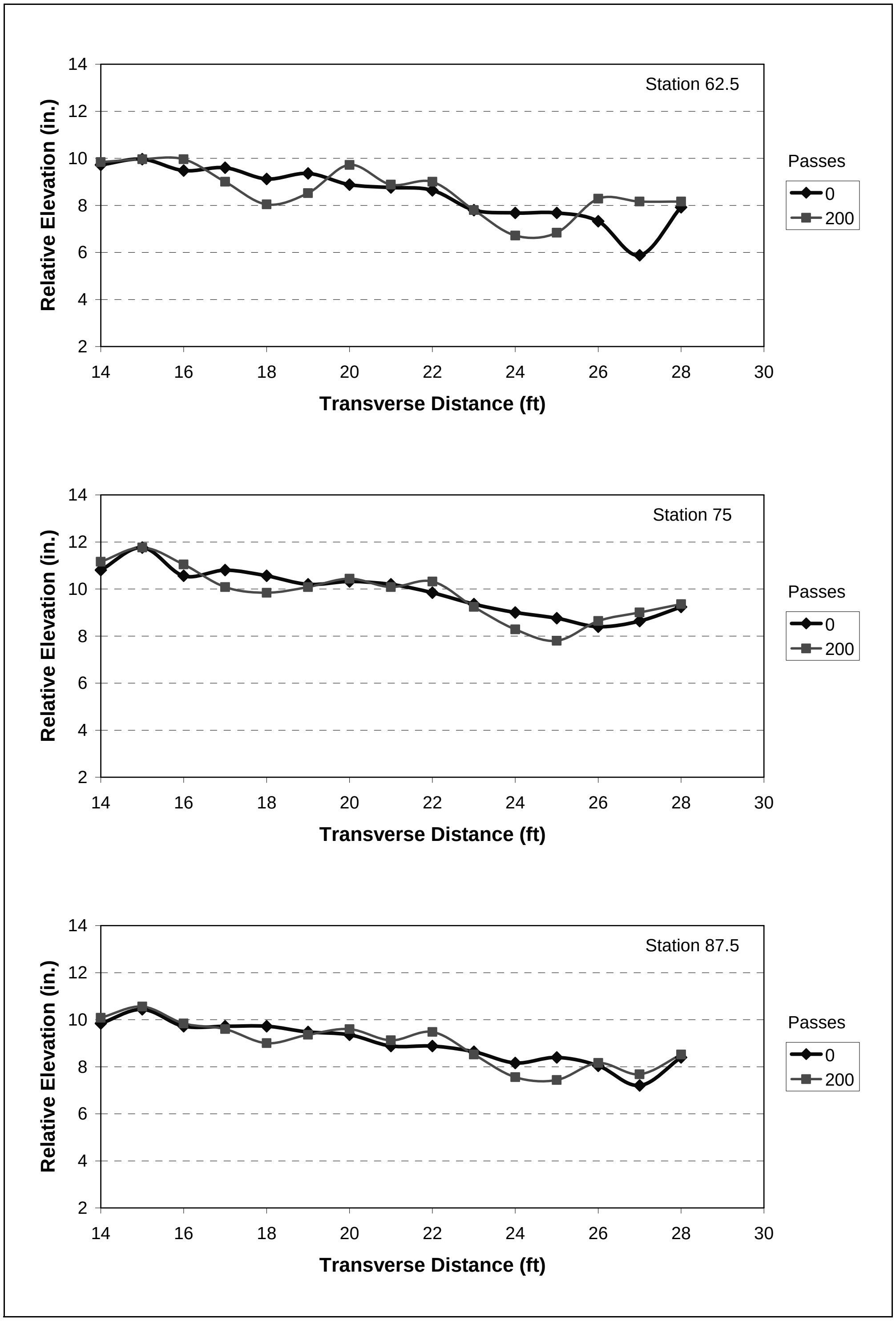


Figure B22. Transverse road surface profiles for Item 2 (LST), maintenance test section, wet lane, 200 passes with dump truck

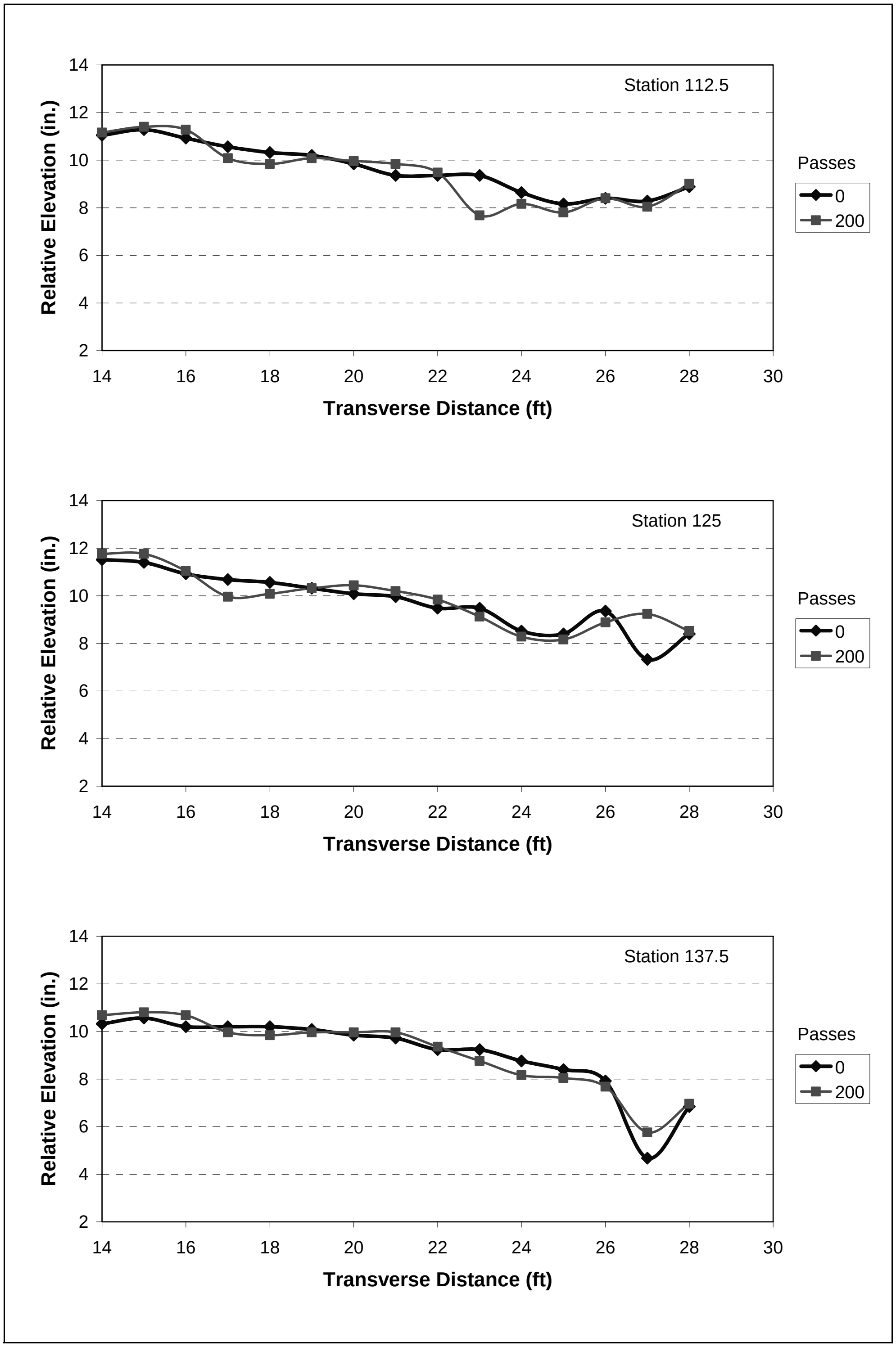


Figure B23. Transverse road surface profiles for Item 3 (SST), maintenance test section, wet lane, 200 passes with dump truck

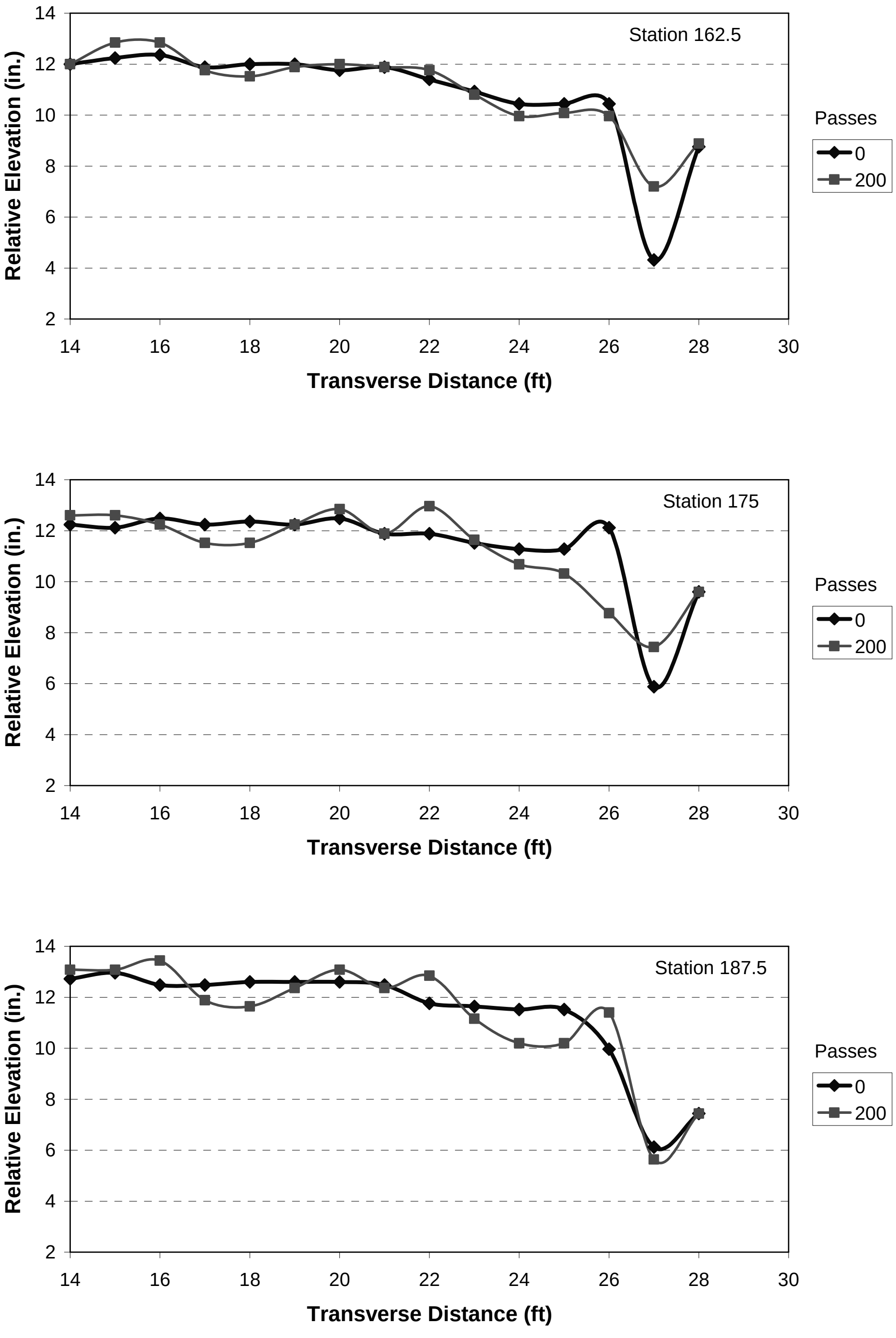


Figure B24. Transverse road surface profiles for Item 4 (IGN), maintenance test section, wet lane, 200 passes with dump truck

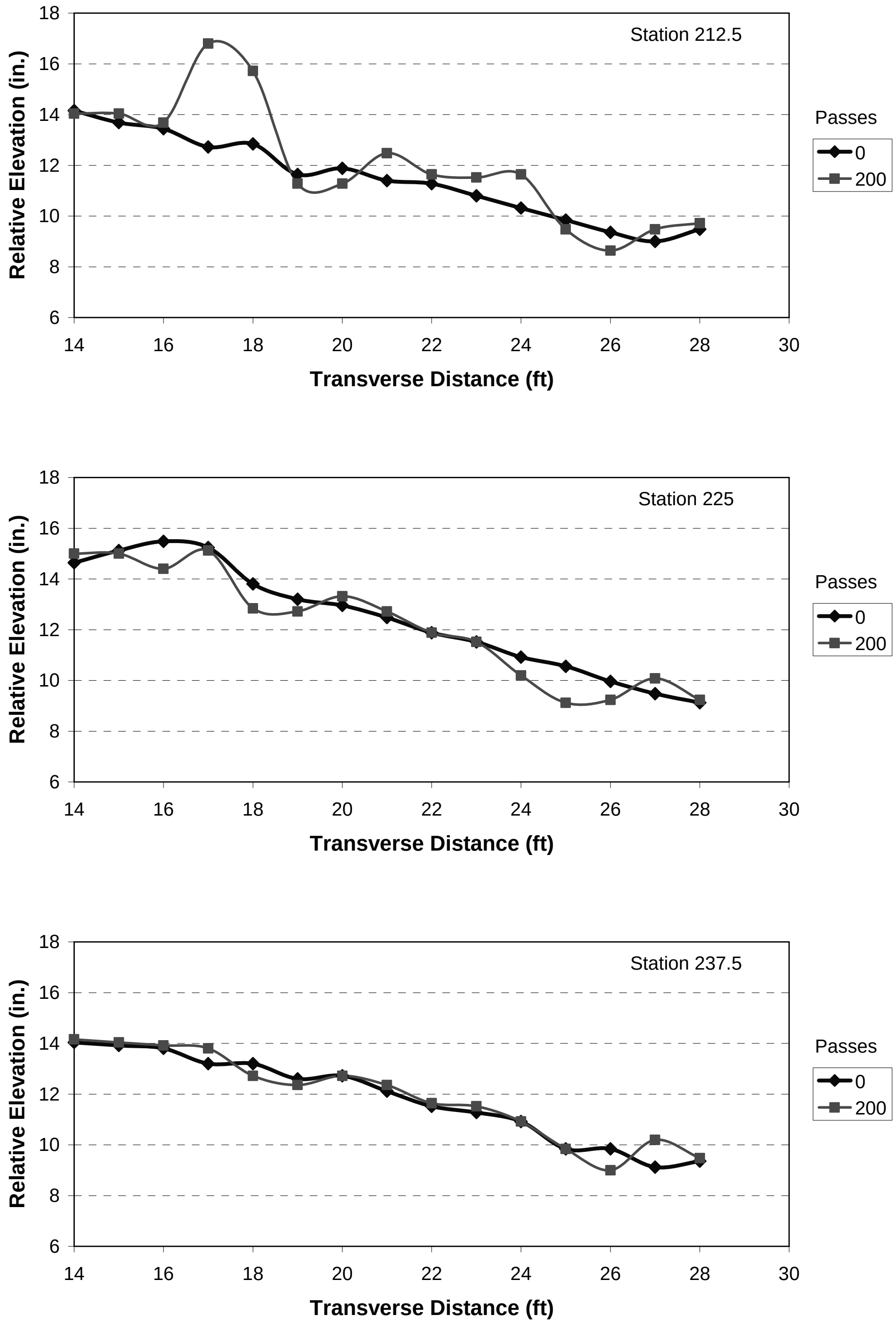


Figure B25. Transverse road surface profiles for Item 5 (SSB), maintenance test section, wet lane, 200 passes with dump truck

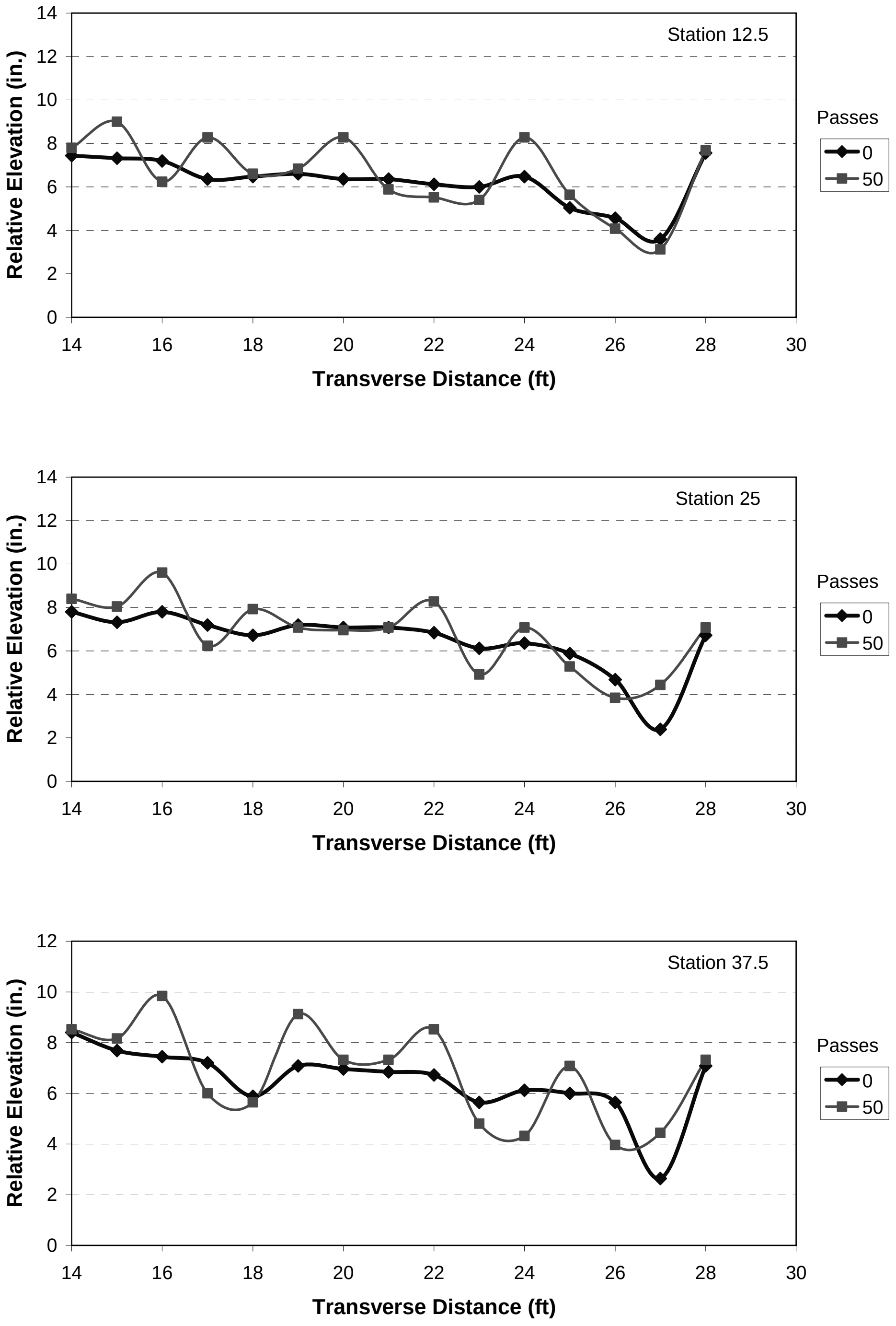


Figure B26. Transverse road surface profiles for Item 1 (SCG), maintenance test section, wet lane, 50 passes with CBR truck

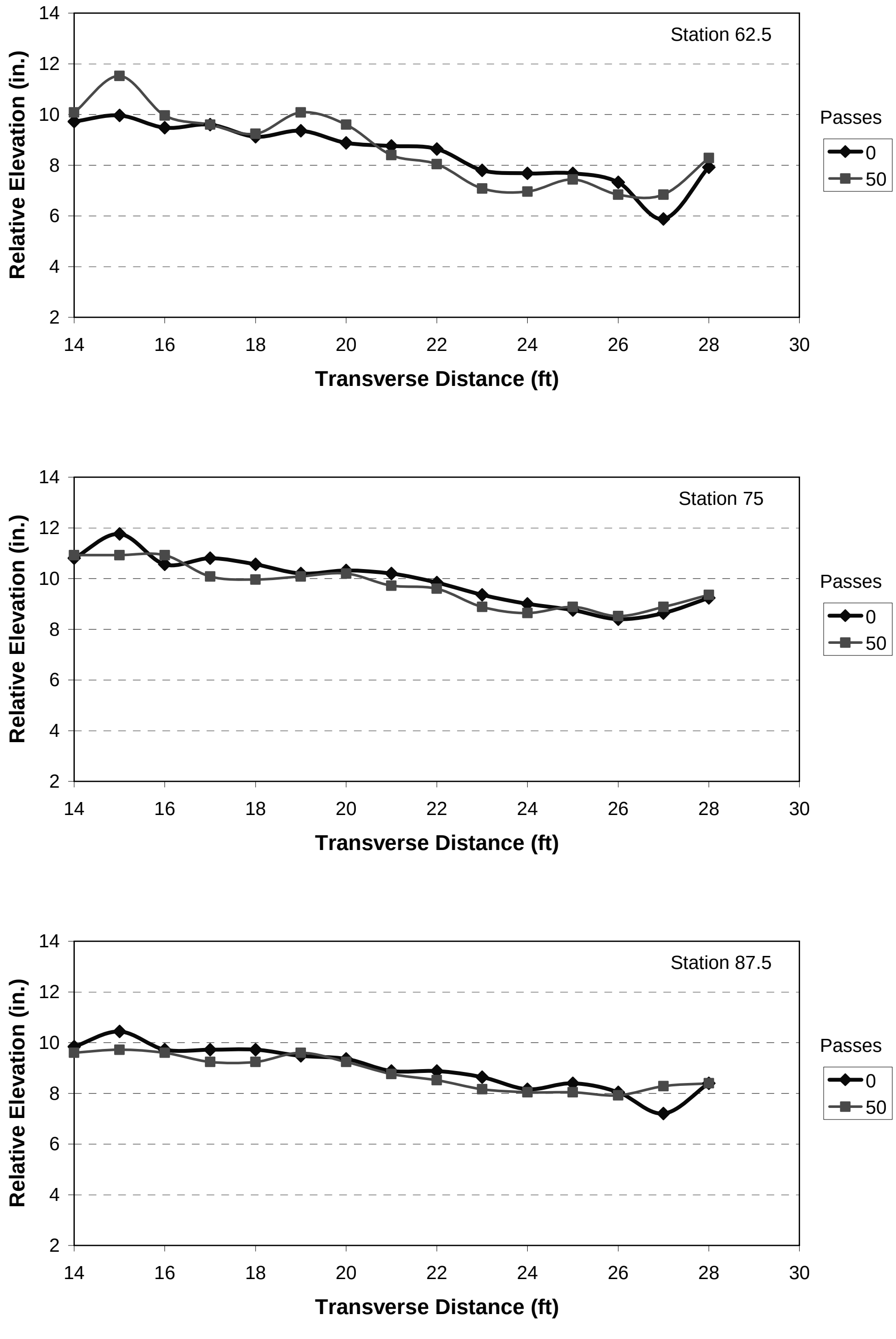


Figure B27. Transverse road surface profiles for Item 2 (LST), maintenance test section, wet lane, 50 passes with CBR truck

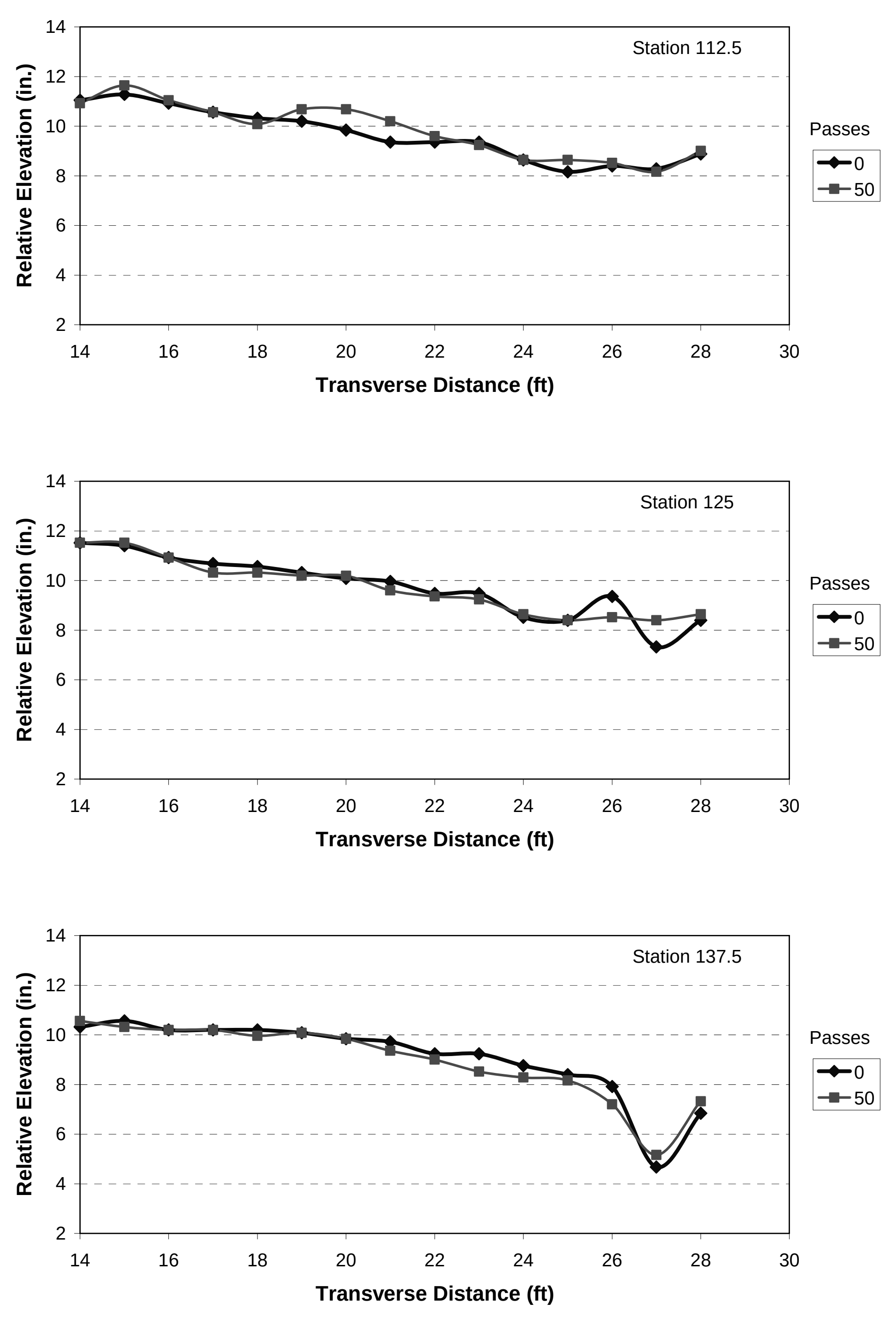


Figure B28. Transverse road surface profiles for Item 3 (SST), maintenance test section, wet lane, 50 passes with CBR truck

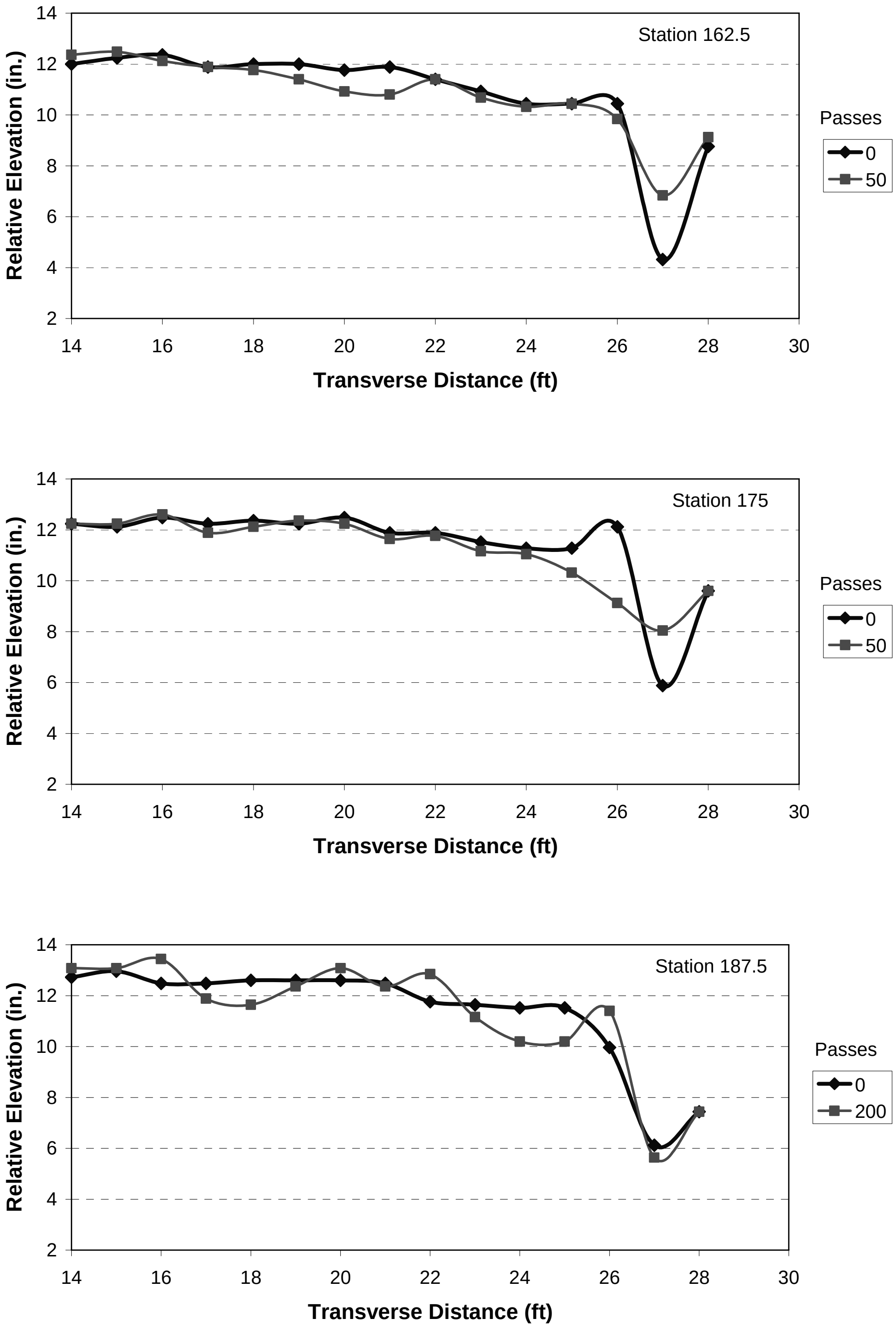


Figure B29. Transverse road surface profiles for Item 4 (IGN), maintenance test section, wet lane, 50 passes with CBR truck

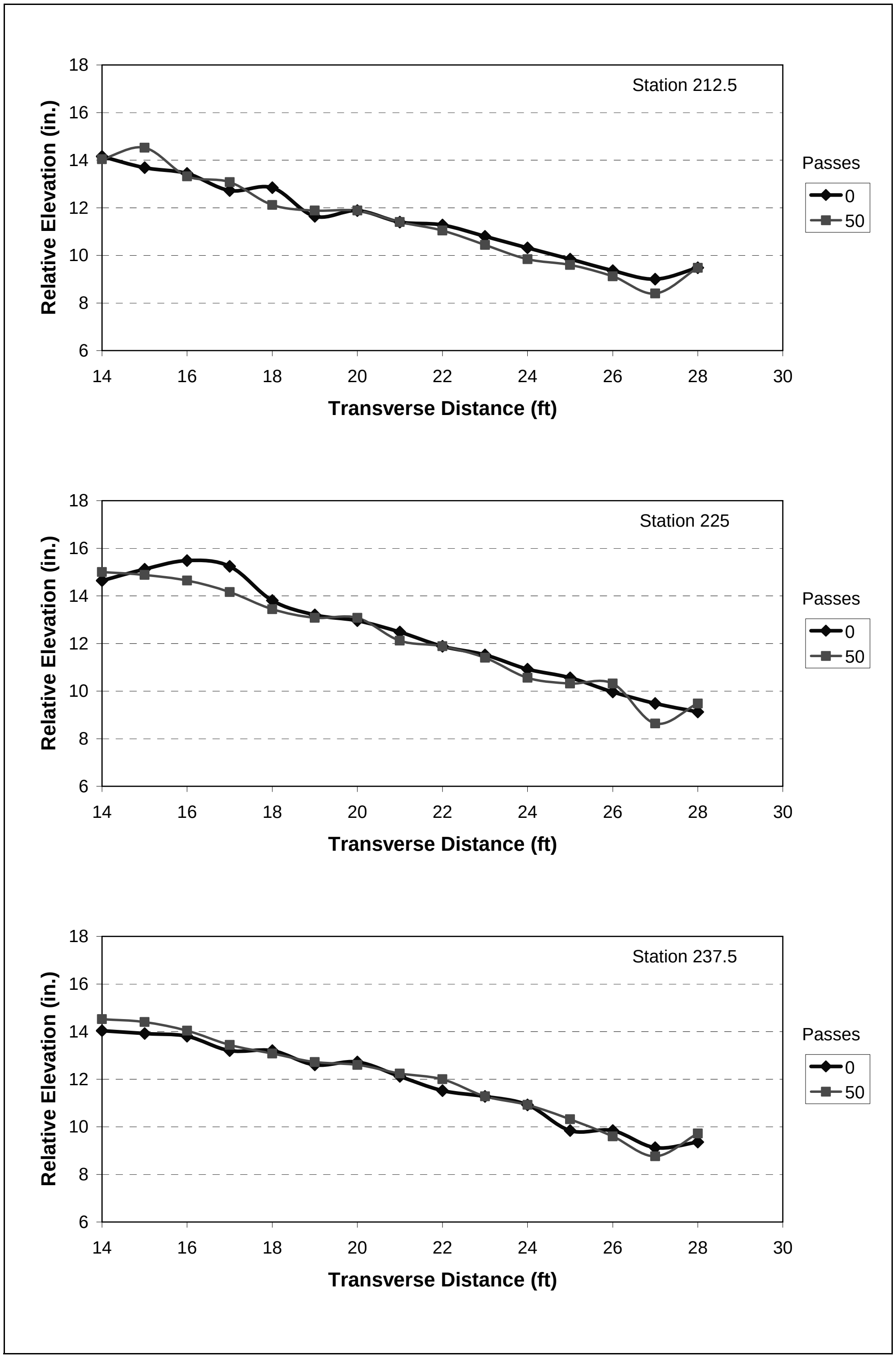


Figure B30. Transverse road surface profiles for Item 5 (SSB), maintenance test section, wet lane, 50 passes with CBR truck

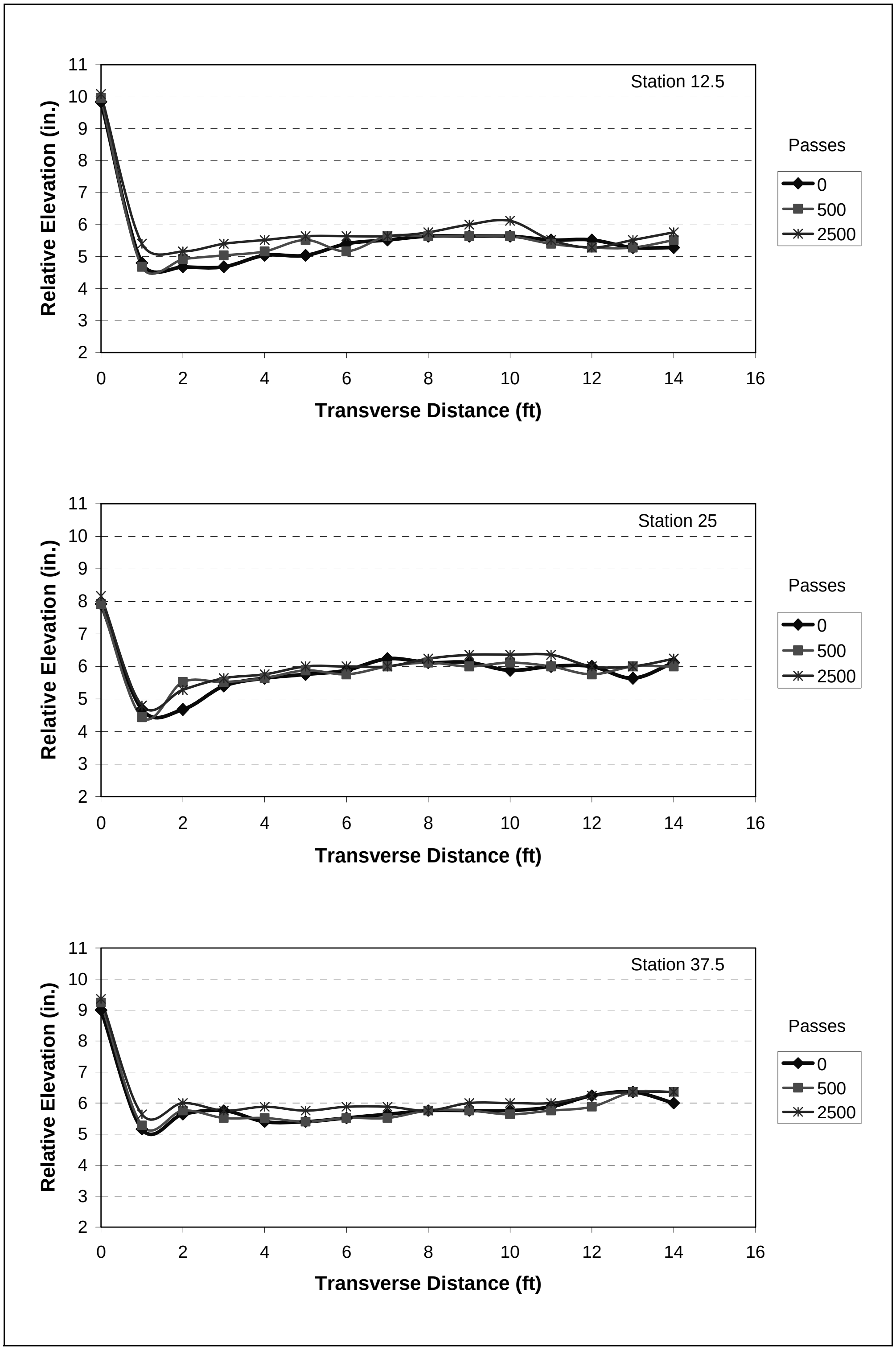


Figure B31. Transverse road surface profiles for Item 6 (SCG), new construction test section, dry lane, 2500 passes with pickup truck

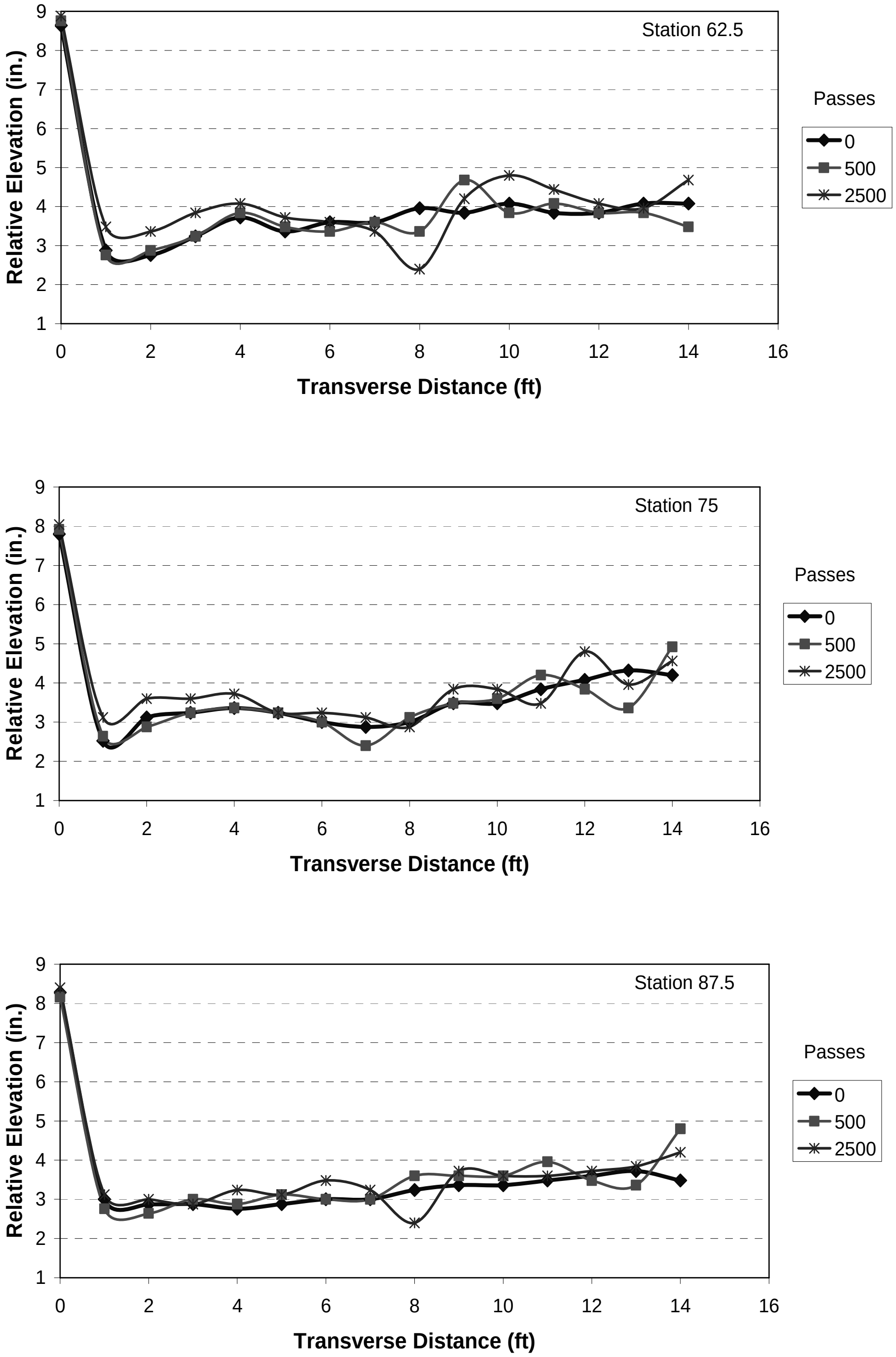


Figure B32. Transverse road surface profiles for Item 7 (LST), new construction test section, dry lane, 2500 passes with pickup truck

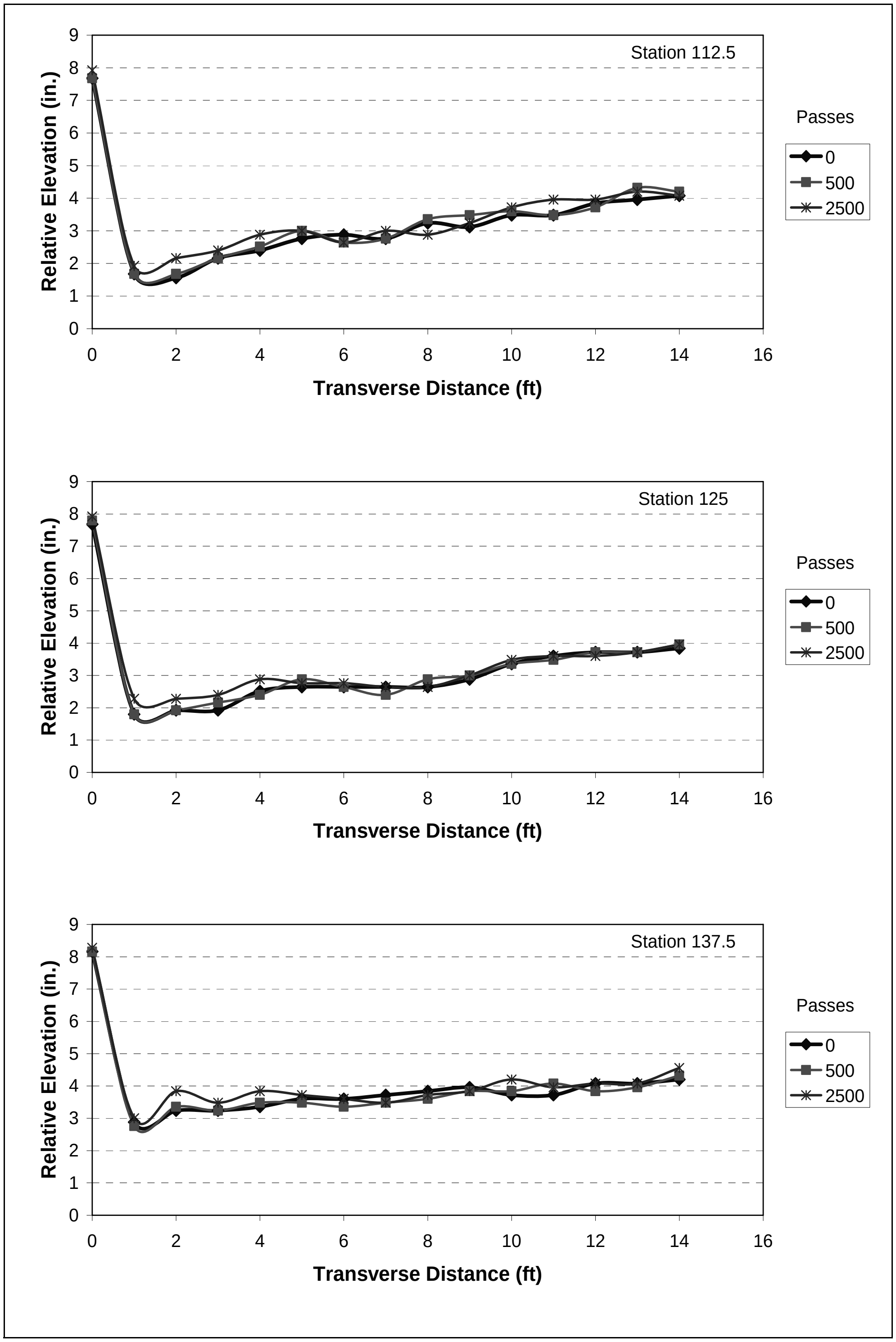


Figure B33. Transverse road surface profiles for Item 8 (SST), new construction test section, dry lane, 2500 passes with pickup truck

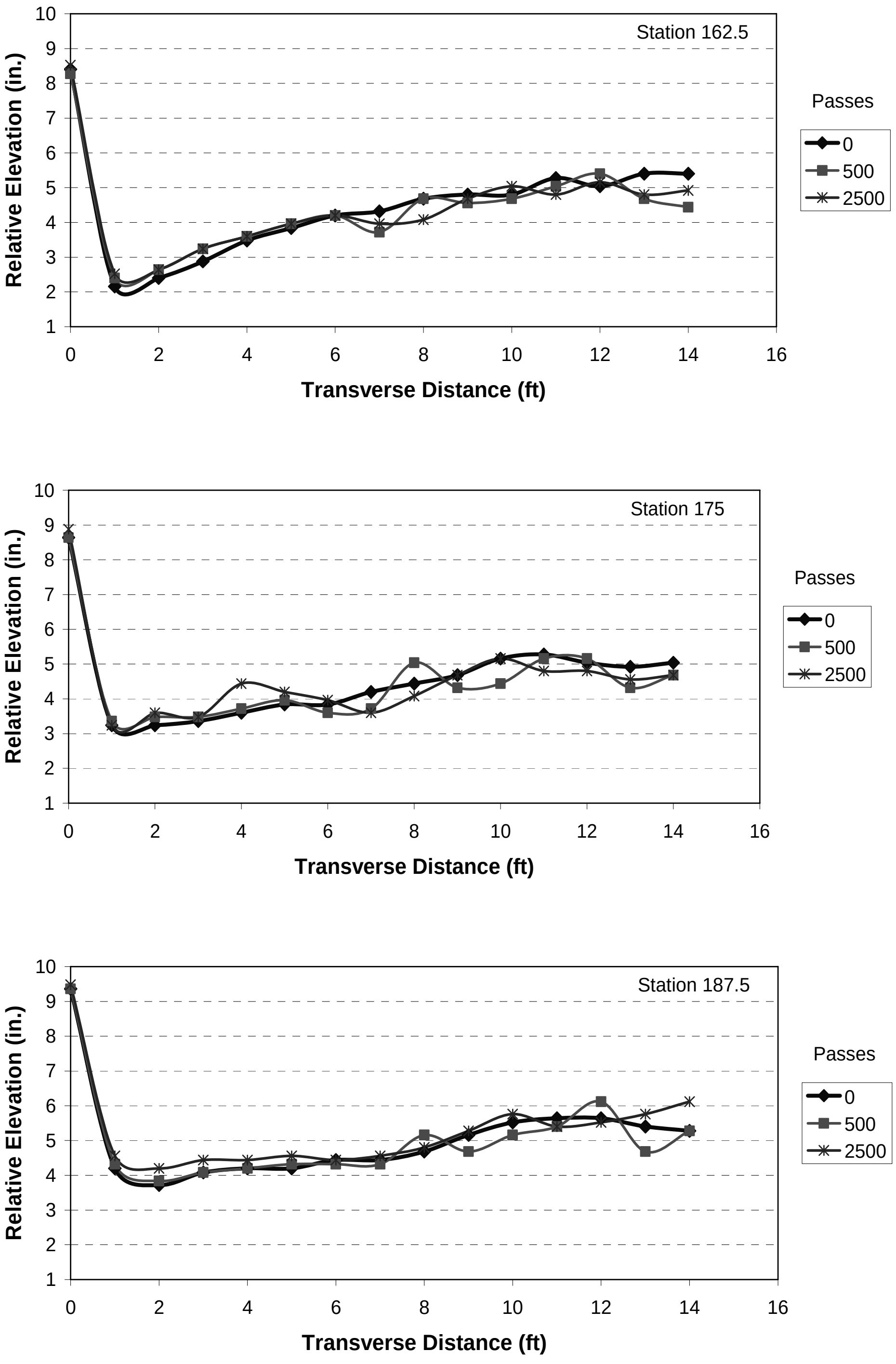


Figure B34. Transverse road surface profiles for Item 9 (IGN), new construction test section, dry lane, 2500 passes with pickup truck

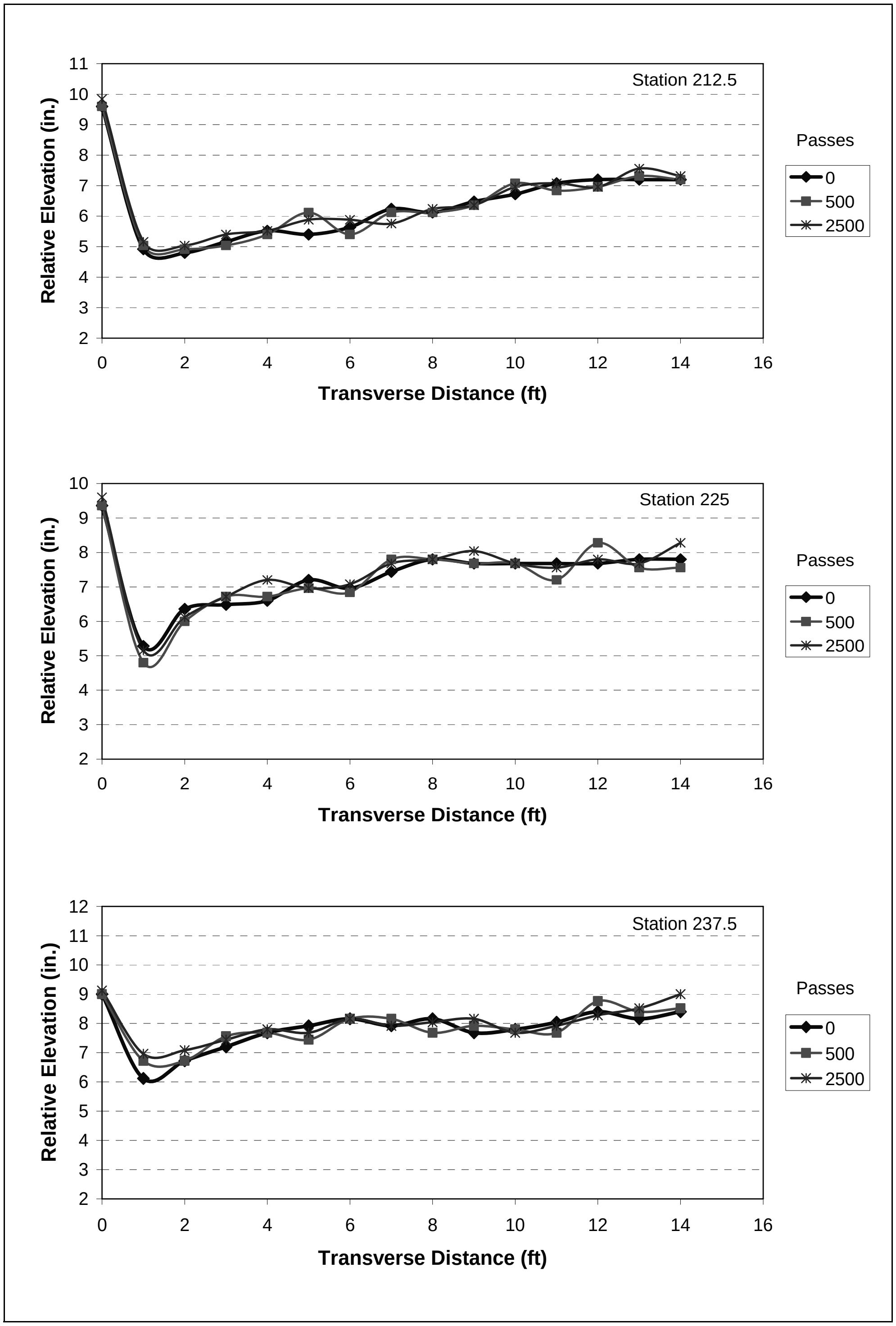


Figure B35. Transverse road surface profiles for Item 10 (SSB), new construction test section, dry lane, 2500 passes with pickup truck

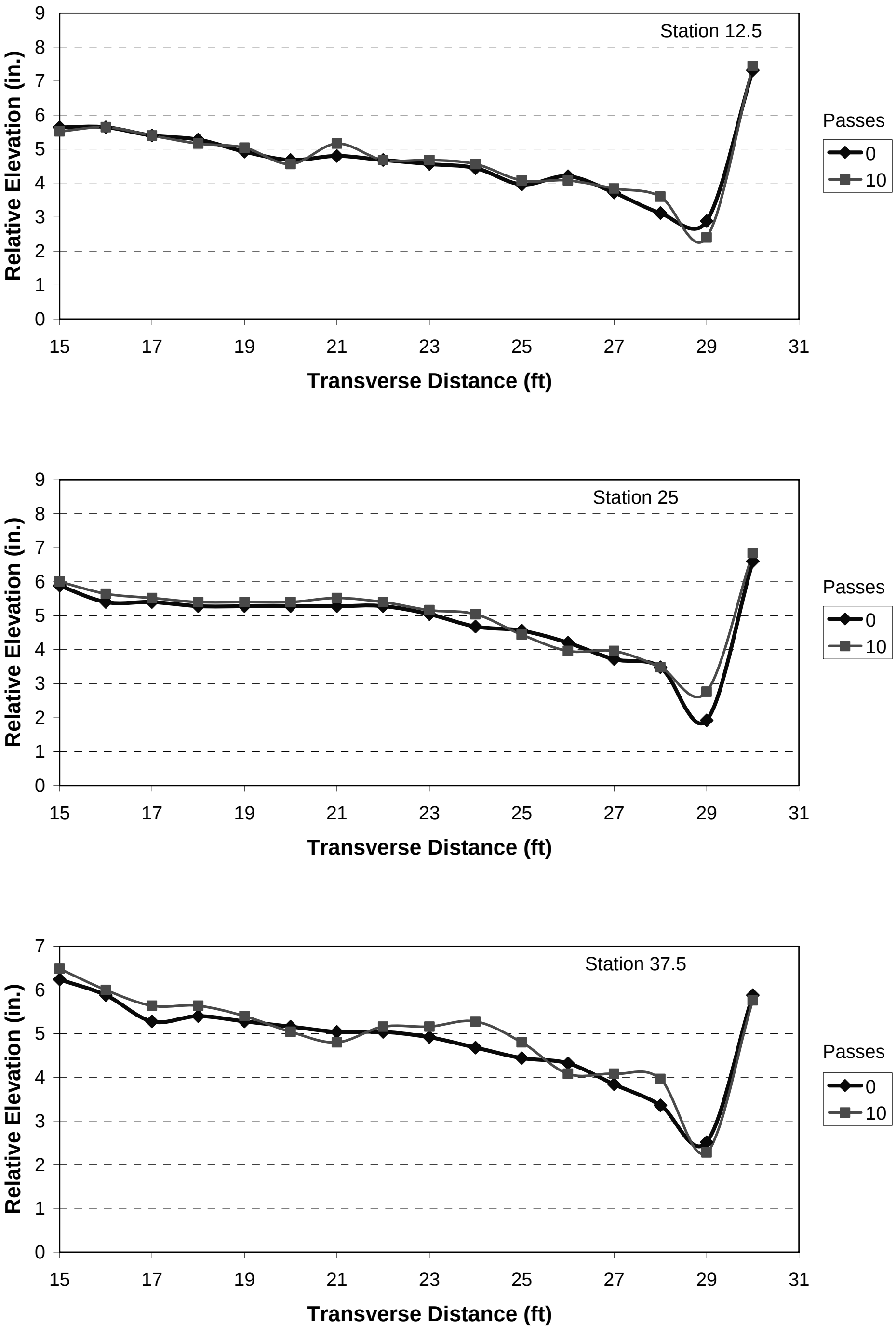


Figure B36. Transverse road surface profiles for Item 6 (SCG), new construction test section, wet lane, 10 passes with pickup truck

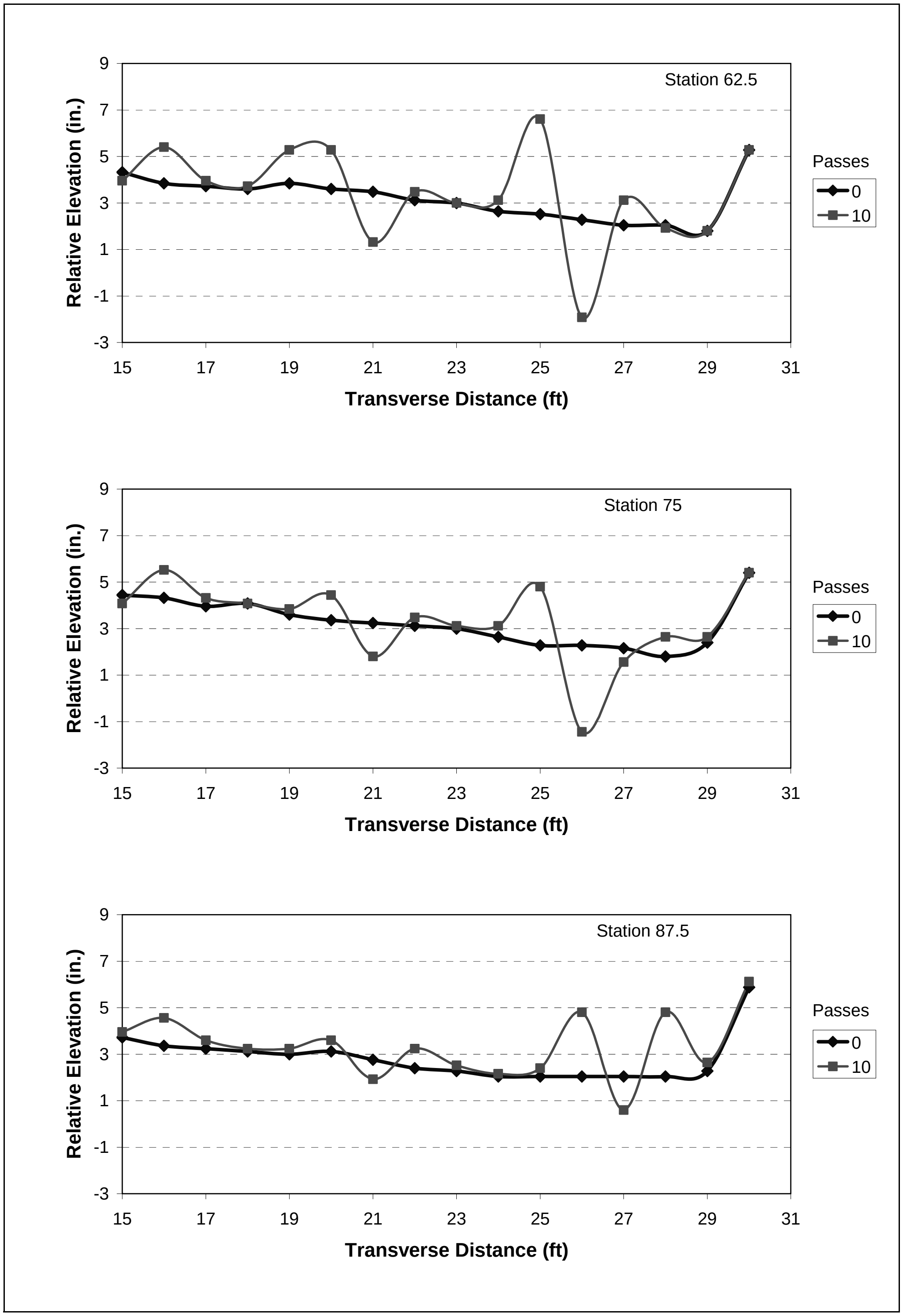


Figure B37. Transverse road surface profiles for Item 7 (LST), new construction test section, wet lane, 10 passes with pickup truck

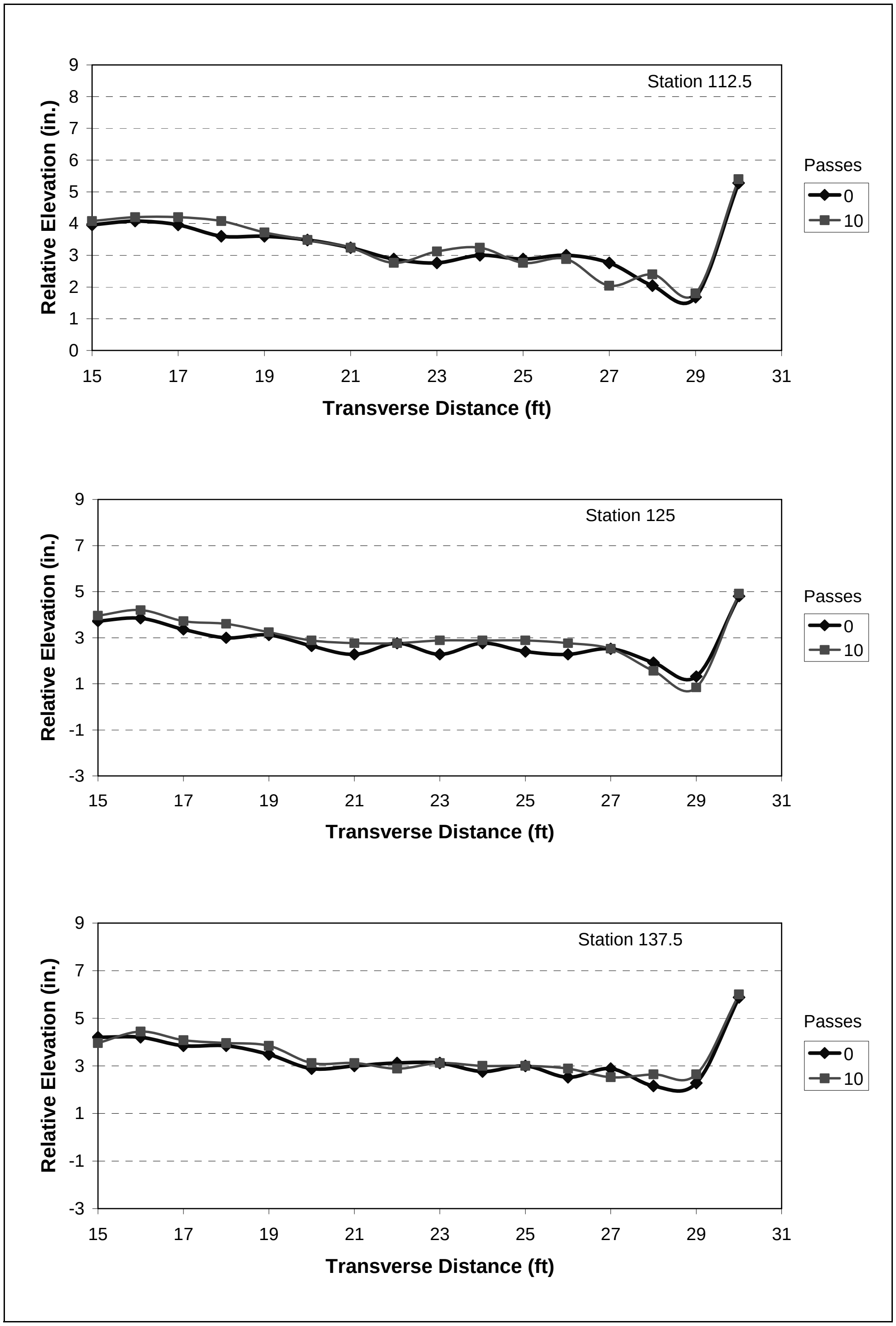


Figure B38. Transverse road surface profiles for Item 8 (SST), new construction test section, wet lane, 10 passes with pickup truck

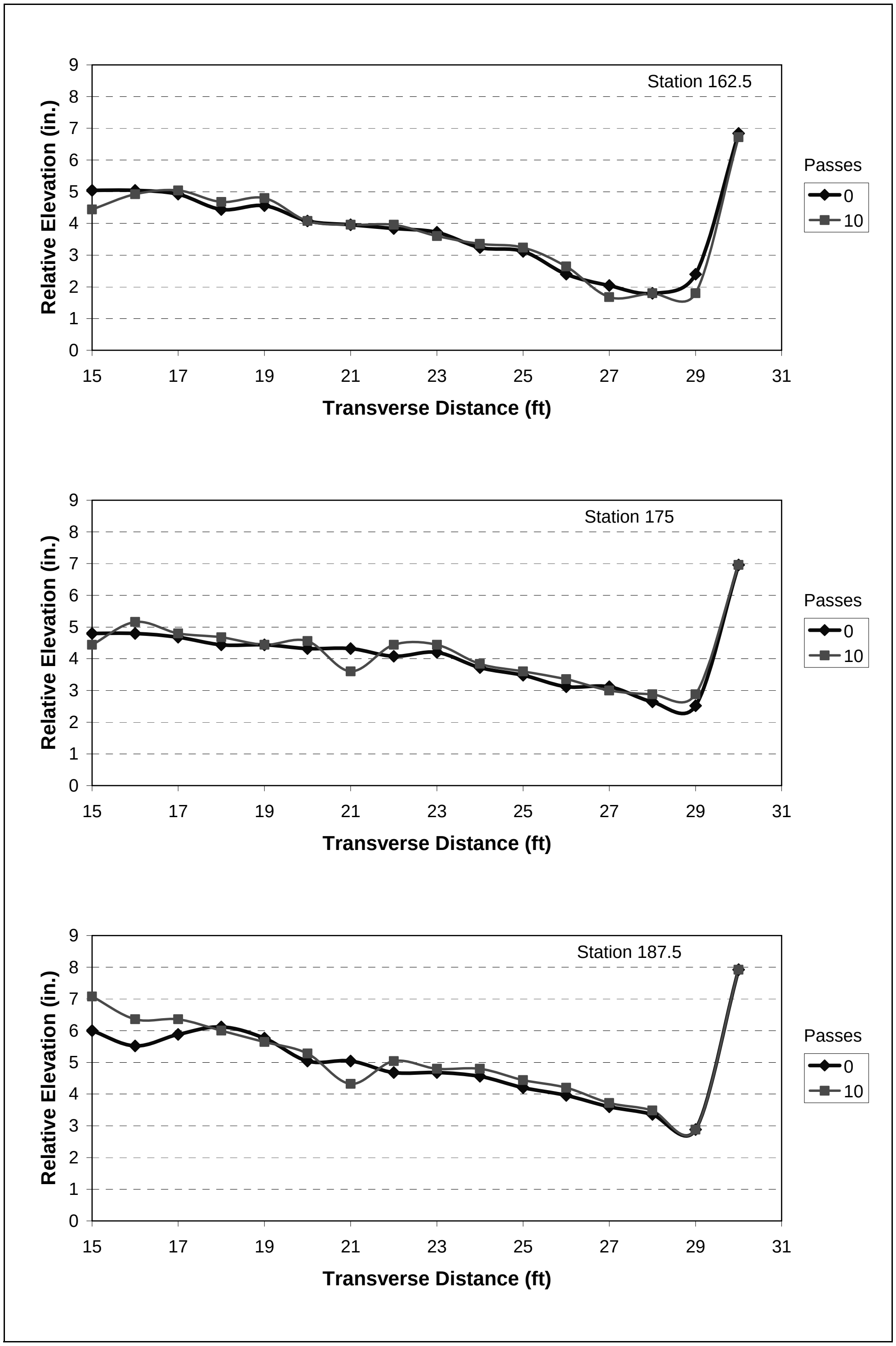


Figure B39. Transverse road surface profiles for Item 9 (IGN), new construction test section, wet lane, 10 passes with pickup truck

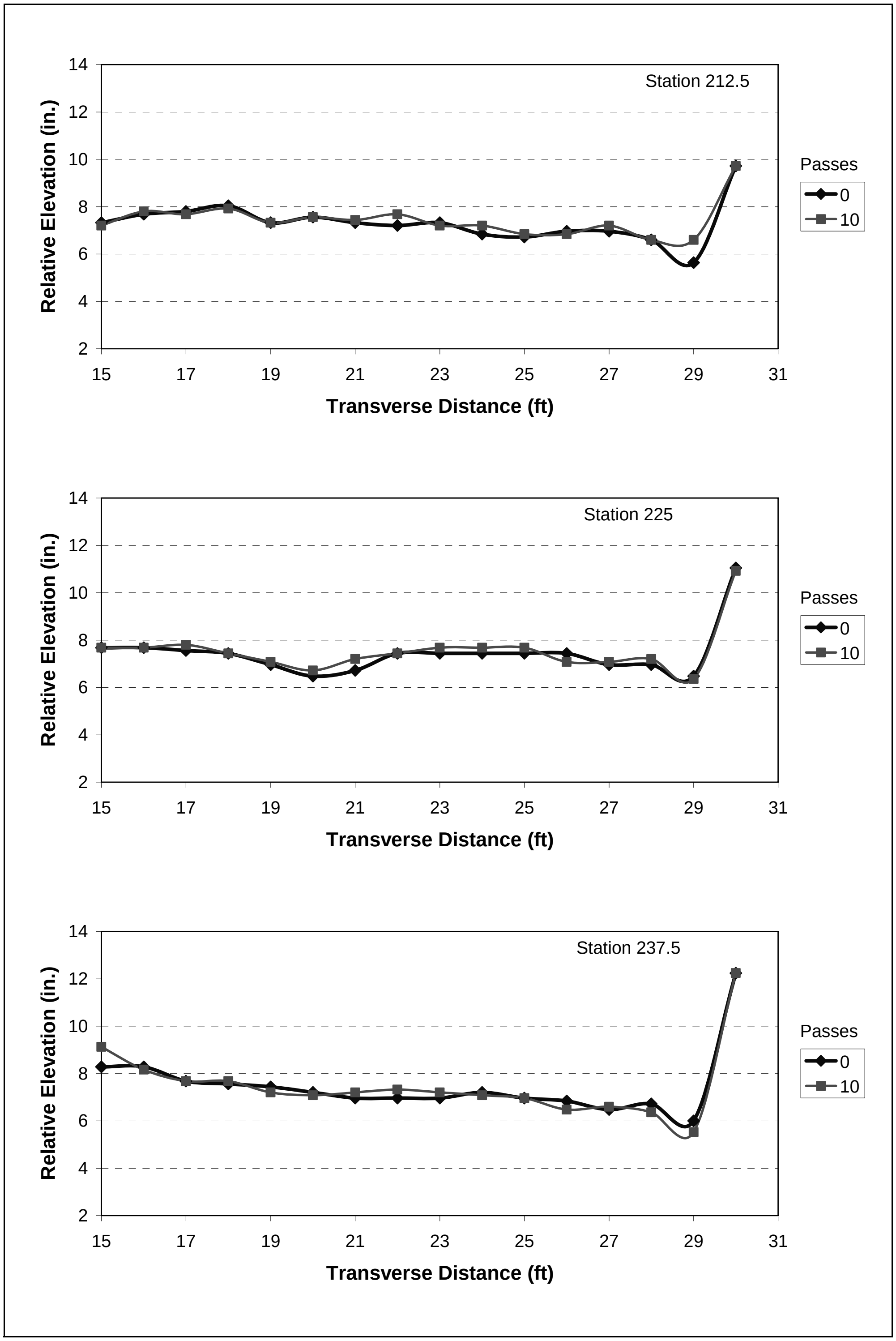


Figure B40. Transverse road surface profiles for Item 10 (SSB), new construction test section, wet lane, 10 passes with pickup truck

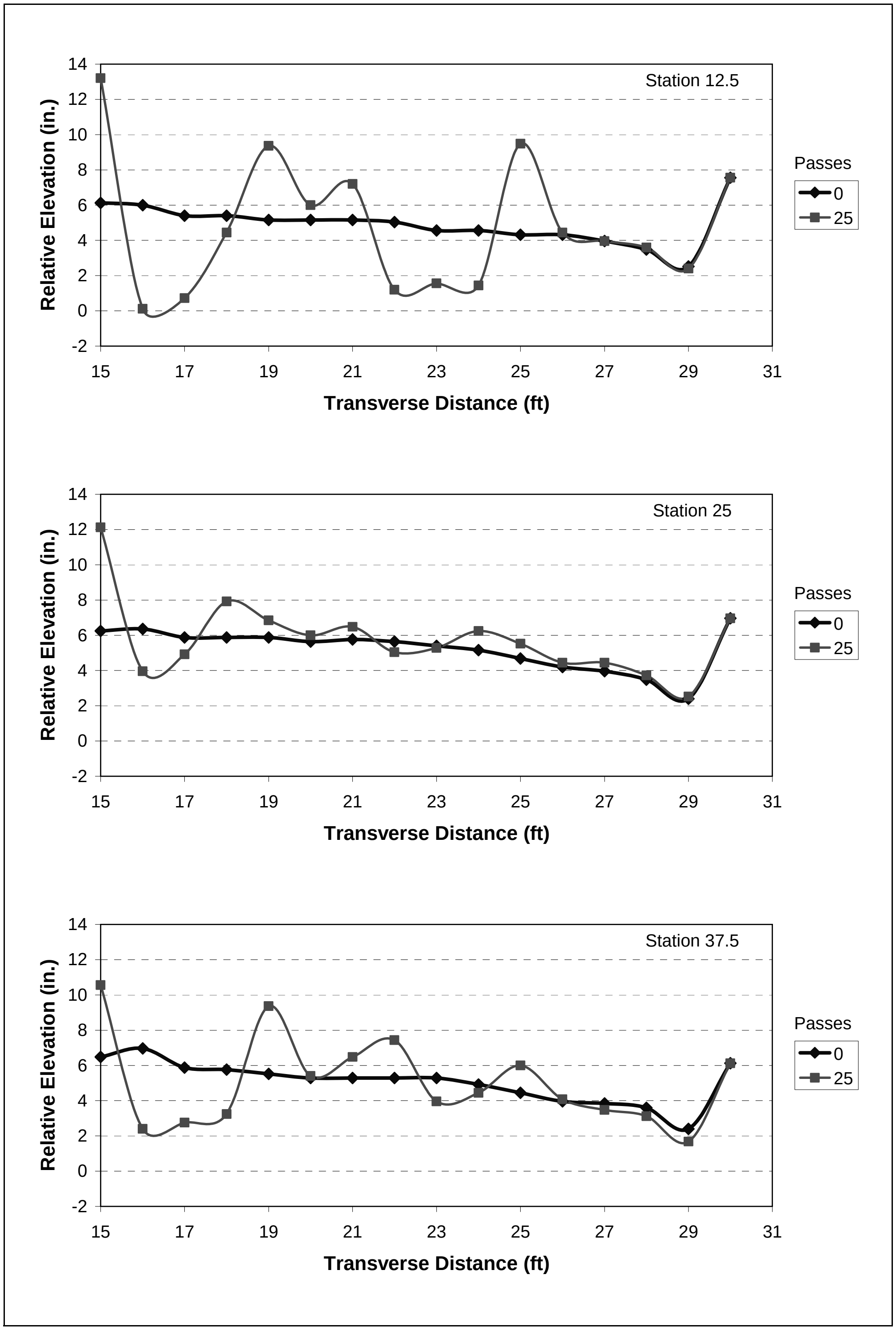


Figure B41. Transverse road surface profiles for Item 6 (SCG), new construction test section, wet lane, 25 passes with CBR truck

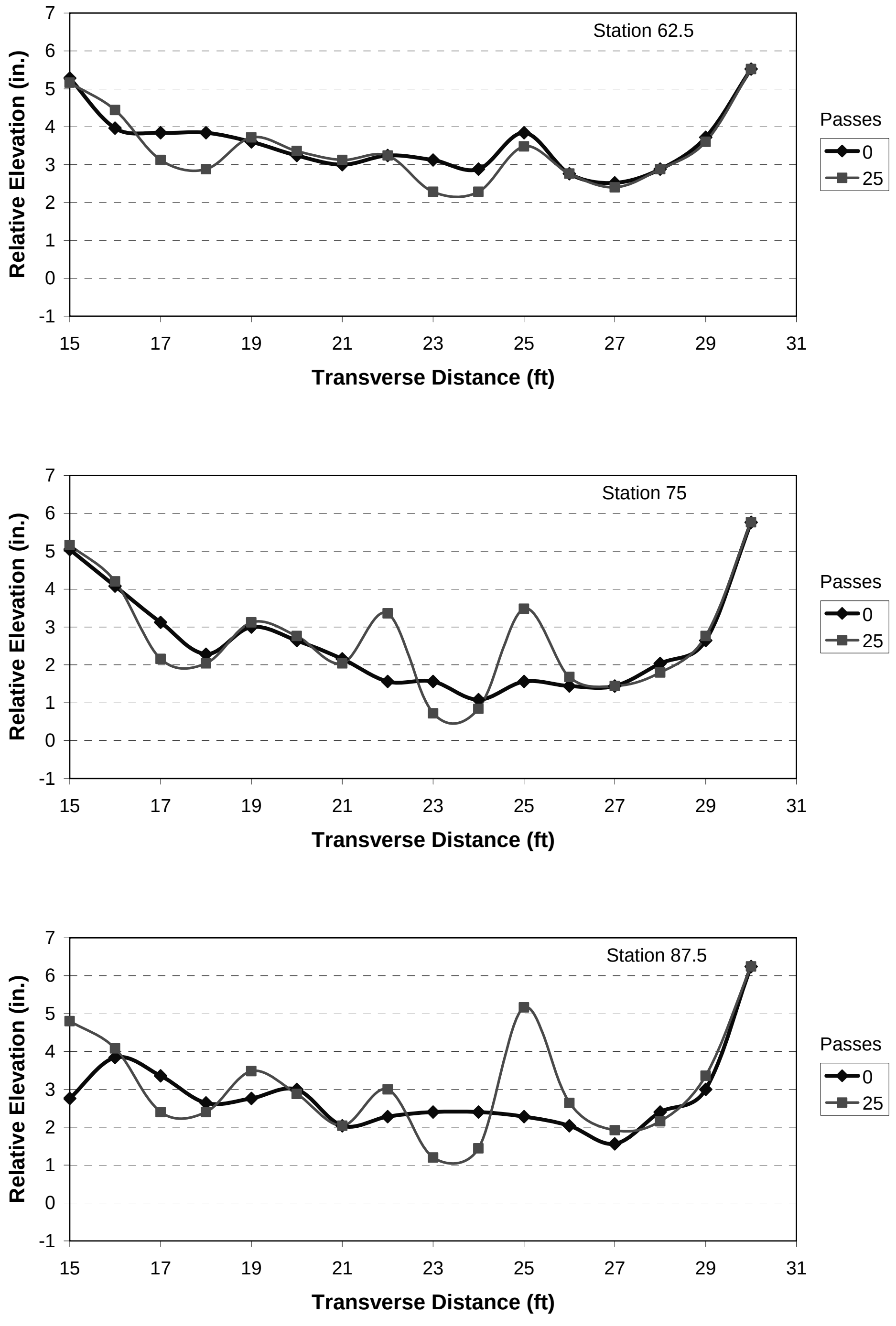


Figure B42. Transverse road surface profiles for Item 7 (LST), new construction test section, wet lane, 25 passes with CBR truck

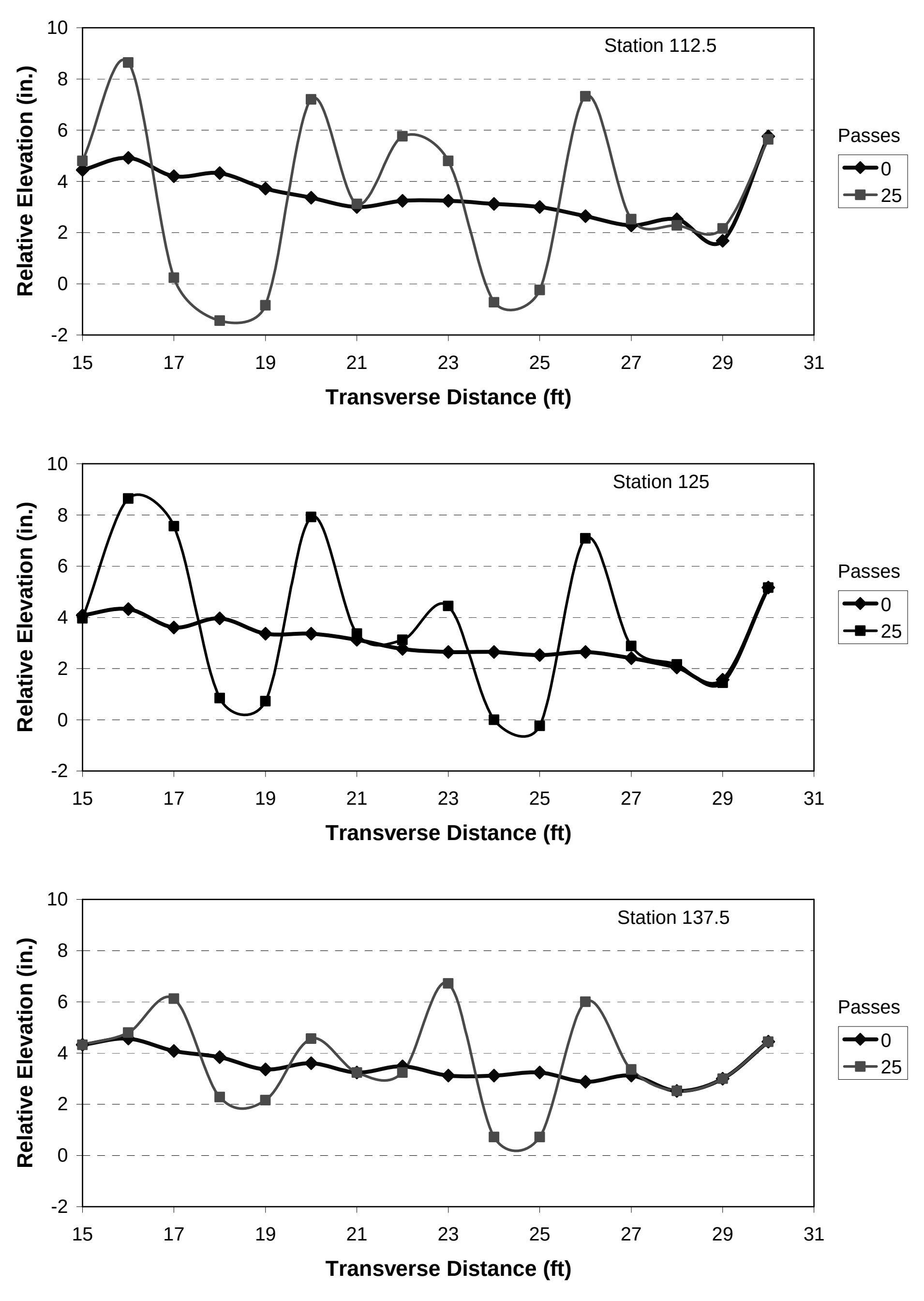


Figure B43. Transverse road surface profiles for Item 8 (SST), new construction test section, wet lane, 25 passes with CBR truck

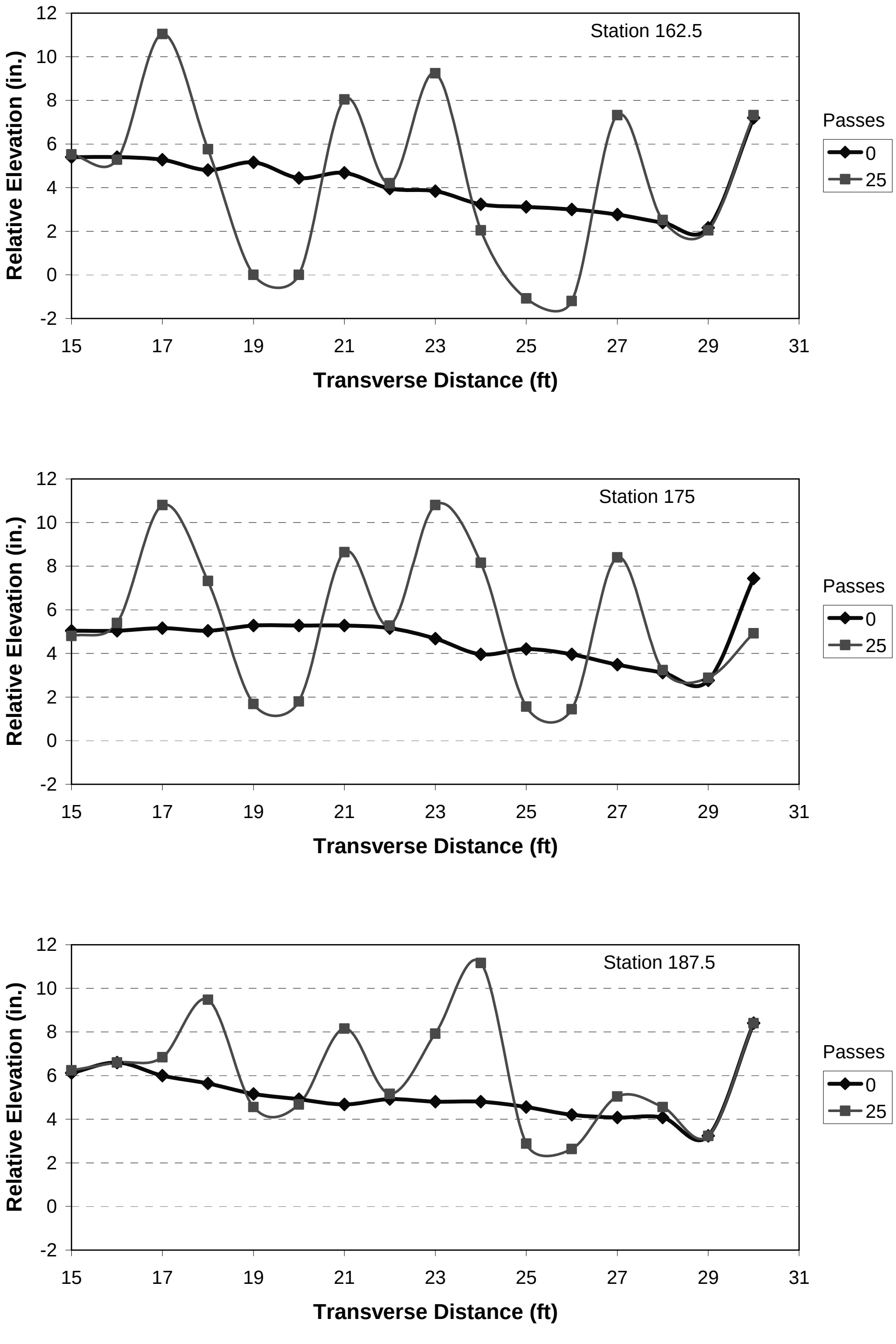


Figure B44. Transverse road surface profiles for Item 9 (IGN), new construction test section, wet lane, 25 passes with CBR truck

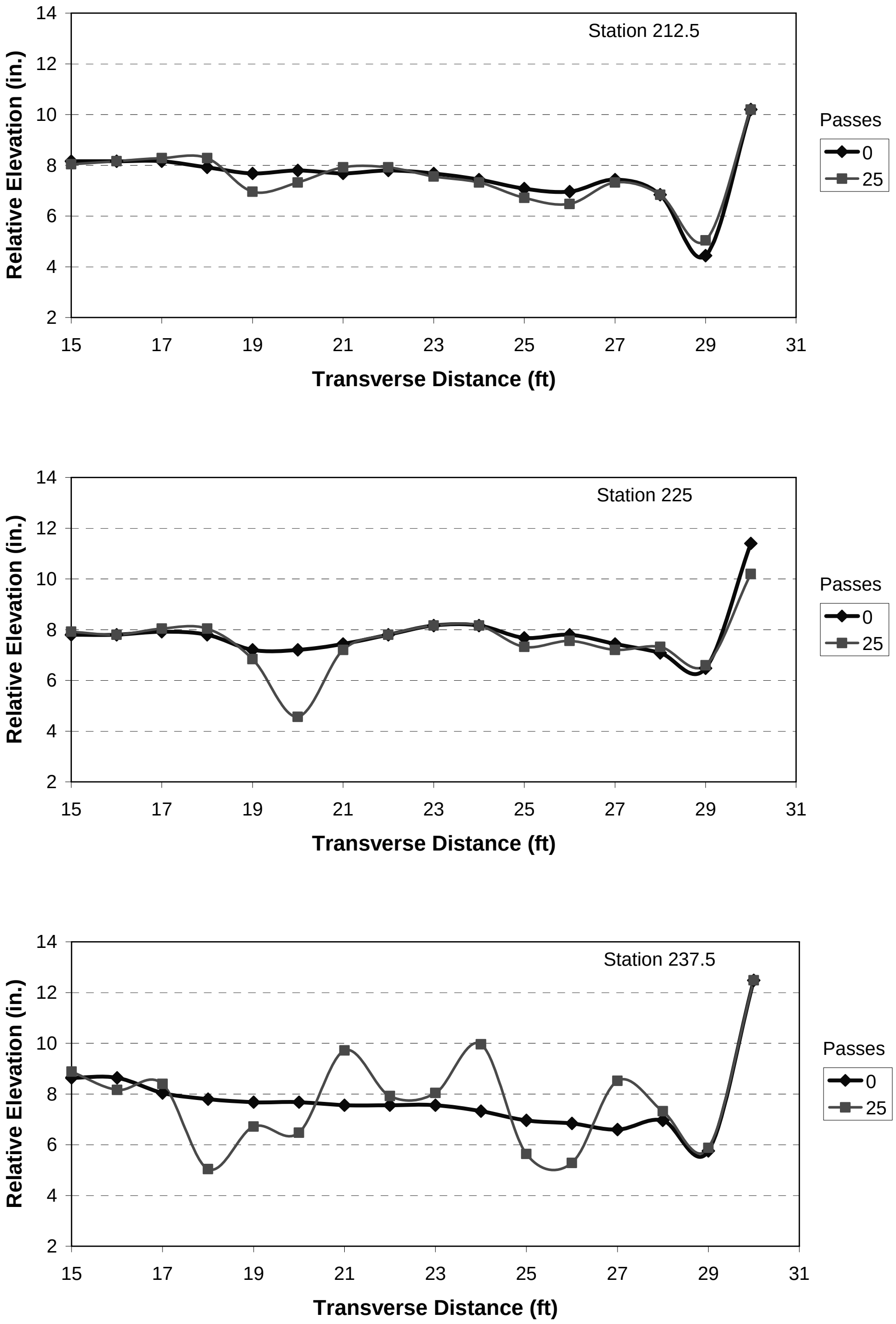


Figure B45. Transverse road surface profiles for Item 10 (SSB), new construction test section, wet lane, 25 passes with CBR truck

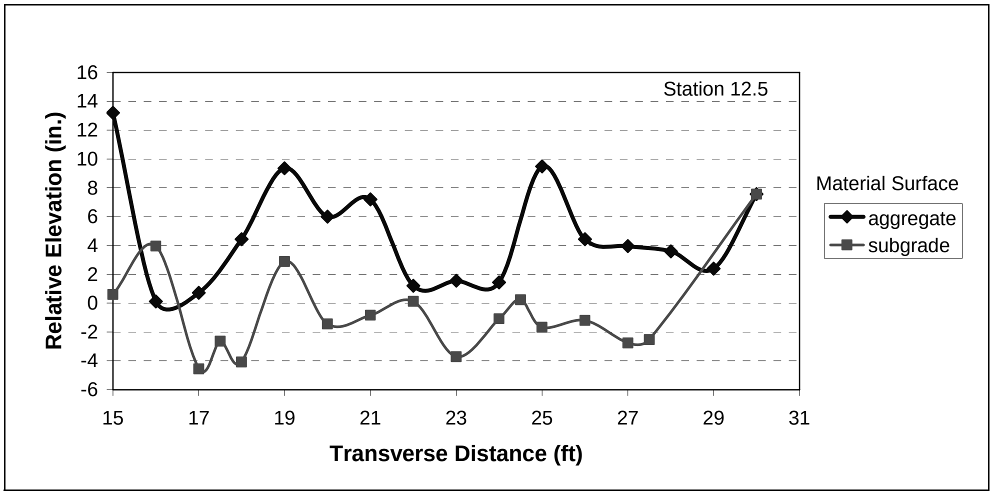


Figure B46. Transverse profiles (road surface and subgrade) for Item 6 (SCG), new construction test section, wet lane, 25 passes with CBR truck

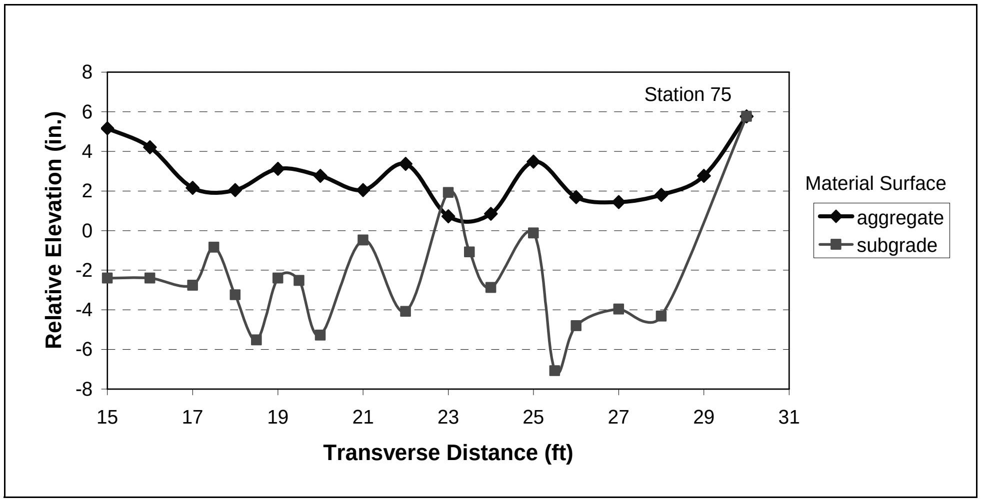


Figure B47. Transverse profiles (road surface and subgrade) for Item 7 (LST), new construction test section, wet lane, 25 passes with CBR truck

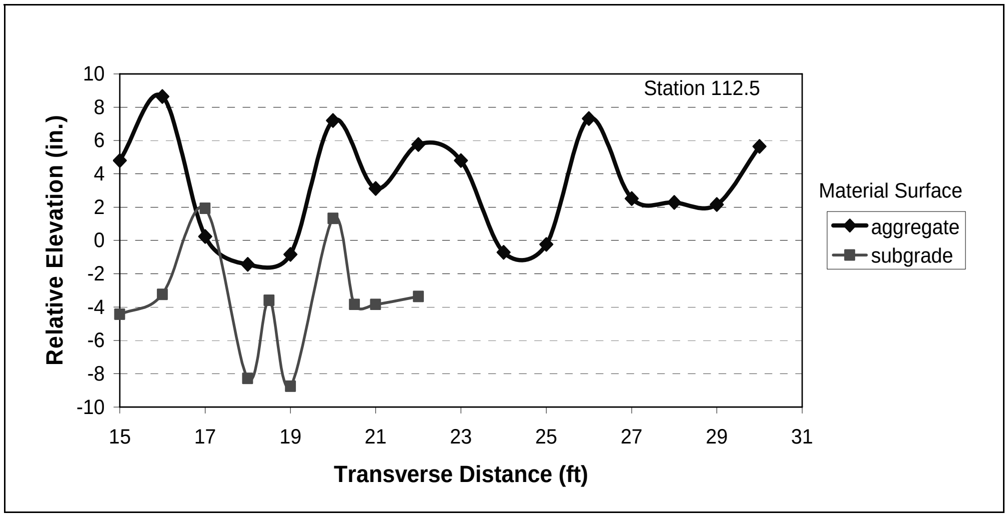


Figure B48. Transverse profiles (road surface and subgrade) for Item 8 (SST), new construction test section, wet lane, 25 passes with CBR truck

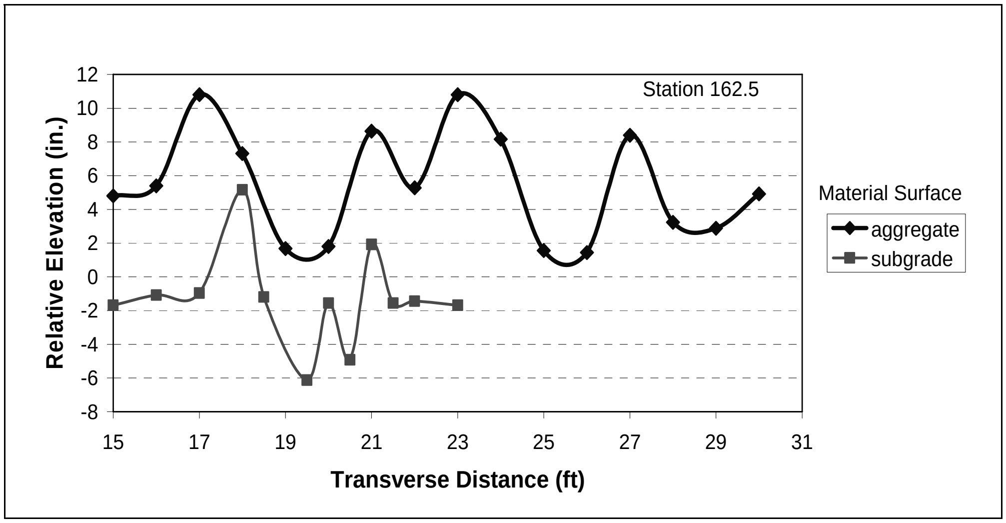


Figure B49. Transverse profiles (road surface and subgrade) for Item 9 (IGN), new construction test section, wet lane, 25 passes with CBR truck

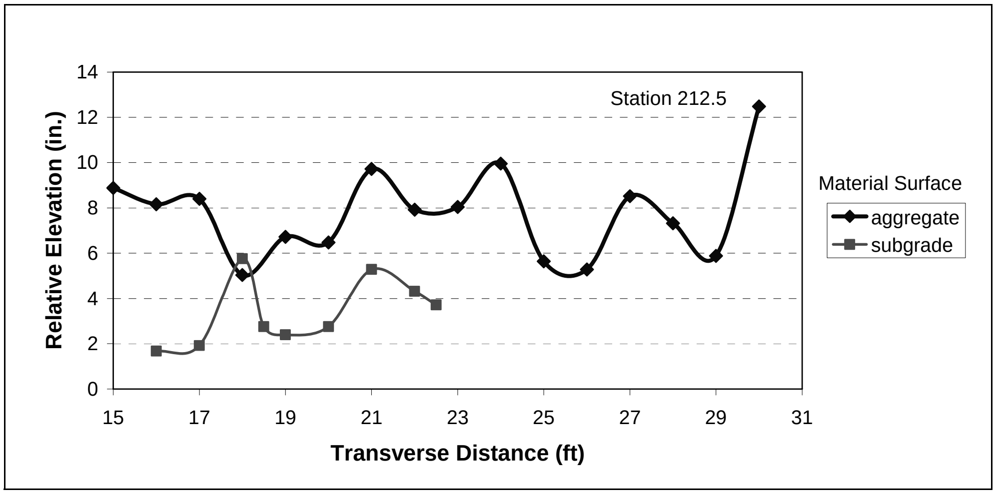


Figure B50. Transverse profiles (road surface and subgrade) for Item 10 (SSB), new construction test section, wet lane, 25 passes with CBR truck

Appendix C
Road Performance Photos

Photo C1. Item 1 (SCG), dry lane, maintenance test section, 500 passes with pickup truck

Photo C2. Item 1 (SCG), dry lane, maintenance test section, 500 passes with pickup truck

Photo C3. Item 2 (LST), dry lane, maintenance test section, 500 passes with pickup truck

Photo C4. Item 2 (LST), dry lane, maintenance test section, 500 passes with pickup truck

Photo C5. Item 3 (SST), dry lane, maintenance test section, 500 passes with pickup truck

Photo C6. Item 3 (SST), dry lane, maintenance test section, 500 passes with pickup truck

Photo C7. Item 4 (IGN), dry lane, maintenance test section, 500 passes with pickup truck

Photo C8. Item 4 (IGN), dry lane, maintenance test section, 500 passes with pickup truck

Photo C9. Item 5 (SSB), dry lane, maintenance test section, 500 passes with pickup truck

Photo C10. Item 5 (SSB), dry lane, maintenance test section, 500 passes with pickup truck

Photo C11. Item 1 (SCG), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C12. Item 1 (SCG), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C13. Item 2 (LST), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C14. Item 2 (LST), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C15. Item 3 (SST), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C16. Item 3 (SST), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C17. Item 4 (IGN), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C18. Item 4 (IGN), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C19. Item 5 (SSB), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C20. Item 5 (SSB), dry lane, maintenance test section, 2500 passes with pickup truck

Photo C21. Item 1 (SCG), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C22. Item 1 (SCG), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C23. Item 2 (LST), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C24. Item 2 (LST), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C25. Item 3 (SST), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C26. Item 3 (SST), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C27. Item 4 (IGN), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C28. Item 4 (IGN), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C29. Item 5 (SSB), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C30. Item 5 (SSB), dry lane, maintenance test section, 200 passes with emulsion truck

Photo C31. Item 1 (SCG), wet lane, maintenance test section, 200 passes with pickup truck

Photo C32. Item 1 (SCG), wet lane, maintenance test section, 200 passes with pickup truck

Photo C33. Item 2 (LST), wet lane, maintenance test section, 200 passes with pickup truck

Photo C34. Item 2 (LST), wet lane, maintenance test section, 200 passes with pickup truck

Photo C35. Item 3 (SST), wet lane, maintenance test section, 200 passes with pickup truck

Photo C36. Item 3 (SST), wet lane, maintenance test section, 200 passes with pickup truck

Photo C37. Item 4 (IGN), wet lane, maintenance test section, 200 passes with pickup truck

Photo C38. Item 4 (IGN), wet lane, maintenance test section, 200 passes with pickup truck

Photo C39. Item 5 (SSB), wet lane, maintenance test section, 200 passes with pickup truck

Photo C40. Item 5 (SSB), wet lane, maintenance test section, 200 passes with pickup truck

Photo C41. Item 1 (SCG), wet lane, maintenance test section, 200 passes with dump truck

Photo C42. Item 1 (SCG), wet lane, maintenance test section, 200 passes with dump truck

Photo C43. Item 2 (LST), wet lane, maintenance test section, 200 passes with dump truck

Photo C44. Item 2 (LST), wet lane, maintenance test section, 200 passes with dump truck

Photo C45. Item 3 (SST), wet lane, maintenance test section, 200 passes with dump truck

Photo C46. Item 3 (SST), wet lane, maintenance test section, 200 passes with dump truck

Photo C47. Item 4 (IGN), wet lane, maintenance test section, 200 passes with dump truck

Photo C48. Item 4 (IGN), wet lane, maintenance test section, 200 passes with dump truck

Photo C49. Item 5 (SSB), wet lane, maintenance test section, 200 passes with dump truck

Photo C50. Item 5 (SSB), wet lane, maintenance test section, 200 passes with dump truck

Photo C51. Item 1 (SCG), wet lane, maintenance test section, 150 passes with pickup truck

Photo C52. Item 1 (SCG), wet lane, maintenance test section, 150 passes with pickup truck

Photo C53. Item 2 (LST), wet lane, maintenance test section, 150 passes with pickup truck

Photo C54. Item 2 (LST), wet lane, maintenance test section, 150 passes with pickup truck

Photo C55. Item 3 (SST), wet lane, maintenance test section, 150 passes with pickup truck

Photo C56. Item 3 (SST), wet lane, maintenance test section, 150 passes with pickup truck

Photo C57. Item 4 (IGN), wet lane, maintenance test section, 150 passes with pickup truck

Photo C58. Item 4 (IGN), wet lane, maintenance test section, 150 passes with pickup truck

Photo C59. Item 5 (SSB), wet lane, maintenance test section, 150 passes with pickup truck

Photo C60. Item 5 (SSB), wet lane, maintenance test section, 150 passes with pickup truck

Photo C61. Item 1 (SCG), wet lane, maintenance test section, 50 passes with CBR truck

Photo C62. Item 1 (SCG), wet lane, maintenance test section, 50 passes with CBR truck

Photo C63. Item 2 (LST), wet lane, maintenance test section, 50 passes with CBR truck

Photo C64. Item 2 (LST), wet lane, maintenance test section, 50 passes with CBR truck

Photo C65. Item 3 (SST), wet lane, maintenance test section, 50 passes with CBR truck

Photo C66. Item 3 (SST), wet lane, maintenance test section, 50 passes with CBR truck

Photo C67. Item 4 (IGN), wet lane, maintenance test section, 50 passes with CBR truck

Photo C68. Item 4 (IGN), wet lane, maintenance test section, 50 passes with CBR truck

Photo C69. Item 5 (SSB), wet lane, maintenance test section, 50 passes with CBR truck

Photo C70. Item 5 (SSB), wet lane, maintenance test section, 50 passes with CBR truck

Photo C71. Item 6 (SCG), dry lane, new construction test section, 500 passes with pickup truck

Photo C72. Item 6 (SCG), dry lane, new construction test section, 500 passes with pickup truck

Photo C73. Item 7 (LST), dry lane, new construction test section, 500 passes with pickup truck

Photo C74. Item 7 (LST), dry lane, new construction test section, 500 passes with pickup truck

Photo C75. Item 8 (SST), dry lane, new construction test section, 500 passes with pickup truck

Photo C76. Item 8 (SST), dry lane, new construction test section, 500 passes with pickup truck

Photo C77. Item 9 (IGN), dry lane, new construction test section, 500 passes with pickup truck

Photo C78. Item 9 (IGN), dry lane, new construction test section, 500 passes with pickup truck

Photo C79. Item 10 (SSB), dry lane, new construction test section, 500 passes with pickup truck

Photo C80. Item 10 (SSB), dry lane, new construction test section, 500 passes with pickup truck

Photo C81. Item 6 (SCG), dry lane, new construction test section, 2500 passes with pickup truck

Photo C82. Item 6 (SCG), dry lane, new construction test section, 2500 passes with pickup truck

Photo C83. Item 7 (LST), dry lane, new construction test section, 2500 passes with pickup truck

Photo C84. Item 7 (LST), dry lane, new construction test section, 2500 passes with pickup truck

Photo C85. Item 8 (SST), dry lane, new construction test section, 2500 passes with pickup truck

Photo C86. Item 8 (SST), dry lane, new construction test section, 2500 passes with pickup truck

Photo C87. Item 9 (IGN), dry lane, new construction test section, 2500 passes with pickup truck

Photo C88. Item 9 (IGN), dry lane, new construction test section, 2500 passes with pickup truck

Photo C89. Item 10 (SSB), dry lane, new construction test section, 2500 passes with pickup truck

Photo C90. Item 10 (SSB), dry lane, new construction test section, 2500 passes with pickup truck

Photo C91. Item 7 (LST), dry lane, new construction test section, 10 passes with dump truck

Photo C92. Item 7 (LST), dry lane, new construction test section, 10 passes with dump truck

Photo C93. Item 7 (LST), dry lane, new construction test section, 10 passes with dump truck

Photo C94. Item 7 (LST), dry lane, new construction test section, 10 passes with dump truck

Photo C95. Item 7 (LST), dry lane, new construction test section, 15 passes with dump truck

Photo C96. Item 7 (LST), dry lane, new construction test section, 15 passes with dump truck

Photo C97. Item 6 (SCG), wet lane, new construction test section, 25 passes with pickup truck

Photo C98. Item 7 (LST), wet lane, new construction test section, 25 passes with pickup truck

Photo C99. Item 8 (SST), wet lane, new construction test section, 25 passes with pickup truck

Photo C100. Item 9 (IGN), wet lane, new construction test section, 25 passes with pickup truck

Photo C101. Item 9 (IGN), wet lane, new construction test section, 25 passes with pickup truck

Photo C102. Item 9 (IGN), wet lane, new construction test section, 25 passes with pickup truck

Photo C103. Item 10 (SSB), wet lane, new construction test section, 25 passes with pickup truck

Photo C104. Item 6 (SCG), wet lane, new construction test section, 25 passes with CBR truck

Photo C105. Item 6 (SCG), wet lane, new construction test section, 25 passes with CBR truck

Photo C106. Item 7 (LST), wet lane, new construction test section, 25 passes with CBR truck

Photo C107. Item 7 (LST), wet lane, new construction test section, 25 passes with CBR truck

Photo C108. Item 8 (SST), wet lane, new construction test section, 25 passes with CBR truck

Photo C109. Item 8 (SST), wet lane, new construction test section, 25 passes with CBR truck

Photo C110. Item 9 (IGN), wet lane, new construction test section, 25 passes with CBR truck

Photo C111. Item 9 (IGN), wet lane, new construction test section, 25 passes with CBR truck

Photo C112. Item 10 (SSB), wet lane, new construction test section, 25 passes with CBR truck

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14. ABSTRACT

Engineers at the Vicksburg District (MVK) of the U.S. Army Engineer Division, Mississippi Valley (MVD), are responsible for the design and construction of levees all along the Mississippi River and its tributaries within the District's boundaries. The local Levee Boards are responsible for maintaining approximately 990 miles (1.6 million meters) of unpaved roads, and the District is responsible for maintaining approximately 390 miles (627,000 m) of unpaved roads that reside on top of the levees. Over the years, the MVK has developed its own specifications to meet these needs. Historically, MVK has relied upon sources of sand clay-gravel that could provide consistent products. However, these sources are becoming depleted, so the products have recently become inconsistent. As a result, the MVK has expanded its specifications to facilitate bid submittals by producers of crushed aggregates.

The purpose of the investigation reported herein was to improve the MVK, MVD, specifications by characterizing various aggregate types in the laboratory, along with collecting performance data under traffic. Because of MVK's recent struggles in finding consistent aggregate sources, both natural and crushed sources of aggregate were included in this study. Trafficking and performance monitoring were accomplished under controlled test track conditions. A review of specifications used by other agencies was also conducted in order to take advantage of their knowledge.

15. SUBJECT TERMS

Crushed aggregates	Maintenance	Traffic test
Levees	Sand clay-gravel	Unpaved roads

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