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16. Abstract: This report documents the findings from a research study that reviewed TxDOT's Wet Weather Skid Accident Reduction Program's (WWARP's) aggregate classification system. It evaluated various lab test procedures that are used in the classification of aggregates as well as the field skid resistance performance of 27 different aggregate sources that belonged to synthetic, sandstone, igneous, gravel and carbonate categories. The findings showed that hard, durable aggregates characterized by >80% AIR or <8% MD losses, provided excellent to very good skid resistance regardless of the aggregate residual polish value. In general, all test methods evaluated showed better capability in separating excellent/very good quality aggregates than in identifying very poor/poor quality aggregates. In other words, the special limitation in these test methods was found to be in their ability to classify borderline aggregates into satisfactory and unsatisfactory categories. The WWARP aggregate classification system based on Residual PV, MSS loss and AIR proved to be effective in separating Excellent/Very Good (Class A) from Good/Fair (Class B) materials. However, this classification system failed to separate the few aggregate sources with poor field performance from those with good/fair performance.

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Review of TxDOT WWARP Aggregate Classification System

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CHAPTER I
INTRODUCTION

GENERAL

Skid resistance is an important, safety related performance parameter that must be taken into consideration in the design of the surface courses for highway pavements. The skid resistance of a paved surface is expressed in terms of a *Skid Number (SN).* It is defined as the ratio between the frictional resistance acting along the plane of sliding and the load perpendicular to this plane. It represents the frictional resistance that the pavement offers to vehicles during acceleration, deceleration (braking) and turning actions. High pavement skid numbers ensure that the vehicles would not slide (or skid) on the pavement surface during the above vehicle maneuvers.

In 1967, the Federal Highway Administration (FHWA) issued Highway Safety Program Standard 12 (HSPS No.12) requiring each state DOT to establish standards for pavement design and construction with specific provisions for high skid resistance qualities. The HSPS No. 12 further specified that each State have a program for resurfacing or other surface treatment with emphasis on correction of locations or sections of streets and highways with low skid resistance and high or potentially high accident rates susceptible to reduction by providing improved surfaces. Subsequently, in the July of 1973, the FHWA issued IM 21-2-73, providing basic guidelines for a Skid Accident Reduction Program. Another FHWA document relating to skid safety is its Technical Advisory T 5040.17: Skid Accident Reduction Program published on December 23, 1980 [1]. The essential elements of this technical advisory are:

- Evaluation of pavement design, construction and maintenance practices to ensure the skid resistance provided by the pavements meets the needs of traffic,
- Wet weather accident location studies to identify roadways with high incidence of wet weather accidents, determine corrective measures, and take appropriate actions in a timely and systematic manner, and
- Pavement skid resistance testing program.

The most recent FHWA publication addressing frictional behavior of highway pavements is FHWA Technical Advisory T 5040.36: Surface Texture for Asphalt and Concrete Pavements issued on June 17, 2005 [2]. This technical advisory provides information on the state-of-the-practice for providing surface texture/friction on pavements. Also, it includes guidance for selecting techniques that will provide good wet pavement friction and low tire/surface noise characteristics. It identifies a number of aggregate properties that have important influence on the characteristics of asphalt pavement surfaces. These properties are: angularity, soundness, toughness and polish resistance. The magnesium and sodium sulfate tests are identified as suitable test methods for determining aggregate soundness, Los Angeles Abrasion and Micro-Deval tests for aggregate toughness and British Pendulum tests for aggregate polish resistance.

The contents of this report relate to the design of bituminous pavements to achieve good skid resistance. Pavement skid resistance is a function of both the microtexture and the macrotexture of the pavement surface. Microtexture refers to fine-scale grittiness found on the surface of coarse aggregates used in the bituminous mix. Some types of coarse aggregates are capable of maintaining higher microstructure (higher roughness) under the polishing action of traffic better than others. Macrotexture refers to the large-scale roughness obtained through the arrangement of aggregate particles. The shape, size, and gradation of coarse aggregates determine the macrotexture. Some mix designs, such as open graded asphalt friction courses (OGAFCs) with a large proportion of one-size aggregate, provide excellent macrotexture and therefore good skid resistance. Properties of the mix as well as environmental factors (such as temperature) also affect how well the pavement surface will retain its macrotexture under sustained traffic loads. To create a safe, skid resistant HMAC pavement surface, good quality, polish-resistant aggregate must be used in a mix design that provides a stable macrotexture.

TXDOT WET WEATHER SKID ACCIDENT REDUCTION PROGRAM (WWARP)

The Texas Department of Transportation (TxDOT) first developed and implemented a program to address pavement friction in 1974. A bituminous aggregate rating procedure known as *Rated Source Polish Value* (*RSPV*) served as the primary basis for this program.

In addition, TxDOT allowed aggregate qualification based on its skid performance history as a secondary and alternative method. These two methods are described below.

Rated Source Polish Value (RSPV) Procedure

An *RSPV* is required to be established only for those sources that produce material for bituminous pavement surface course construction. As a first step, the candidate source must be included in the Department's aggregate quality monitoring program (*AQMP*). All aggregate sources that are included in the *QM* program are sampled by a Department representative on a regular basis. The samples are then tested in the TxDOT laboratories at the Materials and Pavements Section of the Construction Division (CSTM&P) to determine their polish value. All polish value samples are prepared and tested in accordance with Test Method Tex-438-A, "Accelerated Polish Test for Coarse Aggregates" [3]. The *RSPV* for the aggregate source will be calculated based on the five most recent *QM* polish value test results. The *RSPV* for a given aggregate source represents the lower statistical limit of the PV values above which 90 percent of the aggregate sample population from that source should fall.

The relationship used in the above calculation is shown as Equation (1.1) below:

$$\text{RSPV} = \bar{x} - 1.533 \left(\sqrt{\frac{\text{MS}}{5}} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.1)$$

where:

x = average of the five most recent QM polish values

MS = variance of the five most recent QM polish values

Use of Skid Performance History for Aggregate Evaluation

The above method for the evaluation of aggregate frictional characteristics relies on the results of the aggregate polish value (PV) as determined by test method Tex-438-A. However, available data suggest that some aggregates, especially those belonging to siliceous gravel, may provide good skid performance in the field although they perform poorly in the laboratory polish value test. This finding lead to the development of an alternative method of aggregate qualification, called the *Skid History Program,* which was introduced in 1975. Using this method, an aggregate source may be qualified based on past performance history.

The skid performance history for a given aggregate source is developed from skid numbers (SN_{40}) measured on pavements that have been constructed using aggregates of that type and from that source. A single data point would typically represent the average of a number of measurements made on a given test section of the roadway. For each of these data points, the cumulative number of vehicle passes corresponding to the lane on which the skid measurements were made is estimated and recorded. From this data plots of SN_{40} versus cumulative vehicle passes per lane (VPPL) can be prepared. Figure 1.1 is an example of such a plot that has been obtained for an aggregate source from south Texas. Figure 1.1 (a) uses linear scale and show the deterioration of skid performance with accumulation of traffic. For the analysis, however, the data must be plotted on logarithmic scale. The logarithmic plot for the same aggregate sources is shown in Figure 1.1(b). The bold lines represent the best-fit linear regression models. This linear relationship between $\log_{10}(SN_{40})$ and $\log_{10}(VPPL)$ now represents the skid performance history of the aggregate source. This model will provide the basis for aggregate qualification based on past skid performance. The qualification of the aggregate based on skid history must be performed on a project by project basis. A detailed explanation of the use of skid performance history for aggregate qualifications and its advantages and disadvantages can be found in Jayawickrama and Graham, 1995 [4].

TxDOT's Current Wet Weather Accident Reduction Program

TxDOT's current Wet Weather Accident Reduction Program (WWARP) is documented in Chapter 5 of the Pavement Design Manual [5]. This WWARP consists of 3 separate phases, Phase I: Wet Weather Accident Analysis, Phase II: Aggregate Selection and Phase III: Skid Testing. Phase II: Aggregate selection has direct relevance to this research study and therefore, deserves special attention. As a first step in the aggregate selection, the pavement engineer must determine the overall friction demand (low, moderate or high) on the roadway surface. Table 1.1 below shows the factors that are relevant and the criteria used in the determination of overall frictional demand.

Table 1.1 Determination of Overall Frictional Demand According to TxDOT's Current WWARP [5]

Attribute	**Low**	**Moderate**	**High**
Rainfall (inches/year)	≤20	>20 but ≤40	>40
Traffic (ADT)	≤5,000	>5,000 but ≤15,000	>15,000
Speed (mph)	≤35	>35 but ≤60	>60
Trucks (%)	≤8	>8 but <15	>15
Vertical Grade (%)	≤2	>2 but ≤5	>5
Horizontal Curve (°)	≤3	>3 but ≤7	>7
Driveways (per mile)	≤5	>5 and ≤10	>10
Intersecting Roadways (ADT)	≤500	>500 but ≤750	>750
Parameters Set by Designer	**Low**	**Moderate**	**High**
Cross slope(inches/ft)	3/8-1/2	¼-3/8	≤1/4
Surface Design Life (yrs)	≤3	>3 but ≤7	>7
Macro Texture	Coarse[1]	Medium[2]	Fine[3]

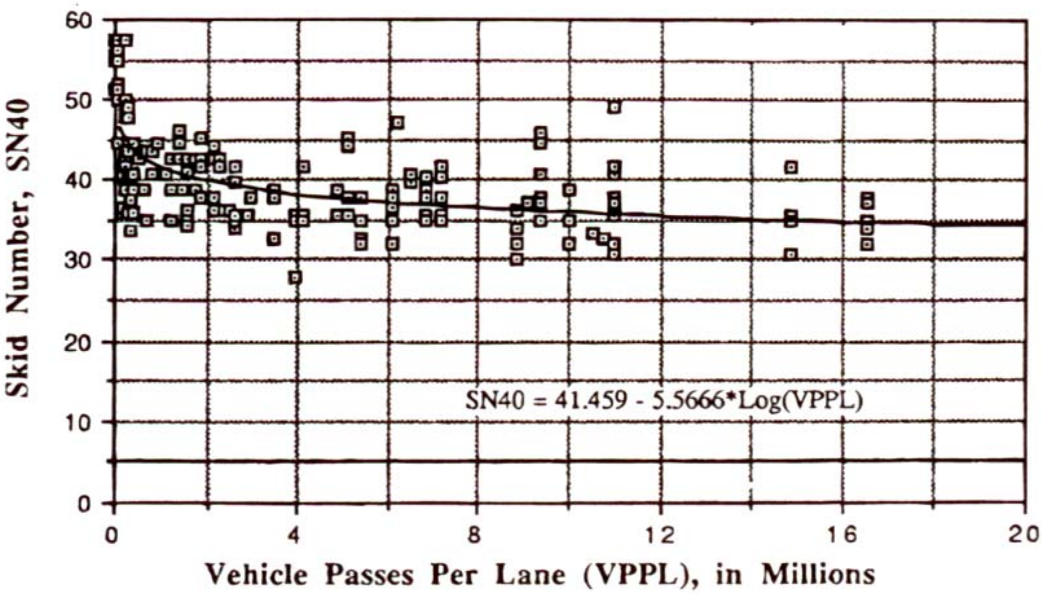
[1] Seal Coat Surface Treatment, OGFC
[2] HMAC Type C and D, CMHB, Superpave
[3] Microsurface, HMAC Type F

The next step in the aggregate selection process involves matching the overall frictional demand with an appropriate surface aggregate classification as shown in Table 1.2 below.

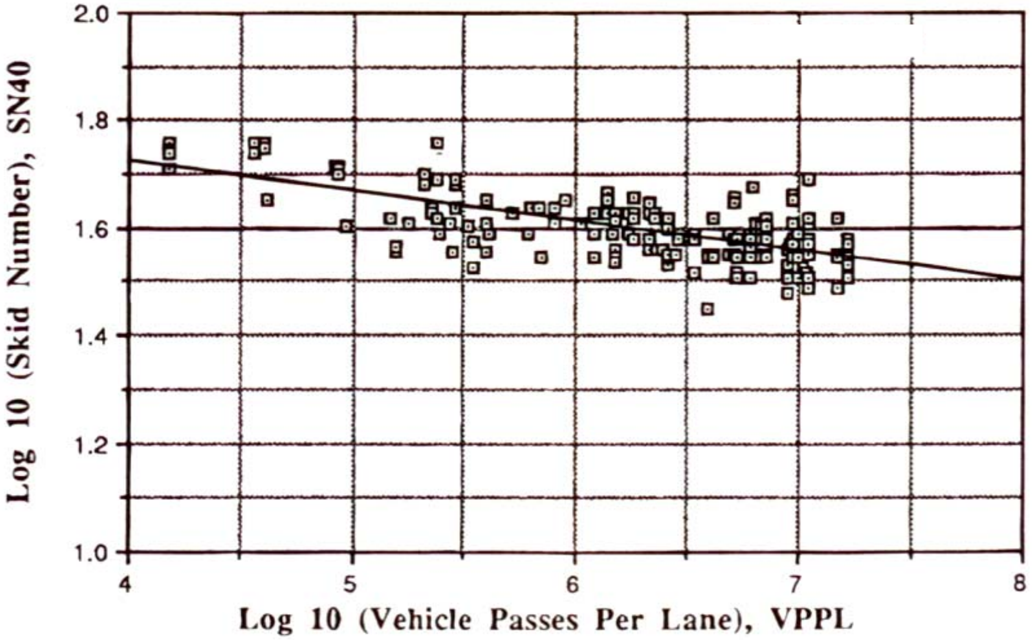
Table 1.2 Recommended Surface Aggregate Classification

Overall Frictional Demand	Recommended Surface Aggregate Classification
Low	C
Moderate	B
High	A

Each bituminous coarse aggregate source is classified into one of four categories (A, B, C, or D) based on a combination of the frictional and durability properties of the aggregate. Frictional and durability indicator tests (such as polish value, soundness, acid insolubility, and Micro Deval) are used to classify the aggregates. For example, a surface



(a)



(b)

Figure 1.1 Skid Performance History for a South Texas Aggregate; (a) Linear Scale Used for VPPL, (b) Logarithmic Scale Used for VPPL

aggregate classification of "A" is assigned to an aggregate that has high frictional and durability properties. CST/M&P (Soils and Aggregates Branch) is responsible for setting the aggregate classification criteria and listing them in the Bituminous Rated Source Quality Catalog every six months.

Figure 1.2 shows a chart that had been developed for the purpose of classifying surface aggregates for bituminous pavements.

OBJECTIVES AND SCOPE OF RESEARCH STUDY

The primary objective of this research study was to evaluate the classification system that is used by TxDOT to categorize bituminous coarse aggregate sources into classes A, B, C and D. The plan that was presented in the original research proposal to achieve this objective involved the construction of a large number of (as many as 60) test pavement sections. The performance of these test pavement sections were to be monitored over the 5-year project duration and performance data thus collected used for verification of the aggregate classification system. To eliminate the influence of many extraneous factors (climatic factors, mix design, construction related factors, traffic conditions etc.) that cause variability in performance data, it was proposed that the test sections built on the same roadway to the extent practicable. It was also thought that these test sections would be built on roadways that carry high ADT so that skid performance can be observed after the test sections have sustained significantly high cumulative vehicle passes.

Difficulties in implementing the proposed research plan became evident during the initial stages of the research study. First of all, the cost of building such a large number of test pavement sections and the time required for construction was found to be prohibitively high. Secondly, the specific aggregate sources that were ideally suited for testing were not located close to areas where such test sections could be built. Thirdly, there were concerns with respect to the use of some of the marginal quality aggregate sources on high ADT roadways for the sake of obtaining research data. For these reasons, the research team and the TxDOT project monitoring committee agreed that it was not practical to pursue the original research plan of constructing special test pavement sections to collect field performance data. As an alternative plan, it was decided that data will be obtained from existing databases and used in the validation process. Accordingly, data from Texas Tech

University research study 0-1459 and TxDOT in-house research study 7-3994 were analyzed. Much of the necessary data on material properties had been archived during previous research projects and were available for the present research study. Where necessary, data was recovered from TxDOT aggregate quality monitoring database. Subsequent chapters of this report provide detailed accounts of laboratory evaluation of aggregate, field evaluation with respect to skid resistance and correlations between laboratory and field SN data.

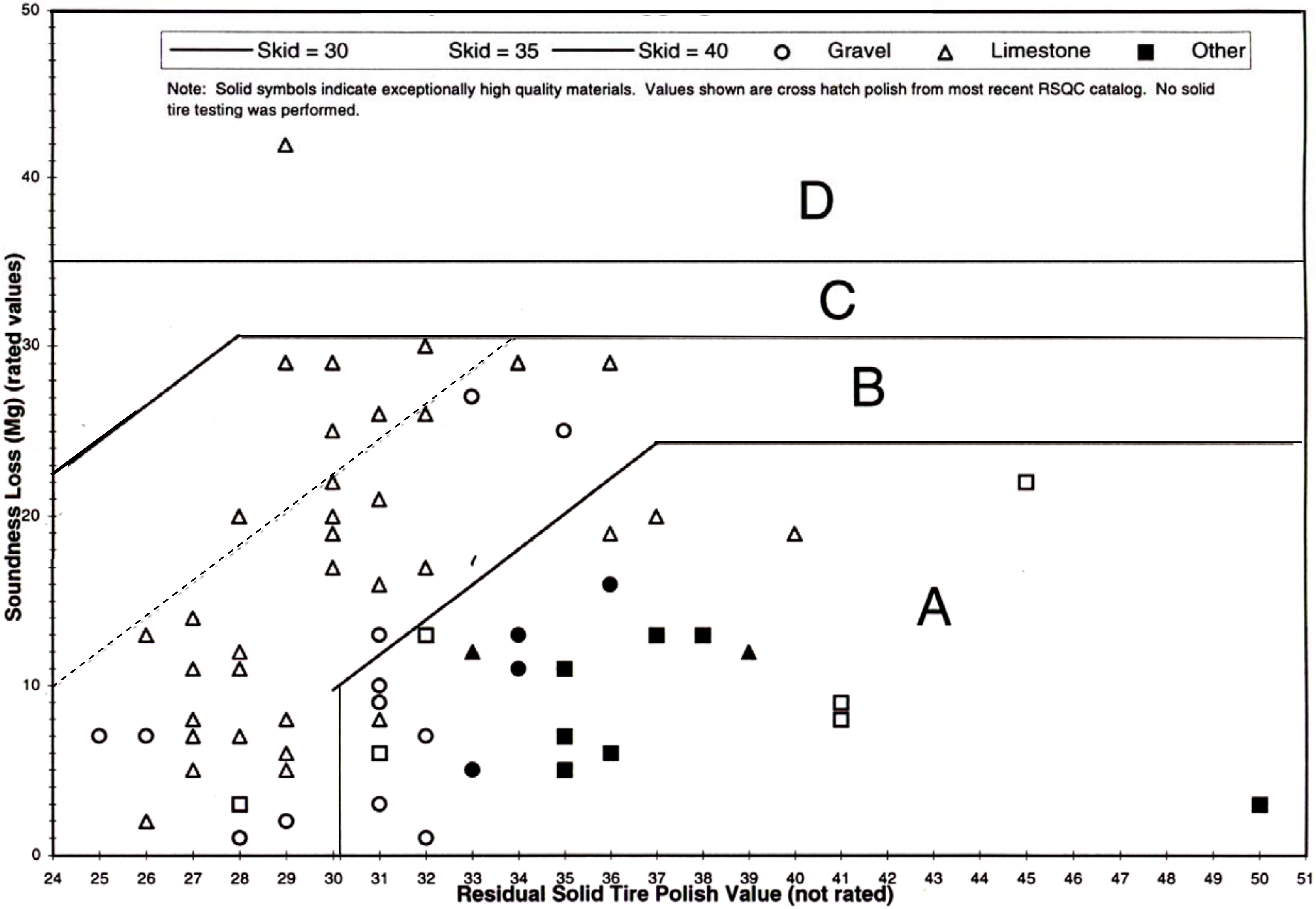


Figure 1.2 Chart for Classification of Bituminous Coarse Aggregates

CHAPTER 2

LABORATORY EVALUATION OF AGGREGATES

OVERVIEW

This research study was completed in three separate phases. They are:

1. Laboratory evaluation of aggregates,
2. Field evaluation of aggregates,
3. Correlations between laboratory and field performance.

This chapter presents findings from Phase I: Laboratory evaluation. The laboratory evaluation could be further divided into two separate tasks. The first task included further evaluation of the suite of aggregates that was sampled for Project 0-1771 based on new test procedures that specifically relate to skid resistance. These tests are Standard Polish Value Test, Residual Polish Value Test and Acid Insoluble Residue Test. These tests were conducted in replicates of 3, so that repeatability of each test procedure can be determined. In the second task, data obtained from TxDOT Materials and Test Lab AQMP data were analyzed. These data offered an opportunity to evaluate the time variability of aggregate lab properties. This chapter presents the findings from both stages of laboratory evaluation.

LABORATORY TESTING CONDUCTED AT TEXAS TECH UNIVERSITY

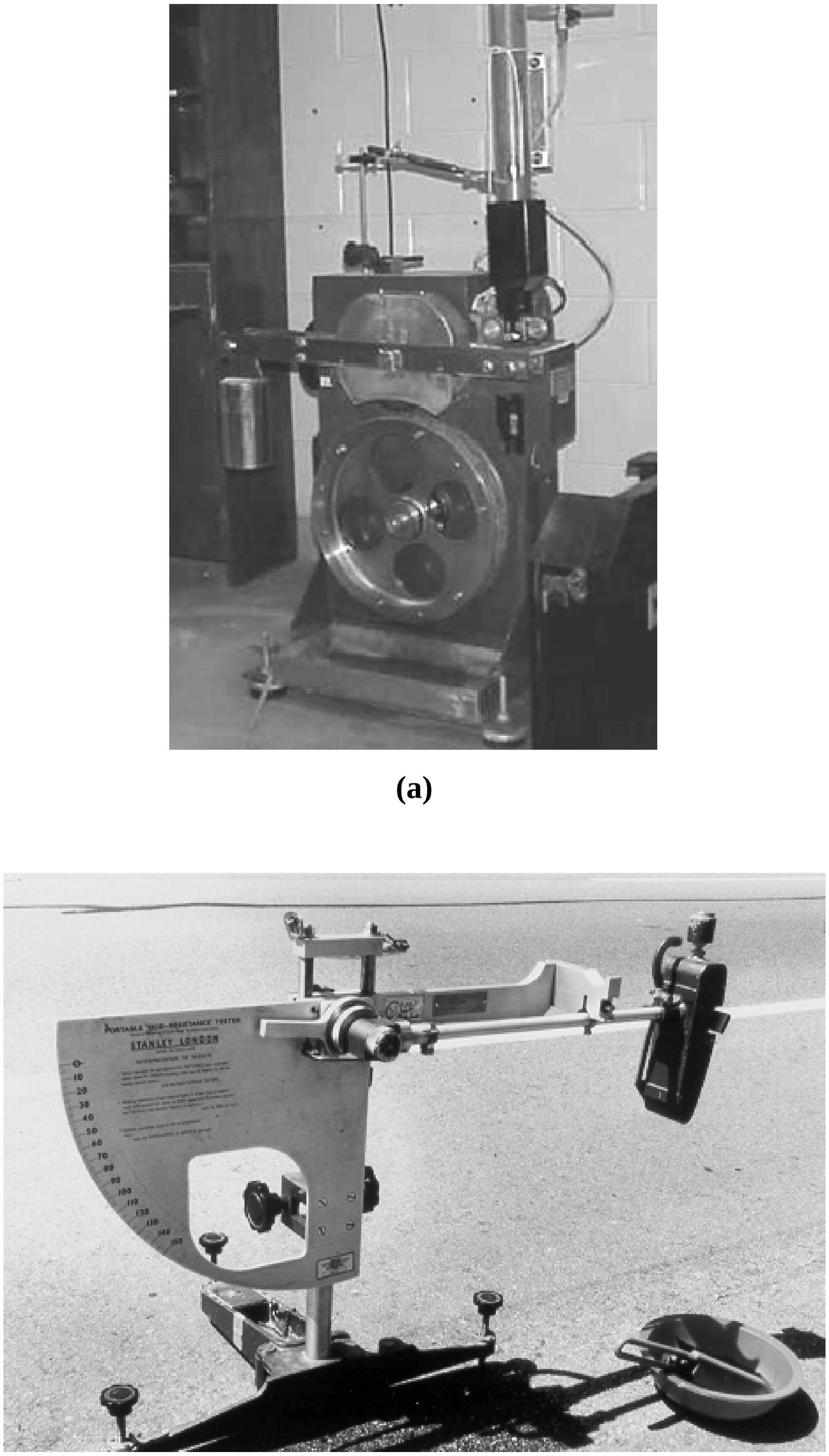
As mentioned above, the lab test program conducted at Texas Tech University included further evaluation of the suite of aggregates that were previously sampled for TxDOT research project 0-1771. The above aggregate suite included a total of 52 sources: 31 limestones, 11 gravels, 8 igneous/metamorphic rocks and 2 sandstones. In project 0-1771, these aggregates were tested to determine their durability characteristics using the Magnesium Sulfate Soundness (MSS) test and the Micro-Deval (MD) test. In this research, the same aggregates were tested to determine their frictional characteristics using the Standard Polish Value, Residual Polish Value and Acid Insoluble Residue tests. These tests were performed in replicates of 3 so that the repeatability of the test procedures could be determined. To perform tests in replicates, fairly large quantities of material were needed because the tests procedures require specified quantities of material in specified size fractions. Sufficient quantities of material were not available for all 52 aggregate sources that were tested for Project 0-1771. Accordingly, a subset of 42 aggregate sources was used in the present test program.

Although MSS and MD tests are generally considered as aggregate durability tests, it should be noted that TxDOT WWARP uses the MSS test (in conjunction with the polish value test) to classify bituminous coarse aggregates groups A, B, C and D (See Figure 1.2). Therefore, the test data obtained from MSS and MD tests are relevant to the present analysis. For this reason, data from both MSS and MD tests are included in this report. However, detailed descriptions of these test methods are not presented because that information can be found in a companion report [6]. The remaining test methods are described in the sections below.

Polish Value Test

In 1966, the Transportation and Road Research Laboratory (TRRL) in England, introduced an accelerated aggregate polishing machine to determine the Polished Stone Value (PSV) [7]. This test was developed as a result of over 10 years of intensive research and development by the Road Research Laboratory of the Department of Scientific and Industrial Research - a British government organization concerned with studying problems that aid in designing, building maintaining and using highways.

In 1971 researchers from the Texas Highway Department extensively studied the use of the accelerated aggregate polishing test and recommended its usage to qualify aggregates for use in pavement surface courses [8]. The test standard, BS 812:1967, was recommended with modifications to qualify aggregates to be used on Texas Highways. In the United States, the polish value test is performed according to ASTM standards – ASTM D 3319 [9] and ASTM E 303 [10]. The ASTM standard D 3319 provides a detailed description about the specifications and a procedure to polish an aggregate sample using the Wessex aggregate polishing machine, also known as the British Wheel. Figure 2.1 (a) shows the British Wheel. Secondly, the test standard outlines a procedure for determining the polish value of the aggregate coupon with the British Pendulum Tester (BPT). Standard E-303 provides a detailed description and specifications to calibrate and operate the BPT. Figure 2.1(b) shows the British Pendulum Tester.



(a)

(b)

Figure 2.1 Equipment Used in the Determination of Aggregate Polish Value

(a) British Polishing Wheel, (b) British Pendulum Tester

The test method, Tex 438-A, which is a modification of the ASTM standards to determine aggregate polish value, is widely used by TxDOT [3]. The TxDOT procedure essentially combines the two ASTM standards. In Test Method Tex-438-A, the polish value of an aggregate is reported as the average of four British Pendulum Numbers (BPNs) obtained from the second through fifth swings of the pendulum. In this report, the polish value determined based on the average of 2nd through 5th swings is referred to as the *Standard Polish Value*. In a research study conducted by TxDOT in 1998, it was noted that the BPN decreases rapidly with each swing of the pendulum and then finally reach a steady residual number [11]. Based on this finding, the researchers of the above study introduced a new parameter called the *Residual Polish Value.* The Residual Polish Value is defined as the first constant BPN that has been reached four consecutive times as the pendulum swing continues. Moreover, the researchers noted that the pneumatic cross-hatch tire that was in use at the time produced a differential wear pattern on the polish value test coupons. This, in turn caused apparent high polish value test results for softer aggregates. Therefore, they recommended that the pneumatic cross-hatch tire be replaced with a solid tire when testing aggregates for residual polish value to achieve more uniform wear and more repeatable results. Figure 1.2 illustrates the concept of residual polish value. The Residual Polish Value is therefore considered to be a better indicator of aggregates wearing characteristics than the Standard Polish Value and later incorporated in the WWARP aggregate classification by TxDOT.

Acid Insoluble Residue Test

ASTM standard D 3042-86 provides the specifications and a detailed description of the procedure to determine the insoluble residue content of a given aggregate sample [12]. TxDOT uses test method Tex-612 J, for the same purpose [13]. The objective of both these test procedures is to determine the percentage of the non-carbonate particles present in the aggregate sample. This is achieved by dissolving a known weight of the aggregate sample in hydrochloric acid. Since, any carbonates present in the aggregate particles will react with the acid to yield carbon dioxide and water as by products, the residue left behind in the reaction is mainly comprised of the non-carbonate portion of the aggregate and other complex chlorides.

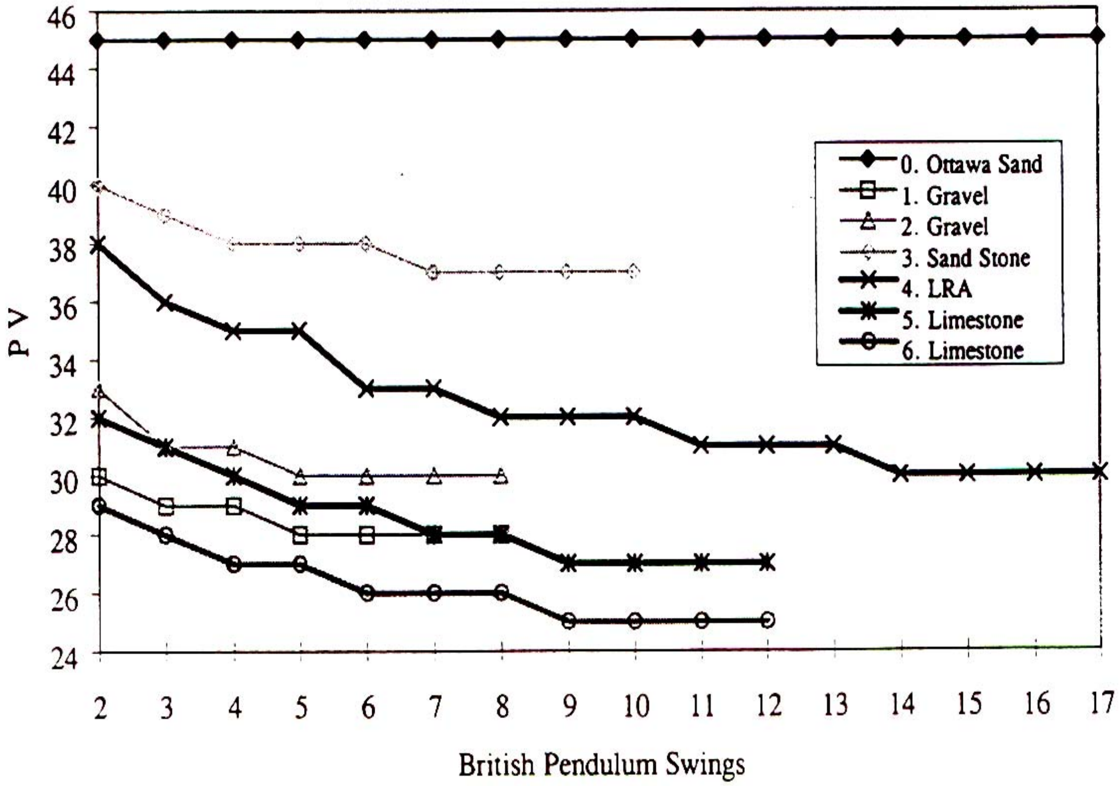


Figure 2.2 Standard Polish Value versus Residual Polish Value

The TxDOT procedure utilizes a 100-gram sample of the aggregate in this test. In contrast, the ASTM procedure recommends that the test be performed on a 500-gram aggregate sample. The TxDOT procedure does not stipulate the number of repetitions to be performed on a given aggregate in order to obtain a representative value for the aggregate source. The ASTM procedure, on the other hand, recommends that the test be performed in triplicate and by the same operator. Another difference between the two test specifications is found on the volume of acid to be used. TxDOT recommends a specified volume while the ASTM procedure, states that the addition of the acid be continued until all reaction of the carbonates has stopped. In addition, it also mentions the heating of the aggregate-acid solution to ensure the completion of the reaction.

TxDOT researchers investigated the use of AIR Test in 1971 [8]. These researchers tried to establish a relationship between the sand size insoluble residue in an aggregate sample with the polish value of the aggregate. The argument used to justify such a relationship was that, the presence of a significant amount of insoluble sand size mineral particles in an aggregate would enhance the microtexture of the aggregate surface and hence, can cause higher polish values exhibited by the aggregate. However, the researchers could not establish a significant relationship between the two laboratory tests.

Test Results

Tables 2.1 through 2.3 present the data obtained from Magnesium Sulfate Soundness (MSS), Micro-Deval (MD), Standard Polish Value, Residual Polish Value and AIR Tests. The test data include the average parameter determined from a minimum of 3 replicates of each test, the standard deviation and the coefficient of variation. To determine the performance of different aggregate types in each of these test procedures, aggregates were divided into general categories of Carbonate gravel, Non-carbonate gravel, Igneous rock, Limestone and Sandstone. The average test parameter was then calculated for each aggregate type. Table 2.4 provides a summary of average values calculated for different aggregate types.

The average values for MSS, MD, Standard PV, Residual PV and AIR are presented as Figures 2.3 through 2.5. Review of these data lead to the following conclusions:

(a) Among different types of aggregates, the Limestones and Sandstones show the worst performance in MSS and MD tests. Non carbonate (siliceous) gravel show the best overall performance.

(b) In the Polish Value Tests sandstones clearly outperformed all other aggregate types. Igneous material showed reasonably good performance while gravels (both carbonate and non-carbonate), and limestones performed poorly.

(c) The drop in the BPN number between the standard and residual polish value tests was the largest for limestones. This difference was the smallest for sandstones and igneous rocks. This means that limestones and gravel categories will be rated even lower when Residual Polish Value is used than when Standard Polish Value is used.

(d) On average igneous rocks and non-carbonates yielded greater than 90% acid insoluble residue content. Sandstones also gave higher than 60% AIR. The AIR for limestones averaged 20% and carbonate gravels 45%.

The next step in the analysis involved the comparison of test methods with regard to their repeatability. In this task, the Coefficient of Variation (COV) was used as the measure of test method variability. Once again, average coefficient of variation calculated for each of the different aggregate types is plotted. These plots are presented in Figures 2.6 through 2.8. The following conclusions may be reached based on the review of these summary plots.

(a) Micro-Deval test has clearly superior repeatability when compared with sulfate soundness test. The MD test may also be considered the most consistent among all tests examined.

(b) The repeatability of Standard and Residual polish value tests were about the same. The test variability in these tests is slightly higher than that of the MD test.

(c) The acid insoluble showed very high variability for carbonate materials while showing very consistent behavior with igneous and non-carbonate materials.

(d) Among different types of aggregates, the non-carbonate gravels showed the greatest variability. This was true in all tests except for the AIR test.

Table 2.1 Results from MSS and MD Tests

SCR ID	Pit	AGG TYPE	MG Soundness			Micro Deval		
			Avg	SD	CV	Avg	SD	CV
42	LOOP 1604 EAST #2	Carbonate Gravel	2.4	0.23	9.49	8.2	0.00	0.00
44	KNIPPA	Carbonate Gravel	1.6	0.17	10.83	8.3	0.10	1.20
49	LUCKETT	Carbonate Gravel	9.0	0.49	5.46	8.4	0.06	0.68
52	CRESLENN	Carbonate Gravel	7.6	0.41	5.43	8.3	0.42	5.04
47	JOHNSON	Non-Carbonate Gravel	5.9	0.52	8.81	7.4	0.25	3.39
46	SHOWERS	Non-Carbonate Gravel	1.8	0.21	11.78	2.3	0.25	10.79
43	EAGLE MILLS, AK	Non-Carbonate Gravel	3.7	0.12	3.15	3.2	0.06	1.82
45	DELIGHT, AK	Non-Carbonate Gravel	3.3	0.58	17.36	3.3	0.07	2.14
50	MANSFIELD	Non-Carbonate Gravel	10.1	1.67	16.43	11.6	0.55	4.73
48	BECK	Non-Carbonate Gravel	11.4	0.67	5.82	6.9	0.64	9.16
41	REALITOS	Non-Carbonate Gravel	1.2	0.19	15.72	1.9	0.12	6.45
3	SWEET HOME, AK	Igneous	1.9	0.26	13.93	3.7	0.10	2.70
5	VADO	Igneous	2.5	0.26	10.58	9.5	0.25	2.66
9	MCKELLIGON	Igneous	14.7	1.14	7.79	10.2	0.31	3.05
4	MILL CREEK , OK	Igneous	4.7	0.25	5.39	8.5	0.21	2.46
51	HOBAN	Igneous	8.1	1.02	12.57	6.9	0.16	2.37
8	KNIPPA	Igneous	5.4	0.62	11.56	7.8	0.23	2.95
7	DAVIS, OK.	Igneous	4.5	0.23	5.09	8.2	0.25	3.06
20	STRINGTOWN, OK	Limestone	4.9	0.67	13.68	8.7	0.06	0.67
35	HUNTER	Limestone	11.9	0.91	7.65	17.9	0.50	2.81
19	DOW CHEM	Limestone	3.1	0.42	13.58	8.4	0.15	1.81
31	ARDMORE, OK	Limestone	5.5	1.17	21.44	8.8	0.45	5.14
14	RICHARDS SPUR, OK	Limestone	6.4	0.21	3.27	12.9	0.42	3.24
18	COOPERTON, OK	Limestone	2.5	0.10	4.00	8.1	0.23	2.84
12	COLEMAN, D, OK	Limestone	14.6	0.85	5.85	15.8	0.26	1.67
16	MCKELLIGON	Limestone	9.8	1.81	18.45	13.5	0.06	0.43
29	COLEMAN, L, OK	Limestone	6.7	0.60	9.04	10.9	0.32	2.94
36	TOWER ROCK, MO	Limestone	18.0	1.24	6.89	21.1	0.40	1.91
32	CHAMBERS	Limestone	24.2	3.75	15.53	25.8	0.15	0.59
11	CLINTON	Limestone	2.9	0.33	11.44	7.4	0.16	2.14
34	CLEMENTS	Limestone	23.0	1.48	6.44	22.3	0.29	1.31
21	SH211	Limestone	10.5	0.59	5.60	18.8	0.40	2.15
24	NEW BRAUNFELS	Limestone	7.4	0.42	5.60	16.9	0.21	1.23
25	BRIDGEPORT	Limestone	14.5	1.12	7.74	16.0	0.52	3.23
40	NUNNELY	Limestone	63.9	1.55	2.42	33.2	1.22	3.68
17	TEHUACANA	Limestone	8.2	0.29	3.50	19.5	0.29	1.50
26	KELLY	Limestone	24.1	2.66	11.07	26.6	1.22	4.59
39	BLACK	Limestone	38.5	5.52	14.33	20.7	0.62	3.00
15	BROWNWOOD	Limestone	9.9	0.52	5.25	12.0	0.78	6.51
22	HUEBNER RD.	Limestone	7.6	0.90	11.81	17.5	0.30	1.71
27	HELOTES	Limestone	24.1	2.66	11.07	26.6	1.22	4.59
30	MADDOX	Limestone	20.0	1.85	9.26	22.0	0.25	1.14
1	BROWNLEE	Sandstone	15.4	0.75	4.86	12.6	0.20	1.59
2	CYRIL, OK	Sandstone	17.3	1.80	10.36	19.4	0.34	1.76

Avg = Average of a minimum of 3 tests; SD = Standard Deviation; COV = Coefficient of Variation = SD/Avg

Table 2.2 Results from Standard and Residual Polish Value Tests

			Standard Results				Residual Results			
SRC_NO	**Pit**	**AGG_TYPE**	**AVG_SPV**	**Std Dev**	**S/2**	**CV**	**AVG_RPV**	**Std Dev**	**S/2**	**CV**
3	LOOP 1604 EAST #2	Gravel	33.1	1.81	0.90	5.47	32.0	1.63	0.82	5.10
4	JOHNSON	Gravel	29.8	1.03	0.51	3.45	27.3	1.71	0.85	6.27
13	SHOWERS	Gravel	29.4	1.27	0.63	4.31	28.0	1.41	0.71	5.05
16	DELIGHT, AK	Gravel	32.8	1.97	0.99	6.01	30.5	1.73	0.87	5.68
31	KNIPPA	Gravel	28.8	2.11	1.06	7.34	25.0	1.41	0.71	5.66
34	MANSFIELD	Gravel	36.7	1.91	0.95	5.20	35.0	2.16	1.08	6.17
37	LUCKETT	Gravel	24.6	0.63	0.31	2.54	22.8	0.96	0.48	4.21
38	CRESLENN	Gravel	26.6	0.88	0.51	3.30	25.3	0.58	0.29	2.28
39	BECK	Gravel	30.0	2.35	1.18	7.85	28.5	2.38	1.19	8.35
50	REALITOS	Gravel	28.1	1.90	0.95	6.75	26.8	2.75	1.38	10.29
17	SWEET HOME, AK	Igneous	30.7	0.66	0.33	2.14	29.5	0.58	0.29	1.96
18	VADO	Igneous	36.5	0.98	0.49	2.68	34.3	0.50	0.25	1.46
19	MCKELLIGON GRANITE	Igneous	30.8	1.51	0.76	4.92	29.0	1.41	0.71	4.88
26	MILL CREEK , OK	Igneous	32.4	1.39	0.70	4.29	30.5	1.73	0.87	5.68
36	HOBAN	Igneous	37.4	1.70	0.85	4.55	35.8	1.50	0.75	4.20
43	KNIPPA	Igneous	31.6	1.11	0.55	3.51	30.0	1.41	0.71	4.71
49	DAVIS, OK.	Igneous	34.4	1.64	0.82	4.77	32.5	1.73	0.87	5.33
1	STRINGTOWN, OK	Limestone	34.8	2.37	1.18	6.80	34.0	2.58	1.29	7.59
5	HUNTER	Limestone	26.8	1.18	0.59	4.40	24.0	0.82	0.41	3.40
6	DOW CHEM	Limestone	26.8	0.97	0.48	3.60	24.3	0.50	0.25	2.06
8	ARDMORE, OK	Limestone	26.5	1.04	0.52	3.93	24.3	0.50	0.25	2.06
10	RICHARDS SPUR, OK	Limestone	26.9	1.30	0.65	4.81	25.8	0.96	0.48	3.72
11	COOPERTON, OK	Limestone	26.2	0.47	0.24	1.81	24.5	0.58	0.29	2.36
12	COLEMAN, OK	Limestone	32.1	1.14	0.57	3.57	29.3	0.96	0.48	3.27
20	MCKELLIGON	Limestone	30.3	1.33	0.66	4.38	27.8	0.50	0.25	1.80
23	COLEMAN, OK	Limestone	33.8	1.14	0.57	3.37	31.5	1.29	0.65	4.10
24	TOWER ROCK, MO	Limestone	31.8	0.31	0.16	0.99	29.5	1.00	0.50	3.39
25	CHAMBERS	Limestone	27.8	1.54	0.77	5.55	25.0	0.82	0.41	3.27
27	CLINTON	Limestone	25.3	0.55	0.28	2.19	24.0	0.00	0.00	0.00
29	CLEMENTS	Limestone	32.3	0.46	0.23	1.42	29.3	0.50	0.25	1.71
30	SH211	Limestone	27.3	0.89	0.44	3.27	24.5	0.58	0.29	2.36
32	NEW BRAUNFELS	Limestone	28.8	0.61	0.31	2.13	24.3	0.96	0.48	3.95
33	BRIDGEPORT	Limestone	30.1	0.48	0.24	1.59	26.0	0.82	0.41	3.14
35	NUNNELY	Limestone	35.7	1.23	0.62	3.45	30.5	1.91	0.96	6.28
40	TEHUACANA	Limestone	25.3	0.55	0.28	2.19	24.0	0.00	0.00	0.00
41	KELLY	Limestone	32.3	0.46	0.23	1.42	29.3	0.50	0.25	1.71
42	BLACK	Limestone	27.3	0.89	0.44	3.27	24.5	0.58	0.29	2.36
44	BROWNWOOD	Limestone	26.8	0.74	0.37	2.75	23.0	0.82	0.41	3.55
45	HUEBNER RD.	Limestone	27.4	1.30	0.65	4.73	24.0	0.82	0.41	3.40
46	HELOTES	Limestone	31.6	0.55	0.28	1.76	29.3	0.50	0.25	1.71
51	MADDOX	Limestone	42.9	1.56	0.78	3.64	40.0	1.41	0.71	3.54
7	BROWNLEE	Sandstone	41.8	1.26	0.63	3.02	39.5	1.27	0.64	3.22
9	CYRIL, OK	Sandstone	41.2	0.31	0.16	0.76	39.5	0.58	0.29	1.46

Avg = Average of a minimum of 3 tests;
SD = Standard Deviation;
COV = Coefficient of Variation = SD/Avg

Table 2.3 Results from Acid Insoluble Residue Test

SRC_NO			**Acid Insoluble Residue**		
	Pit	**AGGTYPE**	***AVG***	**Std Dev**	**CV**
3	LOOP 1604 EAST #2	Gravel	34.8	1.97	5.65
4	JOHNSON	Gravel	98.3	1.27	1.29
13	SHOWERS	Gravel	93.8	3.46	3.70
16	DELIGHT, AK	Gravel	99.9	0.07	0.07
31	KNIPPA	Gravel	29.7	3.66	12.33
34	MANSFIELD	Gravel	85.7	2.38	2.78
37	LUCKETT	Gravel	54.2	5.66	10.44
38	CRESLENN	Gravel	61.4	5.52	8.98
39	BECK	Gravel	88.1	1.38	1.56
50	REALITOS	Gravel	99.2	0.03	0.03
17	SWEET HOME, AK	Igneous	98.4	0.64	0.65
18	VADO	Igneous	99.5	0.04	0.04
19	MCKELLIGON GRANITE, NM	Igneous	99.5	0.49	0.50
26	MILL CREEK , OK	Igneous	95.5	1.17	1.22
36	HOBAN	Igneous	99.9	0.00	0.00
43	KNIPPA	Igneous	94.7	0.35	0.37
49	DAVIS, OK.	Igneous	92.9	2.38	2.56
1	STRINGTOWN, OK	Limestone	81.5	1.56	1.92
5	HUNTER	Limestone	19.6	1.41	7.22
6	DOW CHEM	Limestone	2.5	0.34	13.58
8	ARDMORE, OK	Limestone	20.1	1.63	8.11
10	RICHARDS SPUR, OK	Limestone	30.5	2.76	9.06
11	COOPERTON, OK	Limestone	17.4	1.48	8.56
12	COLEMAN, OK	Limestone	61.3	1.56	2.54
20	MCKELLIGON DOLOMITE	Limestone	16.8	1.45	8.62
23	COLEMAN, OK	Limestone	34.1	1.94	5.69
24	TOWER ROCK, MO	Limestone	6.8	3.30	48.53
25	CHAMBERS	Limestone	8.4	3.08	36.51
27	CLINTON	Limestone	12.1	3.20	26.39
29	CLEMENTS	Limestone	6.5	0.51	7.89
30	SH211	Limestone	20.7	4.53	21.86
32	NEW BRAUNFELS	Limestone	19.8	5.84	29.54
33	BRIDGEPORT	Limestone	10.0	3.90	38.88
35	NUNNELY	Limestone	5.3	0.51	9.53
40	TEHUACANA (BULLARD)	Limestone	28.3	2.69	9.52
41	KELLY	Limestone	4.9	0.13	2.59
42	BLACK	Limestone	2.9	0.74	25.27
44	BROWNWOOD	Limestone	15.5	0.88	5.65
45	HUEBNER RD.	Limestone	5.9	2.84	48.10
46	HELOTES	Limestone	11.5	4.83	42.05
51	MADDOX	Limestone	26.5	4.48	16.90
7	BROWNLEE	Sandstone			
9	CYRIL, OK	Sandstone	67.4	3.54	5.25

Avg = Average of a minimum of 3 tests;
SD = Standard Deviation;
COV = Coefficient of Variation = SD/Avg

Table 2.4 Summary Data Calculated for Each Aggregate Type

		MG Soundness		
	N	**Avg.**	**Sdev**	**CV**
Sandstone	2	16.4	1.3	7.77
Igneous	7	6.0	0.5	9.09
Gravel (NC)	7	5.4	0.6	10.53
Limestone	23	15.1	1.3	8.73
Gravel (C)	4	5.2	0.3	6.34

		Micor Deval		
	N	**Avg.**	**Sdev**	**CV**
Sandstone	2	16.0	0.3	1.69
Igneous	7	7.8	0.2	2.77
Gravel (NC)	7	5.2	0.3	5.29
Limestone	23	17.1	0.4	2.55
Gravel (C)	4	8.3	0.1	1.73

		Standard PV Results		
	N	**Avg.**	**Sdev**	**CV**
Sandstone	2	41.5	0.79	1.89
Igneous	7	33.4	1.28	3.84
Gravel (NC)	7	29.9	1.75	5.85
Limestone	23	29.9	0.96	3.21
Gravel (C)	4	28.2	1.36	4.66

		Solid Residual PV Results		
	N	**Avg.**	**Sdev**	**CV**
Sandstone	2	39.5	0.93	2.34
Igneous	7	31.6	1.27	4.03
Gravel (NC)	7	27.9	1.87	6.73
Limestone	23	27.2	0.83	2.95
Gravel (C)	4	26.3	1.15	4.31

		Acid Insoulble Residue		
	N	**Avg.**	**Sdev**	**CV**
Sandstone	2	67.4	3.54	5.25
Igneous	7	97.2	0.72	0.76
Gravel (NC)	7	94.9	1.31	1.43
Limestone	23	20.2	2.39	18.48
Gravel (C)	4	45.0	4.20	9.35

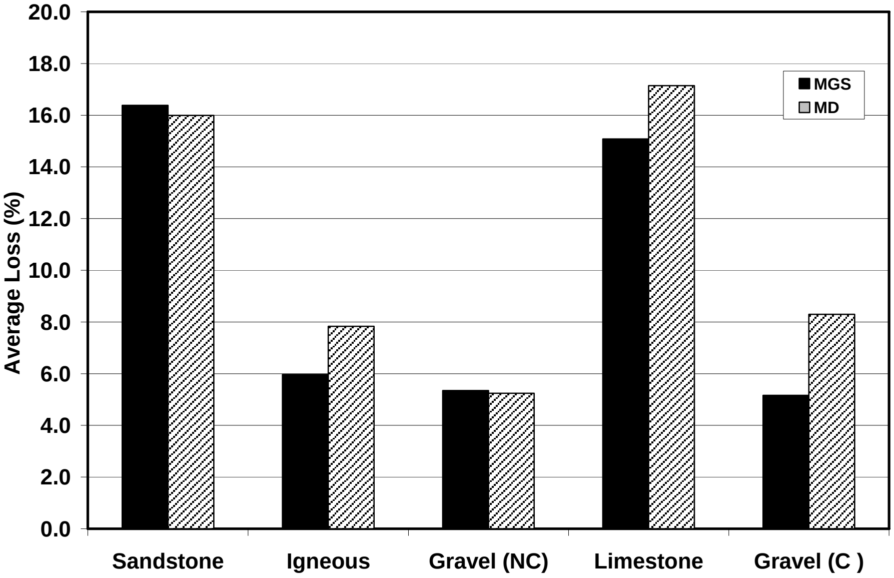


Figure 2.3 Performance of Different Aggregate Types in MSS and MD Tests

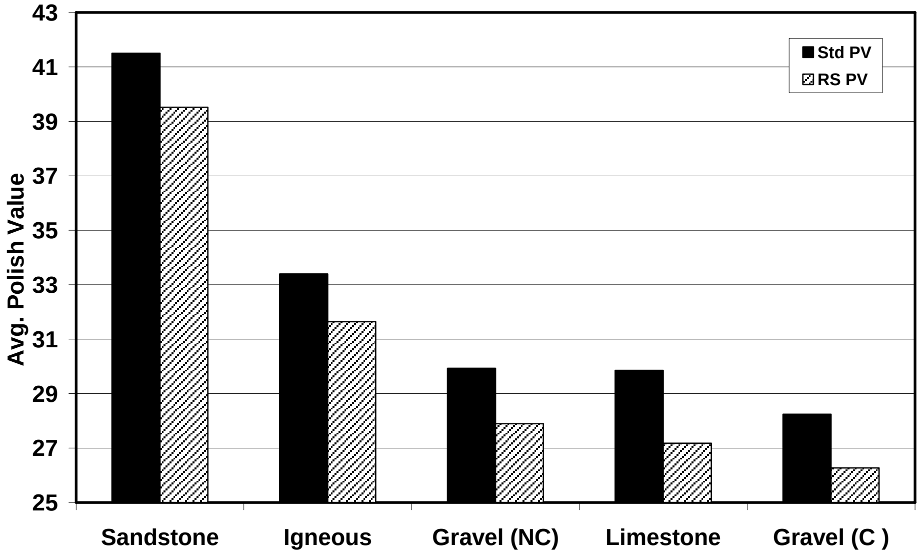


Figure 2.4 Performance of Different Aggregate Types in the Standard and Residual Polish Value Tests

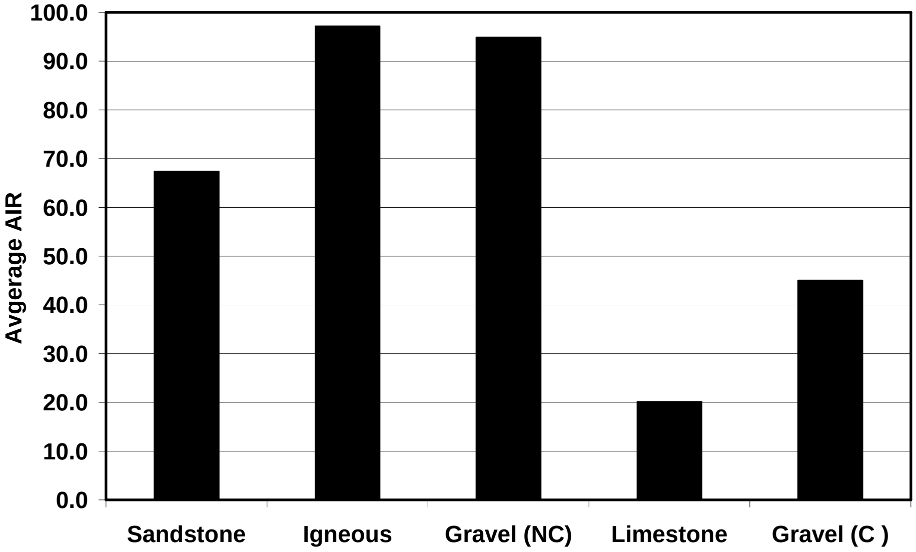


Figure 2.5 Performance of Different Aggregate Types in the Acid Insoluble Residue Test

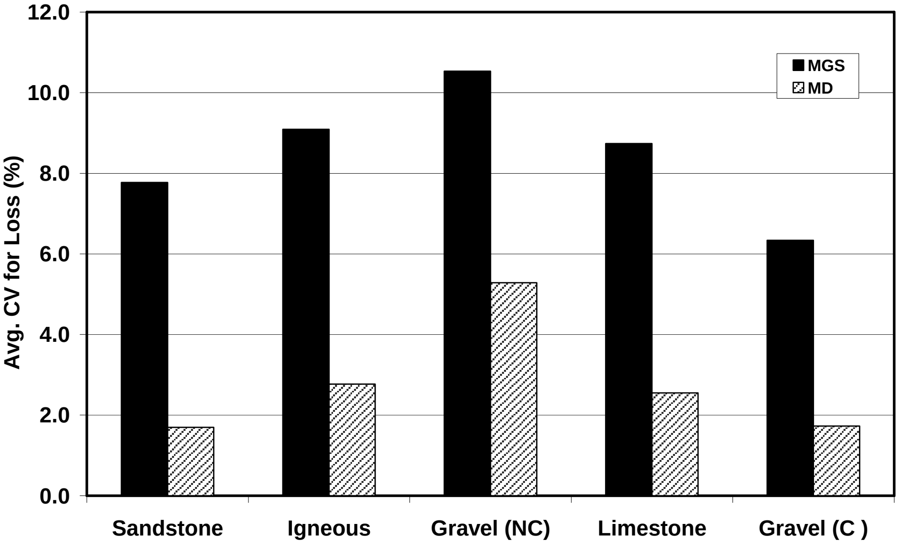


Figure 2.6 Repeatability of MSS and MD Test Methods

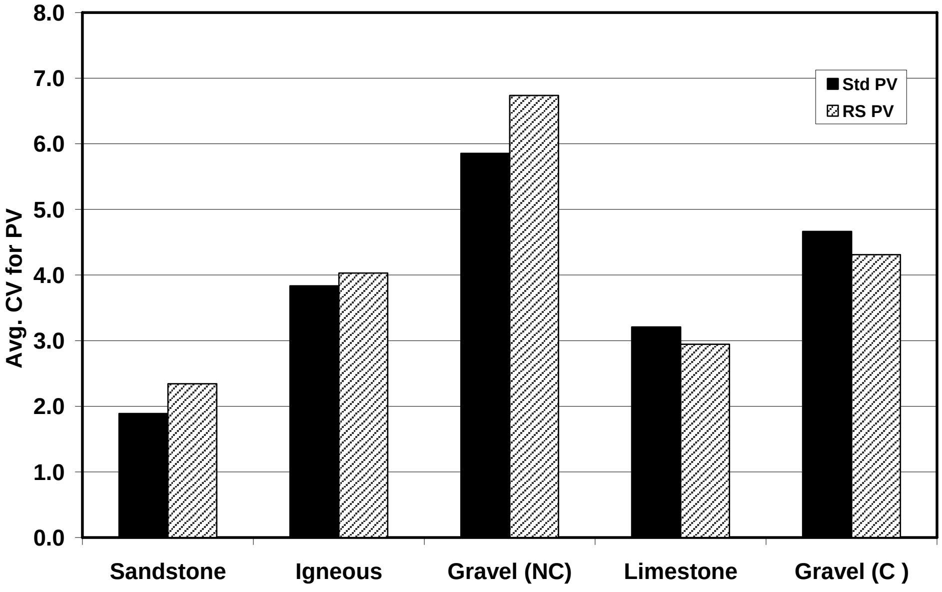


Figure 2.7 Repeatability of Standard and Residual Polish Value Tests

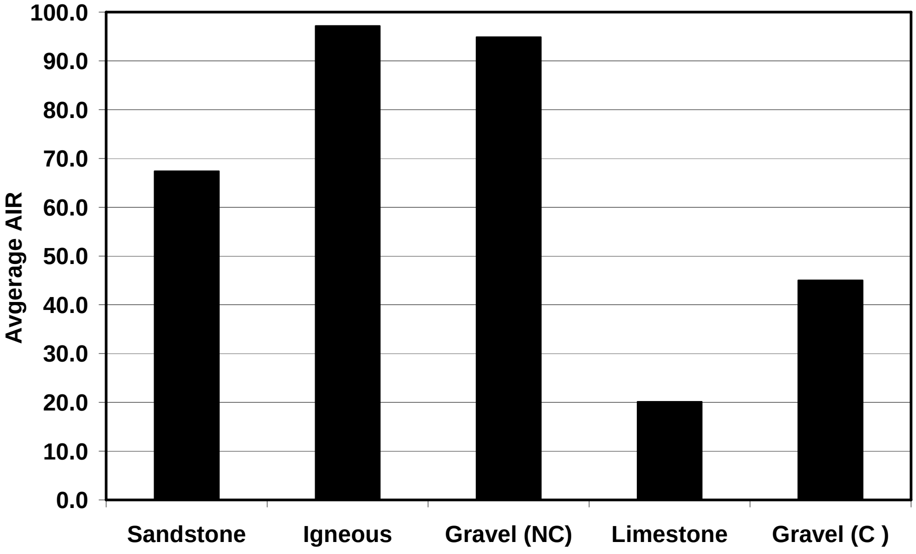


Figure 2.8 Repeatability of Acid Insoluble Test

AGGREGATE SOURCE EVALUATION BASED ON TXDOT AQMP DATA

Bituminous aggregate sources that are included in the TxDOT Aggregate Quality Monitoring Program (AQMP), are sampled and tested on a regular basis by the TxDOT, Materials and Tests laboratories. The tests conducted as a part of the above AQMP program include: standard polished value, residual polished value (solid tire), residual polished value (cross hatched tire), MSS, Micro-Deval, LA abrasion and acid insoluble residue. The database that was developed based on AQMP test data included a total of 169 aggregate sources representing a large number of aggregate producers and source locations. The vast majority of these sources are located within the state although the database included several sources from neighboring states as well. The version of the database that was used in the present analysis was obtained by Texas Tech researchers in May of 2001. It mostly contained data collected in 1998, 1999 and 2000. It must be noted that the list of aggregate sources found in the above database is not the same as the current AQMP list of sources. Some of these sources found in the original list are no longer in production. Others have dropped out of the list because of failure to meet required specifications.

The special value in the TxDOT AQMP database lies in the fact that it contains quality monitoring data that span a fairly long time period. In particular, it has data from tests conducted on material obtained from each source but at different times. Such data allows the time variability of the material to be quantified. Review of the data show that some of the aggregate sources have been sampled and tested more frequently than the others. As a result they have more data points. This may have been because these particular sources have been in more frequent use or because material had exhibited greater degree of variability when compared with others.

This section describes the analysis of TxDOT AQMP data that was undertaken as a part of this study. Once again, the primary thrust in this analysis is on the *time variability* of the materials produced at specified sources as quantified by various laboratory tests. Tables 2.5 through 2.7 show the summary data from MSS/MD tests, Standard/Residual PV Tests and Acid Insoluble Residue Tests available for all AQMP sources. In these tables aggregate sources are sorted according to aggregate type. They show the number of measurements, the average, the standard deviation and coefficient of variation for each source. It should be noted that the variance that is examined here is related to variability of the source with time.

This variance is different from the variance examined in the previous section which was a measure of the repeatability of the test procedure.

Table 2.5, 2.6 and 2.7 provide information on the degree of variability observed in lab data obtained for different aggregate sources. Accordingly, these tables provide source specific time variability information corresponding to each aggregate characterization test. The information can be used to compare one aggregate source versus another. For example, comparison of Coefficients of Variation (CV-values) in Table 2.5 for both Mg Sulfate Soundness and Micro-Deval tests show that the Redlund/SH 211 limestone and Vulcan/Black limestone have had similar variability (approximately 28% in Sulfate Soundness test and about 10% in Micro-Deval Test). By contrast, Pioneer/Clinton limestone has yielded much higher time variability (CV=114% in sulfate soundness and 87% in Micro-Deval test). Similar comparisons can be made with respect to solid tire residual polish value (Table 2.6), cross hatch tire residual polish value (Table 2.6) and AIR tests (Table 2.7) as well. In addition to the above, it will be useful to know whether a particular type of aggregate tends to exhibit greater variability with time than others. Also, it will be useful to find out whether a certain test method is capable of capturing source variability with time better than other tests. Tables 2.5, 2.6 and 2.7 do not provide a convenient basis to make such comparisons. Therefore, in the next step, the same data were summarized by calculating the overall average, average standard deviation and average coefficient of variation for each aggregate type. Table 2.8 provides the above data summary.

The same information found in Table 2.8 is then presented in Figures 2.9 through 2.11 so that data trends can be easily seen. Figure 2.9 represents MSS and MD test data, Figure 2.10 Solid and Cross Hatch Tire Residual PV data and Figure 2.11 Acid Insoluble Residue test data. These plots compare the average test parameters, average of standard deviations and average of coefficients of variation for different aggregate types.

Table 2.5 Analysis of TxDOT AQMP Data; Time Variability of MD and MSS Test Data for Different Aggregate Sources

Source	Pit	Material	Prod Code	MG Soundness				Micro Deval			
				# Data	Avg.	Sdev	CV	# Data	Avg.	Sdev	CV
Southwest	Knippa	Gravel (C)	1523209	5	1.6	0.89	55.90	5	8.8	0.45	5.08
Trinity	Luckett	Gravel (C)	916104	5	7.4	0.89	12.09	5	7.2	4.09	56.76
Bay	Sweet 16	Gravel (NC)	2206706	6	4.2	1.94	46.58	7	3.3	0.89	26.69
E.D. Baker	Johnson	Gravel (NC)	411807	6	7.2	2.79	38.89	6	8.0	1.67	20.92
Fordyce	Showers	Gravel (NC)	2110904	7	2.9	1.35	47.08	7	2.9	0.38	13.23
Hanson	Delight	Gravel (NC)	50116	4	2.8	0.96	34.82	5	3.2	0.45	13.98
Hanson	Eagle Mills	Gravel (NC)	50119	4	4.0	0.82	20.41	4	3.5	1.00	28.57
Hanson	Little River	Gravel (NC)	50114	5	4.2	0.84	19.92	4	3.5	0.58	16.50
Texas S&G	Mansfield	Gravel (NC)	418001	6	7.8	2.32	29.57	5	10.0	1.00	10.00
Upper Valley	D. Garcia	Gravel (NC)	2110905	7	9.1	3.93	43.03	7	5.6	1.72	30.84
Valley Caliche	Beck	Gravel (NC)	2110901	7	7.0	2.89	41.24	7	5.6	1.90	34.15
Wright	Realitos	Gravel (NC)	2206701	7	1.6	0.53	34.02	7	1.9	0.38	20.35
Border Pacfic	Matrimar	Gravel (U)	40103	6	3.0	0.89	29.81	4	11.3	0.96	8.51
Brazos Valley	Cameron	Gravel (U)	Z170003	7	2.7	0.76	27.85	6	8.5	0.55	6.44
Brazos Valley	Fulton	Gravel (U)	Z170006	6	2.8	0.75	26.57	4	7.5	0.58	7.70
Fordyce	Murphy	Gravel (U)	1323505	7	1.0	0.00	0.00	8	2.3	0.79	33.77
Jordan	Rothwell	Gravel (U)	Z250009	9	6.2	3.03	48.73	5	7.0	0.71	10.10
Lipham	Bundy	Gravel (U)	2517308	6	4.8	1.60	33.15	5	7.2	1.30	18.11
Pioneer	Arena	Gravel (U)	1304509	6	1.2	0.41	34.99	6	2.2	0.41	18.84
Thrasher	Thrasher	Gravel (U)	2517302	6	6.5	2.26	34.74	6	8.2	0.98	12.04
Granite Mt	Sweet Home	Igneous	50106	6	1.5	0.84	55.78	5	3.6	0.55	15.21
Hanson	Davis	Igneous	50439	5	3.4	1.82	53.43	4	6.5	1.70	26.31
Hanson	Pedernal	Igneous	50309	4	4.0	1.41	35.36	3	13.3	1.53	11.46
Jobe	McKelligon(Grnt)	Igneous	2407206	4	10.5	2.38	22.67	3	10.7	1.15	10.83
Jobe	Vado	Igneous	50310	5	3.2	2.17	67.75	5	9.6	1.96	20.43
Meridian	Snyder	Igneous	50435	6	3.3	1.03	30.98	6	5.0	0.00	0.00
Meridian	Mill Creek Gr	Igneous	50433	7	1.4	0.53	37.42	6	6.2	1.33	21.55
Meridian	Mill Creek Trap	Igneous	50438	5	2.6	1.67	64.36	4	7.0	2.94	42.06
Trans-Pecos	Hoban	Igneous	619502	5	6.8	2.17	31.88	5	6.0	0.71	11.77
Vulcan	Knippa	Igneous	1523206	6	4.5	1.22	27.22	6	8.7	0.82	9.42
Capital	Fm 1604#2	Limestone	1501515	3	1.3	0.58	43.30	3	10.3	9.24	89.40
Centex	Ruby	Limestone	1410607	4	22.0	10.61	48.25	3	23.0	4.58	19.92
Dolese	Ardmore	Limestone	50412	5	8.8	4.92	55.90	5	10.6	1.52	14.31
Lattimore	Coleman	Limestone	50430	6	7.3	1.51	20.53	2	9.0	1.41	15.71
Luhr	Tower Rock	Limestone	50601	7	19.3	4.23	21.94	7	19.6	2.27	11.61
Martin M	Chambers	Limestone	224921	7	22.6	5.22	23.14	5	21.8	2.95	13.53
Pioneer	Clinton	Limestone	1402701	6	4.8	5.53	114.39	5	9.8	8.53	87.00
Redland	SH 211	Limestone	1516310	10	8.4	2.37	28.17	9	19.1	2.03	10.61
Sunbelt	New Braunfels	Limestone	1504602	7	10.4	4.69	44.93	5	19.6	1.14	5.82
Vulcan	Black	Limestone	822107	10	26.1	7.31	28.01	7	20.5	2.24	10.92
Vulcan	Eastland	Limestone	2306805	4	4.3	1.26	29.61	4	13.0	0.82	6.28
Vulcan	Huebner	Limestone	1501507	4	7.5	1.91	25.53	2	17.5	0.71	4.04
Vulcan	Kelly	Limestone	218409	6	7.8	3.66	46.67	5	14.0	0.71	5.05
Vulcan	Smyth	Limestone	1523205	13	21.4	4.84	22.63	12	20.5	2.04	9.97
Word	Dow	Limestone	1402702	6	2.5	0.84	33.47	6	7.8	0.75	9.61

C = Carbonate Gravel
NC = Non-carbonate Gravel
U = Gravel with Unknown Lithology

Table 2.5 Analysis of TxDOT AQMP Data; Time Variability of MD and MSS Test Data for Different Aggregate Sources (continued from previous page)

Source	Pit	Material	Prod Code	MG Soundness				Micro Deval			
				# Data	Avg.	Sdev	CV	# Data	Avg.	Sdev	CV
Alamo	Weir	Limestone-dolomite	1424603	4	20.3	3.20	15.81	4	24.0	2.16	9.00
Amarillo	4DG	Limestone-dolomite	507805	9	14.0	5.61	40.09	9	19.9	1.49	7.50
Burkett	Perry #2	Limestone-dolomite	325204	5	10.6	3.51	33.09	5	16.6	2.88	17.36
Capitol	Wood	Limestone-dolomite	1424604	6	19.0	8.51	44.78	5	22.6	4.64	20.53
Colorado	Hunter	Limestone-dolomite	1404605	10	20.2	3.91	19.36	8	20.2	2.48	12.25
CSA	Turner	Limestone-dolomite	Z070008	17	19.1	4.01	21.00	14	23.1	1.63	7.04
Dolese	Cooperton	Limestone-dolomite	50415	6	4.0	1.79	44.72	6	9.8	1.47	14.97
Dolese	Richard Spur	Limestone-dolomite	50405	6	6.0	1.67	27.89	5	12.0	1.22	10.21
Hanson	New Braunfels	Limestone-dolomite	1504603	9	9.1	1.54	16.87	7	16.0	1.91	11.97
Hanson	Perch Hill	Limestone-dolomite	224901	7	3.9	0.90	23.33	7	12.3	0.51	4.18
JL Milligan	Aztec Canyon	Limestone-Dolomite	418814	5	15.6	8.56	54.88	5	11.4	3.13	27.46
Jobe	McKelligon(Dolo)	Limestone-dolomite	2407201	6	6.5	3.08	47.42	6	10.8	2.14	19.73
Meridian	Troy	Limestone-dolomite	50434	5	9.0	3.74	41.57	2	10.0	2.83	28.28
Pioneer	Bridgeport	Limestone-dolomite	224902	7	18.1	2.27	12.50	6	19.8	1.72	8.68
Pioneer	Davis	Limestone-dolomite	224905	7	6.3	1.50	23.80	6	14.2	1.33	9.38
Price	Clement	Limestone-dolomite	708802	11	25.5	5.05	19.83	9	22.4	1.80	8.05
Redland	Beckman	Limestone-dolomite	501503	11	17.8	4.26	23.92	9	22.1	2.89	13.08
Stringtown	Stringtown	Limestone-dolomite	50407	5	6.8	3.70	54.43	3	8.7	1.53	17.63
Tex Cr Stone	Feld	Limestone-Dolomite	1424602	8	22.0	6.00	27.27	5	24.2	4.21	17.38
TXI	Bridgeport	Limestone-Dolomite	224904	10	14.8	4.71	31.82	8	17.8	3.15	17.64
Vulcan	Brownwood	Limestone-Dolomite	2302501	9	7.1	2.15	30.20	8	12.8	1.28	10.05
Vulcan	Fm 1604	Limestone-Dolomite	1501506	8	18.6	10.90	58.53	9	19.2	3.46	17.98
Vulcan	Helotes	Limestone-Dolomite	1501514	7	15.7	6.40	40.70	6	25.0	5.48	21.91
Vulcan	Tehuacana	Limestone-Dolomite	914708	3	6.7	1.53	22.91	3	18.0	0.00	0.00
Vulcan	Higgins	Limestone-Dolomite	803005	10	25.4	3.72	14.64	10	21.2	0.98	4.62
Young	Fm 1860	Limestone-Dolomite	916113	2	7.0	2.83	40.41	2	10.0	1.41	14.14
Young	Skihi (Maddox)	Limestone-Dolomite	914709	12	19.4	6.67	34.34	11	24.2	4.34	17.96
Delta	Brownlee	Sandstone	1402704	4	8.0	1.63	20.41	3	11.7	0.58	4.95
Dolese	Cyril	Sandstone	50411	4	19.3	3.59	18.67	5	22.4	5.03	22.45
Meridian	Apple, OK	Sandstone	50437	4	9.3	3.20	34.61	4	8.0	1.15	14.43
TXI	Streetman	Synthetic	1817502	3	2.3	1.53	65.47	6	17.4	2.09	12.06

Table 2.6 Analysis of TxDOT AQMP Data; Time Variability of Solid and Cross Hatch Tire PV Test Data for Different Aggregate Sources

Source	Pit	Material	Prod Code	Solid Tire Residual PV				Cross Hatch Tire Residual PV			
				#Data	Avg.	Sdev	CV	#Data	Avg.	Sdev	CV
Southwest	Knippa	Gravel (C)	1523209	4	28.0	3.83	13.68	5	26.0	1.41	5.44
Trinity	Luckett	Gravel (C)	916104	5	24.2	0.84	3.46	5	23.8	1.10	4.60
Bay	Sweet 16	Gravel (NC)	2206706	4	28.1	2.46	8.75	7	27.3	1.50	5.48
E.D. Baker	Johnson	Gravel (NC)	411807	4	31.8	3.30	10.41	6	32.5	1.87	5.76
Fordyce	Showers	Gravel (NC)	2110904	7	28.3	1.60	5.67	7	27.7	1.70	6.15
Hanson	Delight	Gravel (NC)	50116	4	29.0	3.74	12.90	5	31.4	1.14	3.63
Hanson	Eagle Mills	Gravel (NC)	50119	4	30.8	2.50	8.13	5	32.0	2.35	7.33
Hanson	Little River	Gravel (NC)	50114	4	30.3	1.26	4.16	5	31.0	2.24	7.21
Texas S&G	Mansfield	Gravel (NC)	418001	5	31.8	3.11	9.79	6	32.8	1.83	5.59
Upper Valley	D. Garcia	Gravel (NC)	2110905	6	30.2	2.71	9.00	7	28.9	2.27	7.86
Valley Caliche	Beck	Gravel (NC)	2110901	6	28.4	3.64	12.81	7	27.3	0.76	2.77
Wright	Realitos	Gravel (NC)	2206701	6	26.5	1.05	3.96	8	28.3	1.58	5.60
Border Pacfic	Matrimar	Gravel (U)	40103	5	25.0	2.92	11.66	6	23.7	1.86	7.87
Brazos Valley	Cameron	Gravel (U)	Z170003	6	26.7	2.34	8.77	7	28.4	2.51	8.82
Brazos Valley	Fulton	Gravel (U)	Z170006	7	26.4	1.99	7.52	4	25.0	1.15	4.62
Fordyce	Murphy	Gravel (U)	1323505	6	27.3	2.66	9.73	6	27.2	1.17	4.30
Jordan	Rothwell	Gravel (U)	Z250009	9	28.9	2.37	8.20	9	30.9	1.17	3.78
Lipham	Bundy	Gravel (U)	2517308	4	28.8	2.22	7.71	6	29.7	1.75	5.90
Pioneer	Arena	Gravel (U)	1304509	5	26.5	1.75	6.61	6	28.0	2.53	9.04
Thrasher	Thrasher	Gravel (U)	2517302	5	31.0	2.65	8.53	6	30.0	2.83	9.43
Granite Mt	Sweet Home	Igneous	50106	5	28.8	1.79	6.21	6	29.2	1.60	5.49
Hanson	Davis	Igneous	50439	2	35.0	1.41	4.04	4	37.0	0.82	2.21
Hanson	Pedernal	Igneous	50309	3	39.0	3.00	7.69	5	39.6	1.95	4.92
Jobe	McKelligon(Grnt)	Igneous	2407206	3	31.7	4.73	14.92	4	29.8	3.30	11.11
Jobe	Vado	Igneous	50310	4	33.8	2.50	7.41	5	35.8	4.15	11.58
Meridian	Snyder	Igneous	50435	5	29.2	2.05	7.02	7	31.6	1.62	5.13
Meridian	Mill Creek Gr	Igneous	50433	6	28.7	2.32	8.09	7	30.6	2.99	9.79
Meridian	Mill Creek Trap	Igneous	50438	3	32.7	4.93	15.10	5	35.2	4.87	13.83
Trans-Pecos	Hoban	Igneous	619502	5	33.0	1.58	4.79	5	35.0	0.71	2.02
Vulcan	Knippa	Igneous	1523206	5	30.4	2.07	6.82	6	30.7	2.16	7.04
Capital	Fm 1604#2	Limestone	1501515	2	27.5	0.71	2.57	3	29.3	0.58	1.97
Centex	Ruby	Limestone	1410607	3	29.0	1.73	5.97	3	30.0	4.00	13.33
Dolese	Ardmore	Limestone	50412	4	25.5	1.73	6.79	5	25.8	2.59	10.03
Lattimore	Coleman	Limestone	50430	5	28.2	2.59	9.18	6	29.5	2.17	7.35
Luhr	Tower Rock	Limestone	50601	6	29.2	3.66	12.54	7	29.4	3.10	10.54
Martin M	Chambers	Limestone	224921	7	28.6	2.19	7.64	7	26.4	1.99	7.52
Pioneer	Clinton	Limestone	1402701	5	26.3	1.86	7.06	6	27.2	3.31	12.19
Redland	SH 211	Limestone	1516310	9	26.7	2.00	7.50	11	26.8	1.72	6.42
Sunbelt	New Braunfels	Limestone	1504602	5	26.7	2.54	9.51	7	28.1	1.57	5.59
Vulcan	Black	Limestone	822107	9	27.0	2.78	10.31	8	28.9	1.64	5.69
Vulcan	Eastland	Limestone	2306805	3	24.7	3.79	15.35	4	24.5	1.91	7.82
Vulcan	Huebner	Limestone	1501507	3	25.3	1.53	6.03	4	27.5	2.08	7.57
Vulcan	Kelly	Limestone	218409	6	25.1	1.74	6.95	6	26.0	2.53	9.73
Vulcan	Smyth	Limestone	1523205	11	33.4	2.73	8.18	13	34.9	2.06	5.90
Word	Dow	Limestone	1402702	5	25.4	3.78	14.89	6	25.0	2.10	8.39

C = Carbonate Gravel
NC = Non-carbonate Gravel
U = Gravel with Unknown Lithology

Table 2.6 Analysis of TxDOT AQMP Data; Time Variability of Solid and Cross Hatch Tire PV Test Data for Different Aggregate Sources (continued from previous page)

Source	Pit	Material	Prod Code	Solid Tire Residual PV				Cross Hatch Tire Residual PV			
				#Data	Avg.	Sdev	CV	#Data	Avg.	Sdev	CV
Alamo	Weir	Limestone-dolomite	1424603	4	30.0	2.58	8.61	4	28.8	0.96	3.33
Amarillo	4DG	Limestone-dolomite	507805	7	27.9	1.46	5.25	8	27.3	2.38	8.72
Burkett	Perry #2	Limestone-dolomite	325204	3	27.0	1.73	6.42	5	27.8	1.48	5.34
Capitol	Wood	Limestone-dolomite	1424604	4	29.3	3.86	13.20	5	28.2	1.64	5.83
Colorado	Hunter	Limestone-dolomite	1404605	6	25.3	2.88	11.35	8	27.0	2.07	7.67
CSA	Turner	Limestone-dolomite	Z070008	14	27.9	2.71	9.74	16	31.2	3.05	9.77
Dolese	Cooperton	Limestone-dolomite	50415	5	25.8	0.84	3.24	6	26.0	1.41	5.44
Dolese	Richard Spur	Limestone-dolomite	50405	5	26.0	1.41	5.44	6	26.7	2.07	7.75
Hanson	New Braunfels	Limestone-dolomite	1504603	6	24.7	1.37	5.54	9	26.6	2.96	11.16
Hanson	Perch Hill	Limestone-dolomite	224901	6	25.0	2.19	8.76	6	23.3	0.82	3.50
JL Milligan	Aztec Canyon	Limestone-Dolomite	418814	4	32.0	2.16	6.75	5	34.6	3.05	8.81
Jobe	McKelligon(Dolo)	Limestone-dolomite	2407201	4	27.1	2.39	8.82	6	26.7	2.42	9.08
Meridian	Troy	Limestone-dolomite	50434	4	29.7	3.81	12.83	5	30.6	3.21	10.49
Pioneer	Bridgeport	Limestone-dolomite	224902	5	28.8	1.26	4.38	7	26.3	2.14	8.13
Pioneer	Davis	Limestone-dolomite	224905	5	25.7	2.17	8.44	7	25.4	1.62	6.36
Price	Clement	Limestone-dolomite	708802	6	30.2	2.64	8.75	11	29.8	1.47	4.93
Redland	Beckman	Limestone-dolomite	501503	9	28.0	3.12	11.15	11	27.5	2.25	8.18
Stringtown	Stringtown	Limestone-dolomite	50407	5	31.8	3.42	10.76	5	33.0	3.32	10.05
Tex Cr Stone	Feld	Limestone-Dolomite	1424602	8	28.5	2.88	10.10	8	30.3	2.05	6.79
TXI	Bridgeport	Limestone-Dolomite	224904	9	26.2	2.33	8.90	10	27.9	2.64	9.48
Vulcan	Brownwood	Limestone-Dolomite	2302501	7	23.9	2.12	8.87	10	24.7	1.70	6.89
Vulcan	Fm 1604	Limestone-Dolomite	1501506	7	28.6	2.10	7.32	8	27.6	2.77	10.04
Vulcan	Helotes	Limestone-Dolomite	1501514	6	27.3	1.63	5.97	7	30.0	2.38	7.93
Vulcan	Tehuacana	Limestone-Dolomite	914708	3	36.7	2.89	7.87	3	36.0	2.00	5.56
Vulcan	Higgins	Limestone-Dolomite	803005	7	29.0	1.73	5.97	7	29.4	1.72	5.84
Young	Fm 1860	Limestone-Dolomite	916113	2	28.5	3.54	12.41	2	26.5	2.12	8.00
Young	Skihi (Maddox)	Limestone-Dolomite	914709	9	40.6	3.81	9.40	10	42.8	3.46	8.08
Delta	Brownlee	Sandstone	1402704	3	39.3	0.58	1.47	4	38.0	1.63	4.30
Dolese	Cyril	Sandstone	50411	4	41.8	3.30	7.91	5	42.6	1.14	2.68
Meridian	Apple, OK	Sandstone	50437	3	35.3	2.52	7.12	4	34.8	0.96	2.76
TXI	Streetman	Synthetic	1817502	3	50.0	1.00	2.00	3	48.3	2.08	4.31

C = Carbonate Gravel
NC = Non-carbonate Gravel
U = Gravel with Unknown Lithology

Table 2.7 Analysis of TxDOT AQMP Data; Time Variability of Acid Insoluble Residue Test Data for Different Aggregate Sources

Source	Pit	Material	Prod Code	Acid Insoluble			
				# Data	Avg.	Sdev	CV
Southwest	Knippa	Gravel (C)	1523209	5	22.6	3.21	14.20
Trinity	Luckett	Gravel (C)	916104	5	39.4	4.72	11.99
Bay	Sweet 16	Gravel (NC)	2206706	7	91.1	2.27	2.49
E.D. Baker	Johnson	Gravel (NC)	411807	6	95.3	0.82	0.86
Fordyce	Showers	Gravel (NC)	2110904	7	88.6	3.05	3.44
Hanson	Delight	Gravel (NC)	50116	5	98.2	1.30	1.33
Hanson	Eagle Mills	Gravel (NC)	50119	5	97.4	1.14	1.17
Hanson	Little River	Gravel (NC)	50114	5	97.8	1.92	1.97
Texas S&G	Mansfield	Gravel (NC)	418001	6	83.7	3.20	3.83
Upper Valley	D. Garcia	Gravel (NC)	2110905	6	86.7	1.86	2.15
Valley Caliche	Beck	Gravel (NC)	2110901	6	88.0	4.20	4.77
Wright	Realitos	Gravel (NC)	2206701	7	97.1	1.46	1.51
Border Pacfic	Matrimar	Gravel (U)	40103	5	3.8	1.30	34.31
Brazos Valley	Cameron	Gravel (U)	Z170003	7	39.3	7.85	19.97
Brazos Valley	Fulton	Gravel (U)	Z170006	6	41.8	7.57	18.11
Fordyce	Murphy	Gravel (U)	1323505	7	94.4	2.07	2.19
Jordan	Rothwell	Gravel (U)	Z250009	9	86.6	4.56	5.27
Lipham	Bundy	Gravel (U)	2517308	6	90.5	3.39	3.75
Pioneer	Arena	Gravel (U)	1304509	6	93.7	4.80	5.13
Thrasher	Thrasher	Gravel (U)	2517302	6	85.5	4.81	5.62
Granite Mt	Sweet Home	Igneous	50106	6	95.7	1.51	1.57
Hanson	Davis	Igneous	50439	5	92.2	3.56	3.87
Hanson	Pedernal	Igneous	50309	5	96.6	0.89	0.93
Jobe	McKelligon(Grnt)	Igneous	2407206	4	95.5	1.73	1.81
Jobe	Vado	Igneous	50310	5	98.2	0.84	0.85
Meridian	Snyder	Igneous	50435	6	98.2	0.98	1.00
Meridian	Mill Creek Gr	Igneous	50433	7	98.0	1.29	1.32
Meridian	Mill Creek Trap	Igneous	50438	4	95.3	2.22	2.33
Trans-Pecos	Hoban	Igneous	619502	5	97.4	1.52	1.56
Vulcan	Knippa	Igneous	1523206	6	96.2	3.92	4.08
Capital	Fm 1604#2	Limestone	1501515	3	50.7	5.51	10.87
Centex	Ruby	Limestone	1410607	3	3.7	3.06	83.32
Dolese	Ardmore	Limestone	50412	5	9.6	2.07	21.60
Lattimore	Coleman	Limestone	50430	6	22.8	4.26	18.67
Luhr	Tower Rock	Limestone	50601	7	2.9	0.90	31.49
Martin M	Chambers	Limestone	224921	7	2.1	0.90	41.99
Pioneer	Clinton	Limestone	1402701	6	6.8	3.76	55.08
Redland	SH 211	Limestone	1516310	11	5.1	9.12	179.05
Sunbelt	New Braunfels	Limestone	1504602	7	3.0	1.00	33.33
Vulcan	Black	Limestone	822107	10	1.0	0.47	47.14
Vulcan	Eastland	Limestone	2306805	4	2.5	1.29	51.64
Vulcan	Huebner	Limestone	1501507	4	2.8	1.26	45.76
Vulcan	Kelly	Limestone	218409	5	2.8	0.84	29.88
Vulcan	Smyth	Limestone	1523205	12	9.1	2.39	26.33
Word	Dow	Limestone	1402702	6	1.2	0.98	84.27

C = Carbonate Gravel NC = Non-carbonate Gravel U = Gravel with Unknown Lithology

Table 2.7 Analysis of TxDOT AQMP Data; Time Variability of Acid Insoluble Residue Test Data for Different Aggregate Sources
(continued from previous page)

Source	Pit	Material	Prod Code	Acid Insoluble			
				# Data	Avg.	Sdev	CV
Alamo	Weir	Limestone-dolomite	1424603	4	4.8	2.06	43.40
Amarillo	4DG	Limestone-dolomite	507805	9	1.1	0.60	54.08
Burkett	Perry #2	Limestone-dolomite	325204	5	2.0	0.71	35.36
Capitol	Wood	Limestone-dolomite	1424604	6	3.5	2.81	80.31
Colorado	Hunter	Limestone-dolomite	1404605	9	4.2	2.64	62.41
CSA	Turner	Limestone-dolomite	Z070008	17	2.6	1.46	56.42
Dolese	Cooperton	Limestone-dolomite	50415	5	6.6	1.67	25.35
Dolese	Richard Spur	Limestone-dolomite	50405	5	10.4	2.07	19.94
Hanson	New Braunfels	Limestone-dolomite	1504603	9	3.2	0.97	30.16
Hanson	Perch Hill	Limestone-dolomite	224901	6	1.7	0.52	30.98
JL Milligan	Aztec Canyon	Limestone-Dolomite	418814	5	28.8	10.62	36.86
Jobe	McKelligon(Dolo)	Limestone-dolomite	2407201	5	14.6	2.07	14.20
Meridian	Troy	Limestone-dolomite	50434	5	22.0	2.00	9.09
Pioneer	Bridgeport	Limestone-dolomite	224902	6	2.5	0.84	33.47
Pioneer	Davis	Limestone-dolomite	224905	7	2.1	0.69	32.20
Price	Clement	Limestone-dolomite	708802	11	2.4	1.03	43.45
Redland	Beckman	Limestone-dolomite	501503	11	1.5	0.82	56.39
Stringtown	Stringtown	Limestone-dolomite	50407	5	72.2	4.15	5.74
Tex Cr Stone	Feld	Limestone-Dolomite	1424602	6	4.2	0.75	18.07
TXI	Bridgeport	Limestone-Dolomite	224904	9	2.8	1.20	43.27
Vulcan	Brownwood	Limestone-Dolomite	2302501	10	4.6	3.03	65.78
Vulcan	Fm 1604	Limestone-Dolomite	1501506	8	3.9	1.55	40.07
Vulcan	Helotes	Limestone-Dolomite	1501514	7	5.0	2.52	50.33
Vulcan	Tehuacana	Limestone-Dolomite	914708	3	12.0	3.00	25.00
Vulcan	Higgins	Limestone-Dolomite	803005	7	5.4	0.79	14.49
Young	Fm 1860	Limestone-Dolomite	916113	1	28.0		
Young	Skihi (Maddox)	Limestone-Dolomite	914709	11	17.6	7.55	42.83
Delta	Brownlee	Sandstone	1402704	4	63.3	1.71	2.70
Dolese	Cyril	Sandstone	50411	5	62.4	3.91	6.27
Meridian	Apple, OK	Sandstone	50437	4	98.3	0.50	0.51
TXI	Streetman	Synthetic	1817502	3	97.7	1.53	1.56

Table 2.8 Analysis of TxDOT AQMP Data; Time Variability of Data for Each Aggregate Category

		MG Soundness		
	# Data	Avg.	Avg. Sdev	CV
Synthetic	1	2.33	1.53	65.47
Sandstone	3	12.17	2.81	23.09
Igneous	10	4.13	1.52	36.96
Gravel (NC)	10	5.07	1.84	36.21
Gravel (C)	2	4.50	0.89	19.88
Limestone-Dolomite	27	13.65	4.14	30.32
Limestone	15	11.64	3.96	34.07
Gravel (U)	8	3.53	1.21	34.33

		Micro Deval		
	# Data	Avg.	Avg. Sdev	CV
Synthetic	1	17.35	2.09	12.06
Sandstone	3	14.02	2.25	16.07
Igneous	10	7.65	1.27	16.59
Gravel (NC)	10	4.74	1.00	21.02
Gravel (C)	2	8.00	2.27	28.34
Limestone-Dolomite	27	17.34	2.30	13.26
Limestone	15	15.75	2.73	17.33
Gravel (U)	8	6.76	0.78	11.59

		Solid Tire Residual PV		
	# Data	Avg.	Avg. Sdev	CV
Synthetic	1	50.00	1.00	2.00
Sandstone	3	38.81	2.13	5.50
Igneous	10	32.22	2.64	8.19
Gravel (NC)	10	29.50	2.54	8.60
Gravel (C)	2	26.10	2.33	8.94
Limestone-Dolomite	27	28.57	2.41	8.43
Limestone	15	27.23	2.36	8.65
Gravel (U)	8	27.57	2.36	8.56

		Cross Hatch Tire Residual PV		
	# Data	Avg.	Avg. Sdev	CV
Synthetic	1	48.33	2.08	4.31
Sandstone	3	38.45	1.2	3.2
Igneous	10	33.43	2.4	7.3
Gravel (NC)	10	29.91	1.7	5.7
Gravel (C)	2	24.90	1.3	5.0
Limestone-Dolomite	27	28.96	2.2	7.5
Limestone	15	27.96	2.2	8.0
Gravel (U)	8	27.85	1.9	6.7

		Acid Soluble Residue		
	# Data	Avg.	Avg. Sdev	CV
Synthetic	1	97.67	1.53	1.56
Sandstone	3	74.63	2.04	2.73
Igneous	10	96.32	1.85	1.92
Gravel (NC)	10	92.39	2.12	2.30
Gravel (C)	2	31.00	3.97	12.79
Limestone-Dolomite	27	9.99	2.24	22.38
Limestone	15	8.40	2.52	30.01
Gravel (U)	8	66.95	4.54	6.79

C = Carbonate Gravel NC = Non-carbonate Gravel U = Gravel with Unknown Lithology

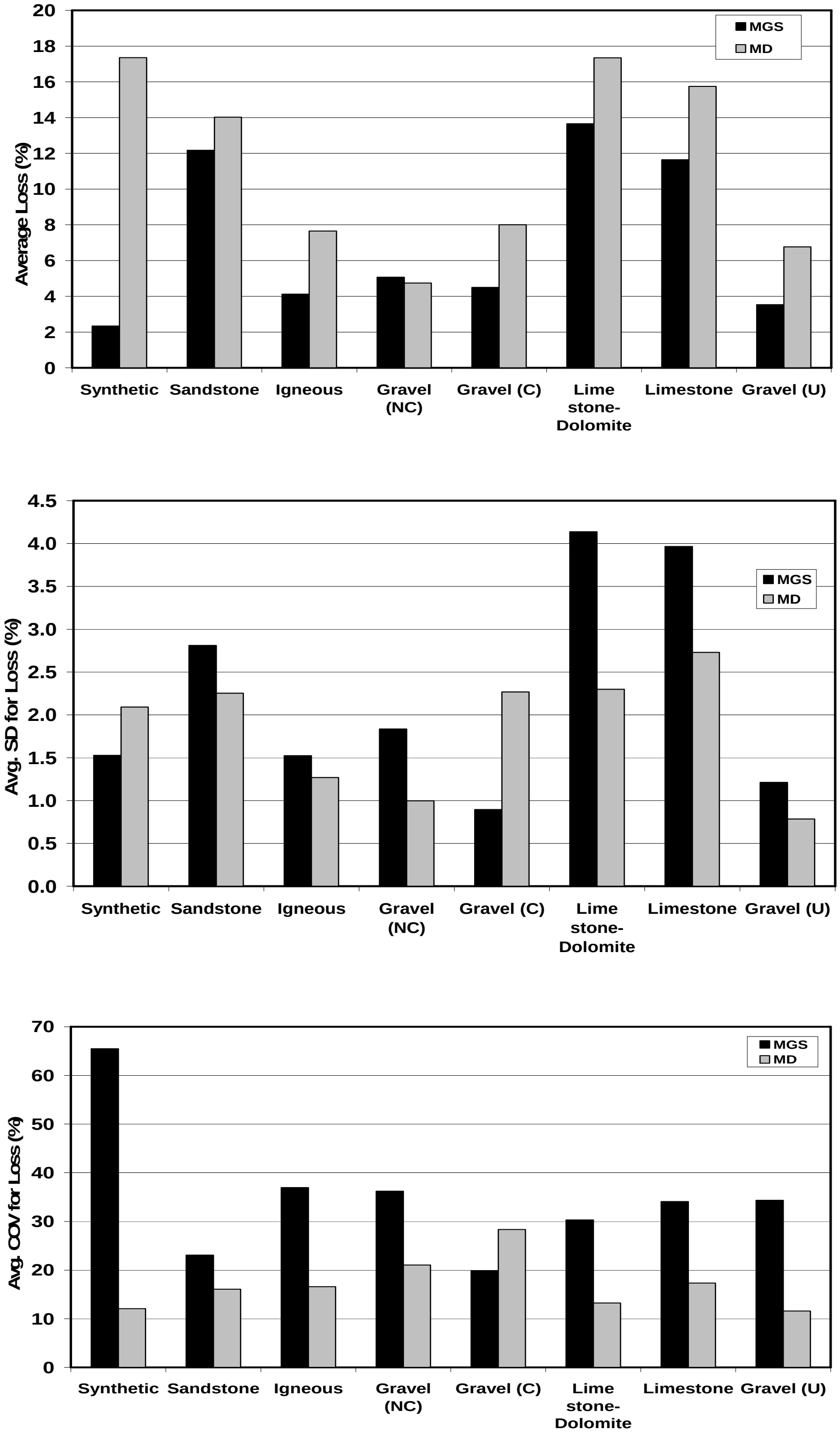


Figure 2.9 Time Variability of MSS and MD Test Data; Average Loss, Average Standard Deviation and Average Coefficient of Variation

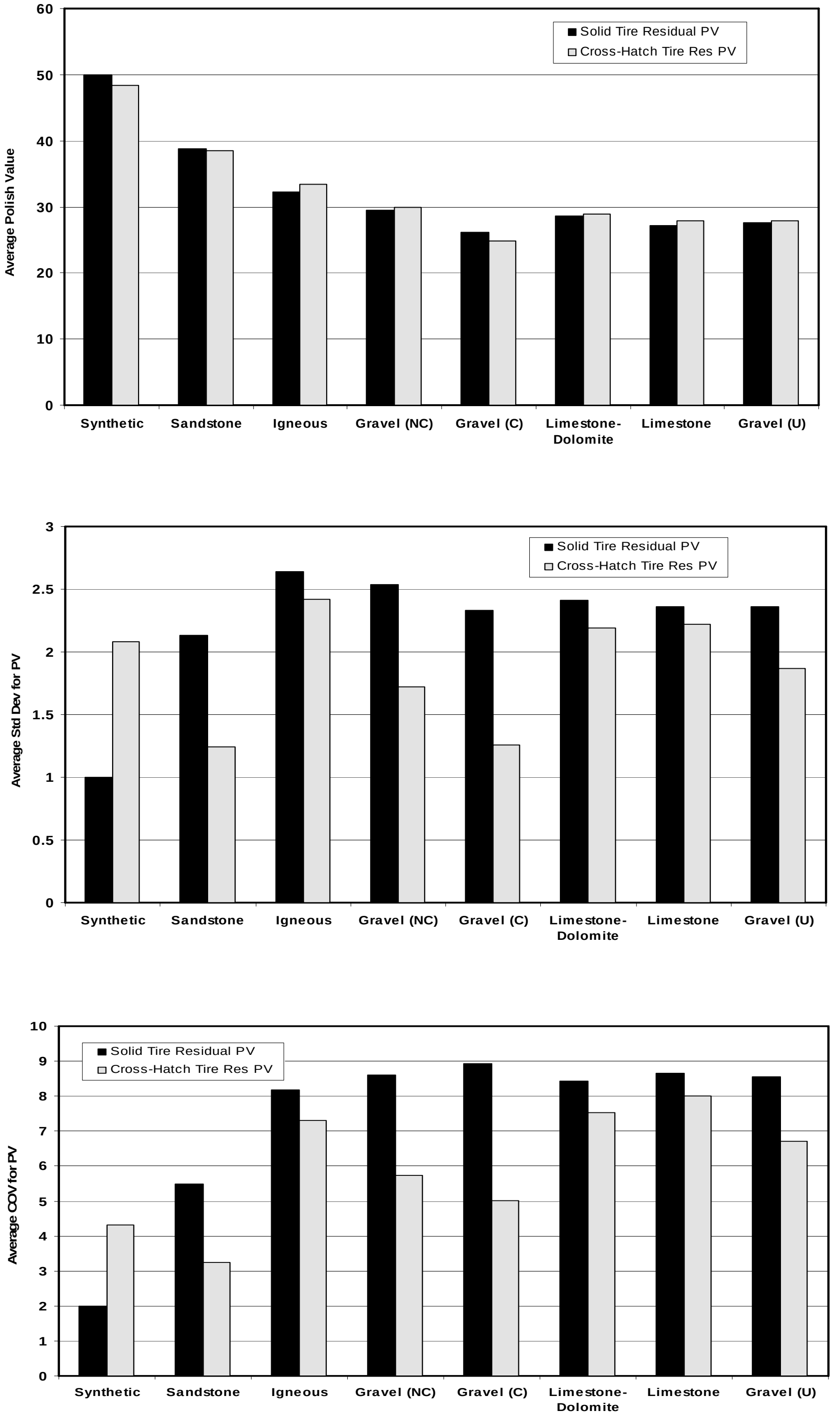


Figure 2.10 Time Variability of Solid and Cross Hatch Tire Residual PV Test Data; Average PV, Average Standard Deviation and Average Coefficient of Variation

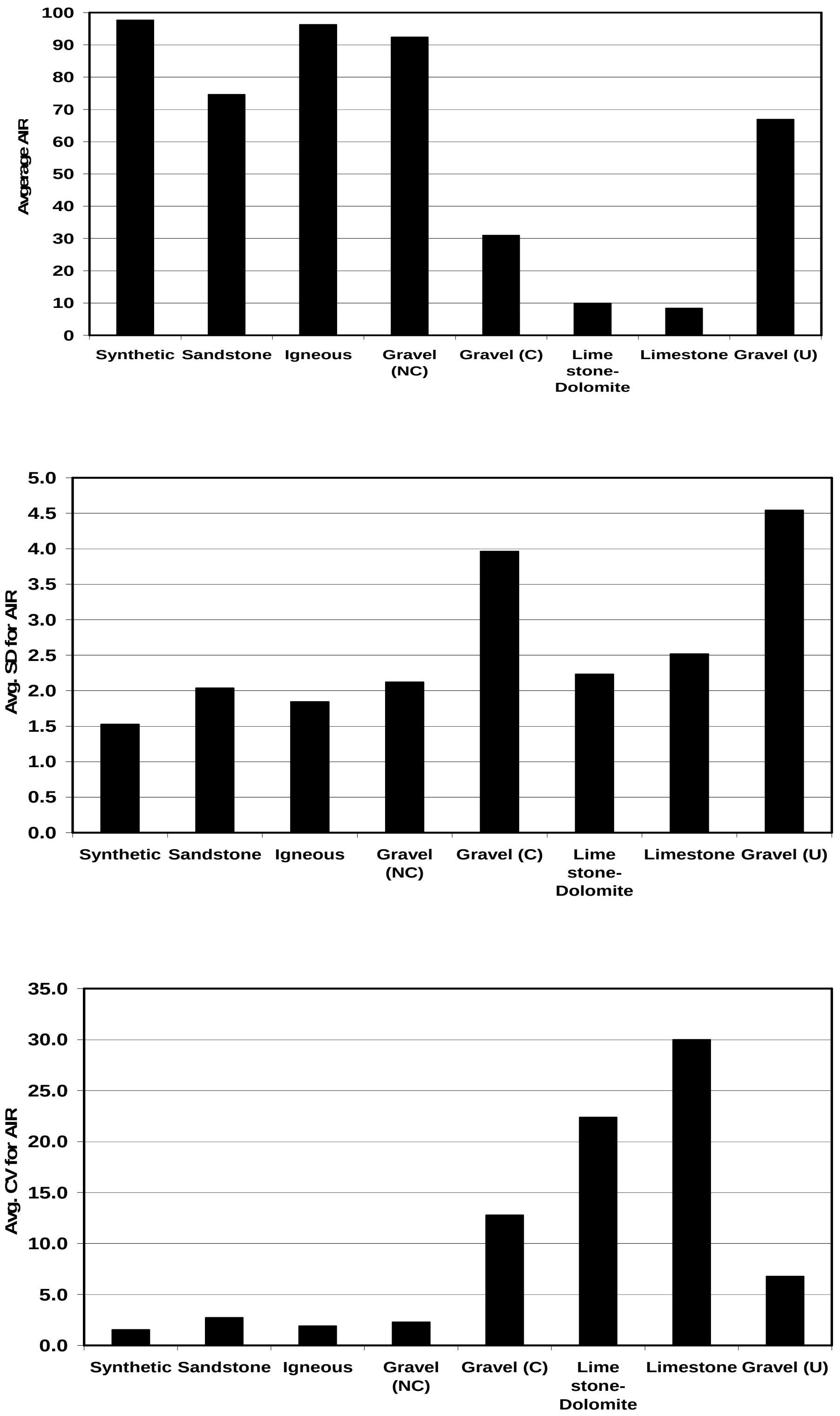


Figure 2.11 Time Variability of Acid Insoluble Residue Test Data
Average AIR, Average Standard Deviation and Average Coefficient of Variation

Several conclusions can be reached based on review of data presented in Figures 2.9, 2.10 and 2.11. These conclusions are listed below.

(a) The performance of different aggregate types in the MSS and MD tests is consistent with the observations made earlier based on tests conducted at Texas Tech. In other words, the limestones, limestone-dolomites and sandstones performed poorly in both MD and MSS tests. The only synthetic aggregate showed contradictory behavior in the two tests. But one should be cautious about drawing conclusions from the apparent contradiction observed in synthetic aggregate category because that aggregate category consisted of only one aggregate source.

(b) Review of data obtained from Solid and Cross Hatch tire residual PV tests, shows that the two tests yield very similar results for all aggregate types. The standard deviation and coefficient variation values however suggest that time variability of aggregate sources as recorded by the solid tire is somewhat higher that recorded by the cross hatch tire. If it is assumed that the repeatability of the two tests are the same, then the data leads to the conclusion that the solid tire polish values has better capability in capturing time variability that occurs in aggregate sources.

(c) In the acid insoluble residue test, contrasting performance can be seen between carbonate aggregates and non-carbonate aggregates. An AIR of 40 or 50 percent can be used to separate the two categories.

(d) Earlier comparison between variability in MD and MSS showed that the variability in MSS test data is 3-4 times larger than that for the MD test. Similar trend can be seen in time variability of MSS and MD data. However, the difference is somewhat less prominent. In the case of carbonate gravels the time variability of MD data was larger.

(e) Texas Tech Laboratory data showed that the acid insoluble residue has very poor repeatability for carbonate aggregates. Similar data trend exists in time variability as well. Coefficients of variation (COVs) calculated for AIR data conducted on limestones, limestone-dolomites and carbonate gravels are very high while COVs calculated for non-carbonate materials remain very low.

In addition to the analyses described above, aggregate sources with time histories of at least 5 pairs of polish value data were selected for further review. For this review, solid and cross hatch tire residual polish values were plotted against the sample/test number. Figures 2.12 through 2.14 are examples of plots obtained. They represent one gravel source, one limestone source, and one limestone-dolomite source. These plots show that the two test variables follow the same general pattern. This suggests that both variables are likely indicating a change in material quality rather than showing random test variability. It can also be seen that the solid tire residual PV shows larger time variations than the cross hatch tire PV value.

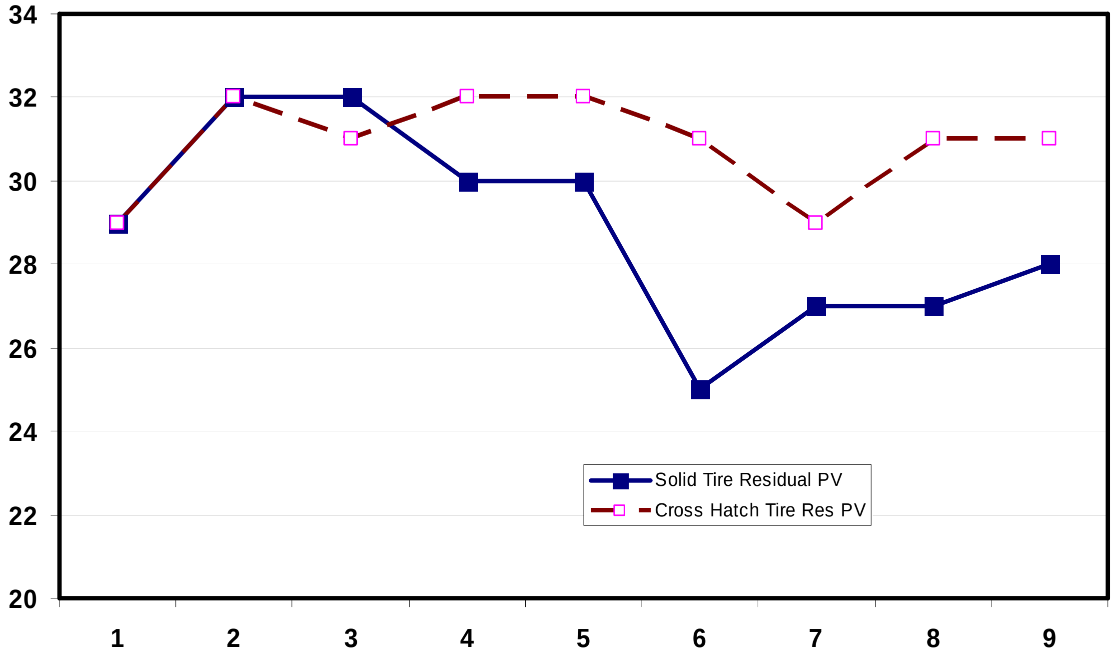


Figure 2.12 Polish Value Time History for a Gravel Source

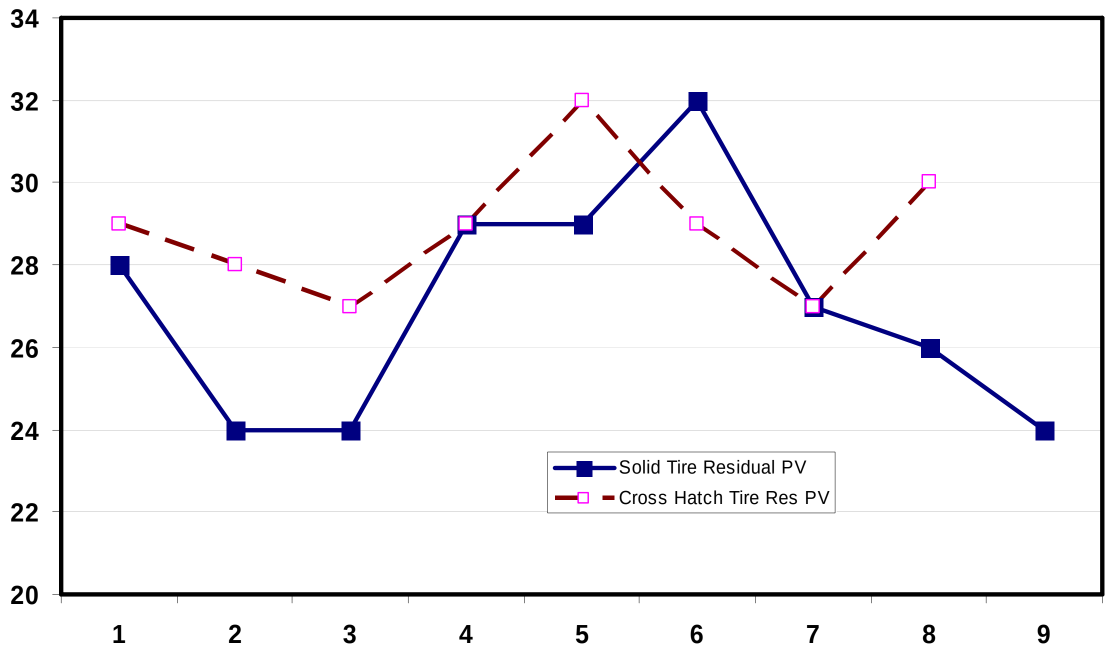


Figure 2.13 Polish Value Time History for a Limestone Source

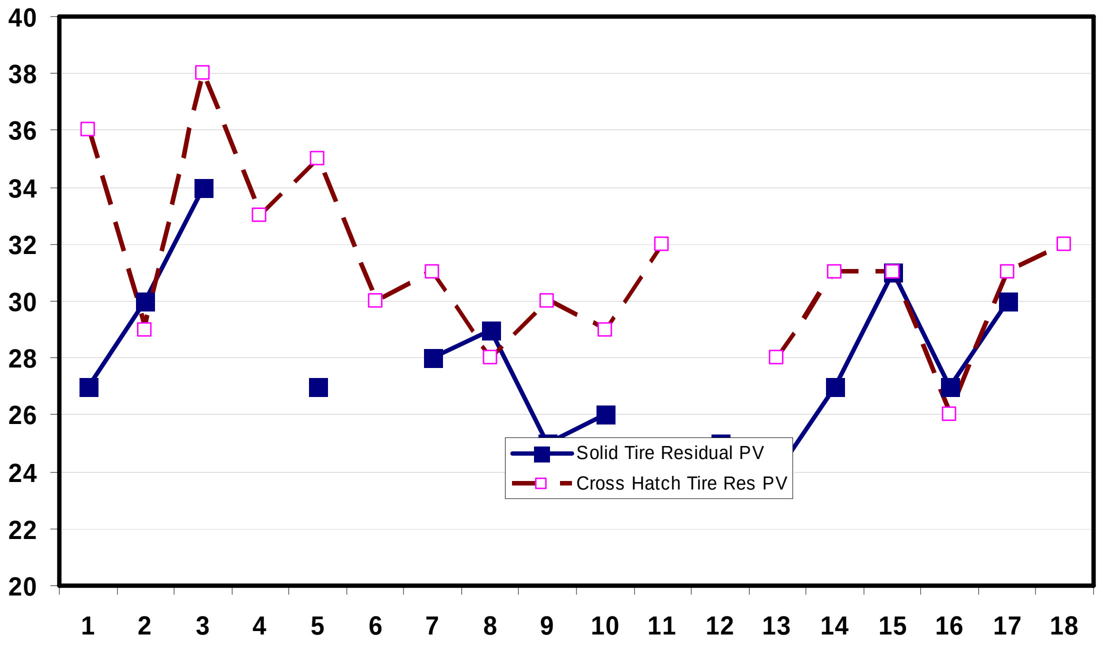


Figure 2.14 Polish Value Time History for a Limestone-Dolomite Source

CHAPTER 3

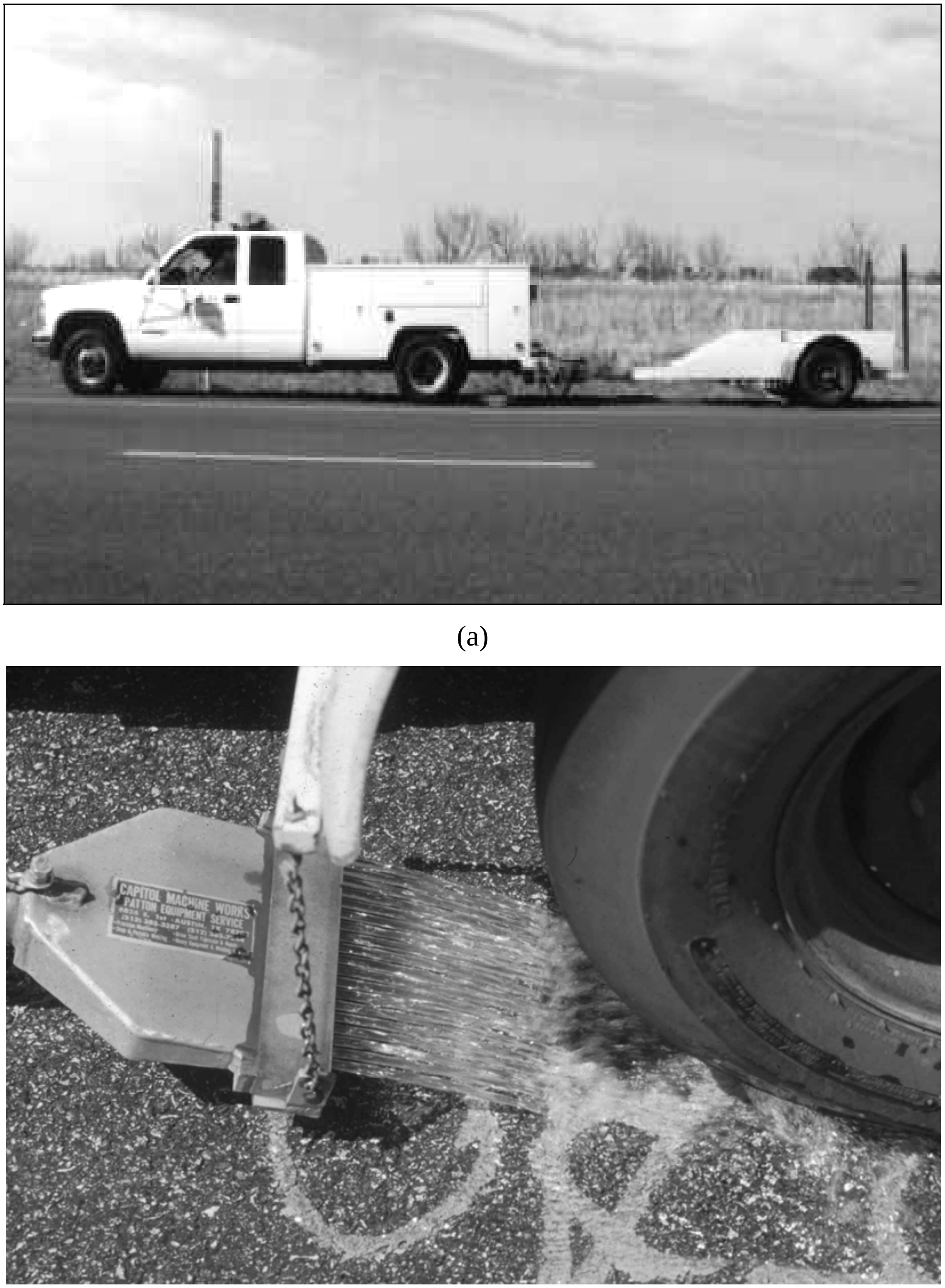
EVALUATION OF AGGREGATE FIELD SKID PERFORMANCE

OVERVIEW

The collection of reliable skid resistance measurements that truly represent the performance of the aggregate in the field is one of the most difficult tasks associated with the development of lab-field performance correlations. The TxDOT procedure for measuring Field skid numbers used a locked wheel skid trailer that is described in ASTM Standard E-274 [13]. The skid trailer is towed by a vehicle with apparatus. The apparatus consists of a transducer, instrumentation, a water supply dispensing system, and actuation control for brake of the test wheel [8].

All of the skid data included in this report were collected prior to 1999. The test procedure used by TxDOT at that time involved the use of a standardized ribbed tire that met ASTM E-501-88 specifications [14]. The travel speed used was 40 mph (64 km/hr). Figure 4.1 shows a typical skid trailer set up used for collection of skid resistance data by TxDOT. Located just in front of the tires are nozzles that spray water at the rate of 4 gallons/min/in (0.6 liters/min/in) when the trailer brakes are activated and the wheels of the trailer become locked. This places a water layer of 0.02 inches (1mm) on the pavement surface for the tires to skid on. The wheel torque during braking is recorded electronically and from this the skid number (SN) is determined from the force required to slide the locked test tire at 40 m/hr (64 km/hr) divided by effective wheel load and multiplied by 100. In 1999, TxDOT implemented changes in its skid testing procedure. These changes included: (a) the use of smooth tire test wheel instead of the previously used ribbed tire wheel, and (b) the use of test speed of 50 mph (80 km/hr) instead of the previously used 40 mph (64 km/hr).

The skid number measured by using locked wheel skid trailer depends not only by the frictional resistance offered by the coarse aggregate roughness but also on many other variables. The macrotexture of the pavement surface, presence of distresses (e.g. bleeding, flushing), fine aggregates can have significant influence. Furthermore, previous TxDOT research study 0-1459 showed that environmental factors such as rainfall, temperature also have major influence on field skid number measurements [15, 16]. For this reason, the original research plan for this project proposed the construction of special test pavement



(a)

(b)

Figure 3.1: (a) Locked-Wheel Skid Trailer used by TxDOT for Skid Number Measurement, (b) Close up View of Water Nozzle Spraying Water in Front of Test Wheel

sections using different coarse aggregates on the same roadway. In this manner all extraneous factors such as mix design, traffic, environmental factors will remain the same and any difference in observed in pavement skid resistance could be attributed to the coarse aggregate. However, during the implementation of the research project, this plan was determined to be impractical based on both cost and time considerations. Consequently, the decision was made to utilize skid number databases developed in previous TxDOT research studies 0-1459 and 7-3994.

FIELD SKID NUMBER DATA

Project 0-1459 Database

In Project 0-1459, conducted by Texas Tech University, a total of 54 pavement sections located in various parts of Texas were tested to determine their skid resistance performance. Figure 3.2 shows the test pavement locations on the Texas map.

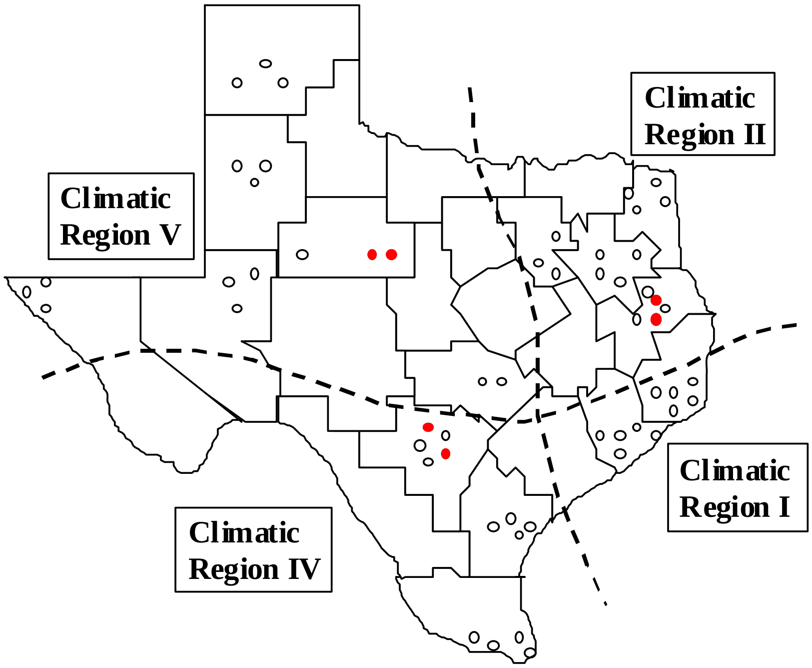


Figure 3.2 Locations of the 54 Test Sections Monitored for Skid Resistance in TxDOT Research Project 0-1459

The test sections represented all 4 climatic regions and 5 different bituminous mix designs. The mix designs included were: OGFC, CMHB (coarse), CMHB (fine), Type C and Type D. The test pavements used 30 carbonate aggregates, 16 siliceous gravels, 3 sandstones and 5 other types of coarse aggregate (igneous, lightweight and traprock). The pavement sections were monitored over a 3-year period 1995 through 1997 with at least one round of skid measurements per year using ribbed tire at 40mph speed.

Skid numbers were taken at five locations, each spaced about 300ft apart, on each test section. Each test section was approximately 1500ft long. On sections where there were two or more lanes in one direction the outside lane was used for testing. Five skid measurements were taken in order to minimize the variability in skid numbers due to non-uniformity in the test surface in the longitudinal direction. Taking sufficient number of skid measurements was necessary to minimize possible error due to this type of random variability. The frictional resistance of the pavement surface also varies in the lateral direction across the travel lane. The skid resistance is a minimum along the wheel path and the measured skid numbers tend to vary depending on the lateral position of the test trailer. Technically, all skid measurements should be performed along the centerline of the left wheel path. Therefore, to reduce the effect of non-uniformity in the lateral direction skidding was made on the left wheel path. Figure 3.3 depicts the five locations where a skid measurement was made on a test section. The average skid number measured on each test section and the corresponding accumulated vehicle passes per lane (AVPPL) at the time field skid testing are shown in Table 3.1.

Table 3.1 Average Field Skid Numbers and Accumulated VPPL from Project 0-1459

Section_ID	AVGSN95	VPPL95	AVGSN96	VPPL96	AVGSN97	VPPL97
04IH00401	48.8	445,454	47.4	1,555,520	48.0	2,740,690
04SH01361	47.6	249,084	48.6	636,522	47.7	1,050,129
04SH01521	55.2	195,228	52.0	498,916	51.2	823,140
05FM22551	40.2	480,974	46.8	1,672,806	43.0	2,925,912
05US00841	50.6	16,331,597	45.4	17,298,047	45.8	18,314,196
06IH00201	54.2	121,723	51.0	509,538	52.5	931,795
06LP02501	45.0	3,909,924	42.5	5,296,273	41.0	6,805,834
08IH00201	37.4	794,763	24.2	3,031,921	25.6	5,011,661
08IH00202	35.6	794,763	21.8	3,031,921	26.2	5,011,661
08IH00203	40.2	460,900	30.4	1,758,245	26.6	2,906,268
10IH00201	46.2	1,016,759	36.2	2,795,802	38.5	5,919,398
10LP03231	47.5	413,100	46.6	1,979,055	47.6	4,728,669
10US00691	38.2	478,012	43.3	1,321,537	42.6	2,802,652
10US00791	58.4	217,708	50.0	603,757	43.4	1,278,217
11FM12751	57.0	3,533,663	55	4,692,295	57.4	6,669,294
11US00591	36.8	4,440,748	32.2	6,031,372	29.2	8,752,736
11US00592	41.4	1,1611,072	41.8	13,424,220	37.4	16,526,292
11US00593	40.0	3,723,090	39.3	6,195,600	38.2	10,425,877
11US00594	54.6	2,174,726	54.4	2,858,835	55.0	4,026,121
12FM13011	44.8	319,785	40.0	488,385	37.8	751,891
12FM20041	62.6	797,742	54.0	1,539,704	54.8	2,377,356
12FM30051	56.5	7,279,629	52.2	8,673,808	58.6	10,853,120
12LP01971	52.4	1,063,488	49.8	1,585,168	52.2	2,400,600
12SH00361	52.8	588,744	44.6	1,465,647	40.2	2,836,419
14US02901	40.8	4,100,417	40.0	5,759,652	42.4	8,373,862
14US02902	41.2	4,495,773	37.0	5,899,738	39.7	8,111,750

Table 3.1 Average Field Skid Numbers and Accumulated VPPL from Project 0-1459 (continued from previous page)

Section_ID	AVGSN95	VPPL95	AVGSN96	VPPL96	AVGSN97	VPPL97
15LP00131	29.8	5,098,940	28.8	6,165,354	29.8	7,994,996
15LP00132	38.0	237,048	37.8	1,580,143	44.8	3,851,653
15LP16041	21.6	15,128,295	22.4	16,682,344	21.6	19,614,891
15US02811	28.2	48,310,830	29.0	53,399,365	31.4	63,001,692
15US02812	42.6	11,664,495	46.0	14,239,710	41.8	19,099,232
16SH03591	N/A	N/A	40.5	612,949	43.0	1,231,660
16US01811	N/A	N/A	60.6	972,348	50.8	1,953,893
16US01812	N/A	N/A	45.2	620,286	39.2	1,246,380
16US02811	52.8	1,259,897	46.8	1,795,427	47.6	2,511,017
18IH00451	44.4	2,626,905	38.4	4,468,217	39.5	7,729,489
18IH035E1	38.2	4,435,665	35.4	6,471,187	36.0	10,076,478
18US01751	46.2	6,704,334	44.8	8,068,795	46.8	10,485,461
19SH00081	48.4	222,666	45.2	608,977	47.6	1,281,262
19US00591	51.0	683,644	45.8	1,869,788	44.9	3,934,203
19US02711	50.5	1,073,556	45.2	1,537,473	47.6	2,334,663
19US02712	60.4	182,590	60.8	505,257	57.6	1,059,771
20FM01051	50.0	3,488,661	45.2	3,788,881	52.0	4,411,696
20FM03651	59.4	874,836	44.6	1,240,861	47.6	2,006,277
20SH00871	49.8	1,583,799	38.8	2,353,739	39.0	3,951,093
20SH03211	45.0	270,070	34.4	849,342	30.8	2,047,958
20US00901	49.8	240,567	41.8	756,564	46.2	1,824,279
21SH00041	50.2	94,064	39.8	542,012	31.4	1,140,555
21SH01001	44.2	2,320,904	42.4	3,082,904	39.4	4,101,040
21SP04871	41.8	225,950	40.2	1,326,999	34.9	2,792,439
21US02811	53.0	177,021	45.4	1,039,632	38.1	2,187,718
24FM06591	33.0	1,028,200	30.0	1,539,668	27.8	2,098,818
24LP03751	42.8	1,835,064	39.6	2,510,142	34.0	3,248,137
24SH00201	33.0	1,354,213	33.8	1,873,327	25.4	2,440,804

Project 7-3994 Database

In the fall of 1997, TxDOT initiated a 3-year in-house research study 7-3994 to develop alternate polish value and soundness specifications to optimize the utilization of available aggregate resources in Texas. As a part of this study, 142 pavement projects representing 39 aggregate sources were monitored for skid resistance. To improve the reliability of skid testing, the researchers used a test procedure that they described as the "race track skid test procedure." The objective of this procedure is to minimize the potential impact from the effects of rainfall on the measured skid number. Originally proposed in Project 0-1459, this procedure uses repeated water spray and scrubbing as skid testing is continued on the same wheel path. Data is collected during the initial conditioning runs as well as subsequent test runs until a set of 5 skid numbers that is within 2-point spread is obtained. The detailed procedure and associated control elements for race track testing can be found in Fu and Chen [2]. The original database developed from Project 7-3994 is also found in the same reference. A subset of the above data for which complete information was available was used in this research.

ANALYSIS OF FIELD SKID DATA

Development of Skid Performance Histories

The skid resistance measured on a given pavement surface changes as the number of vehicle passes on the roadway increases. The skid number is high on a new pavement surface and then it gradually declines as the cumulative vehicle passes on the roadway increases. This trend is evident in data that is shown in Figure 1.1. However, as seen in Figure 1.1(a), the skid numbers then tends to reach a stable "terminal value." The skid numbers measured after this terminal condition has been reached can be used as a true measure of aggregate field skid performance. Therefore, it was necessary to establish a certain minimum threshold value of cumulative vehicle passes for each aggregate skid performance history. Only those skid number measurements taken after the road surface has been exposed to this minimum number of cumulative vehicle passes were considered in the analysis.

Figures 3.3 through 3.7 show examples that demonstrate the field skid data analysis procedure used in this research. Each of these figures is a plot of field measured skid

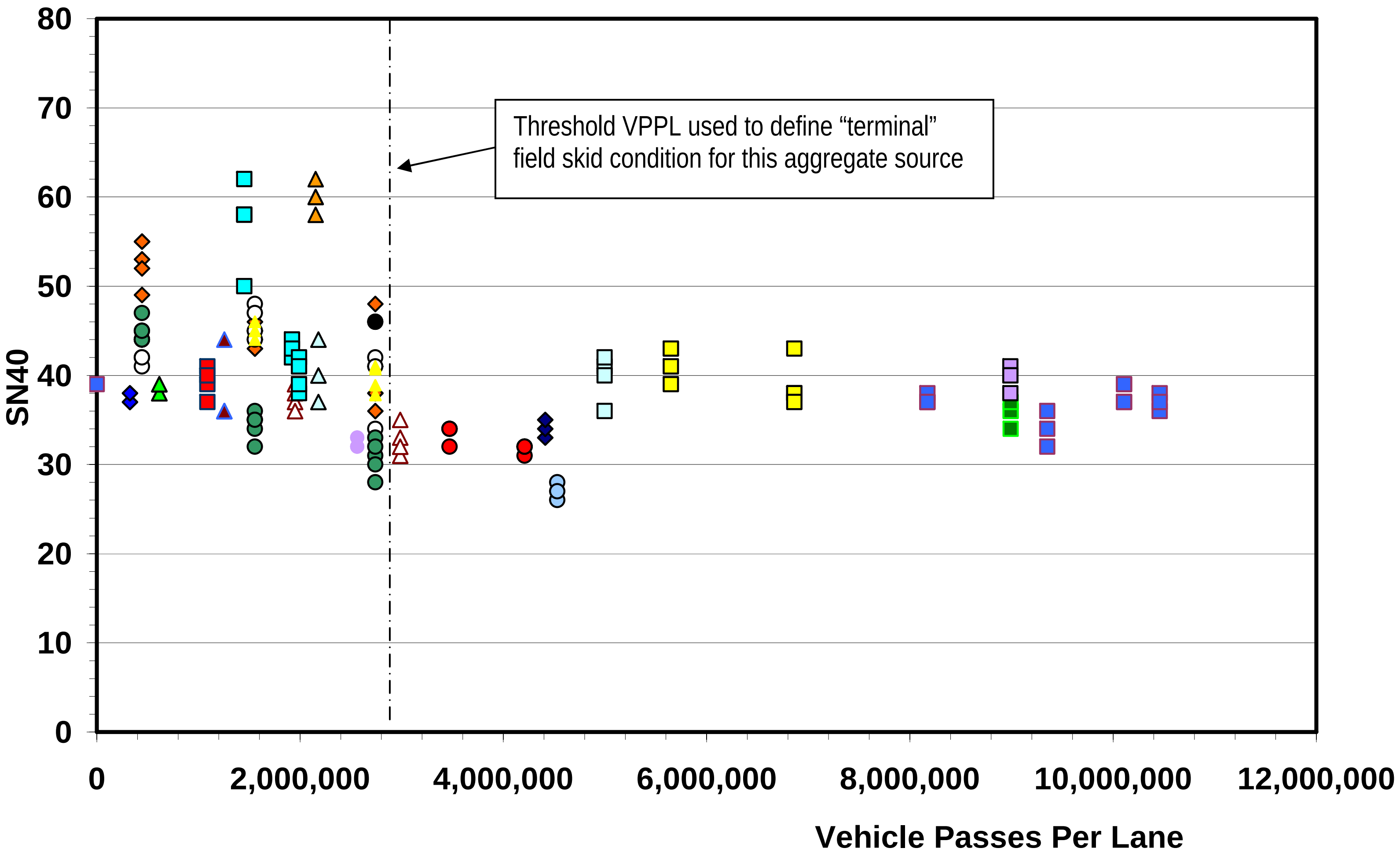


Figure 3.3: Field Skid Performance History for the Limestone Source No. 1501503

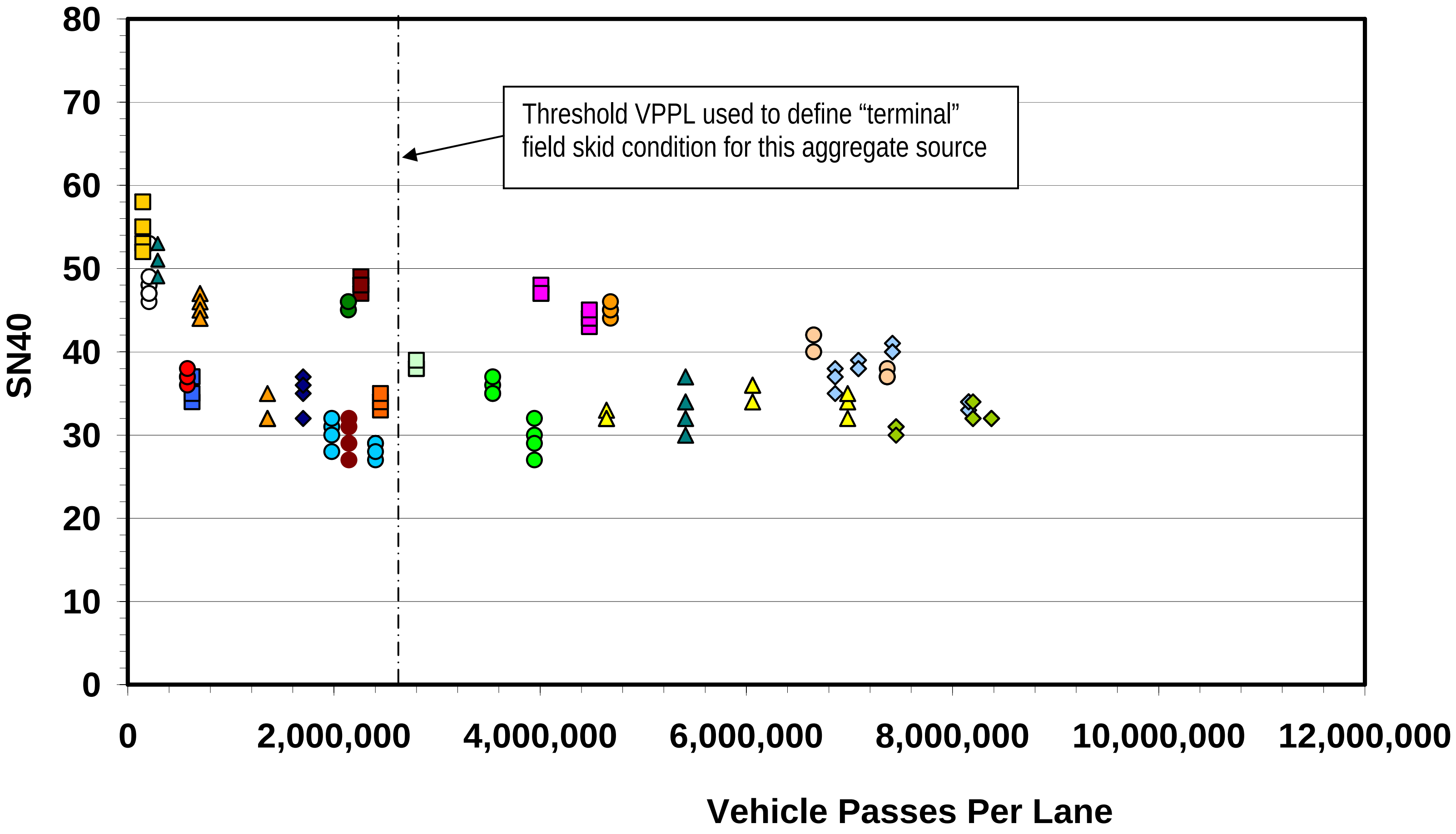


Figure 3.4: Field Skid Performance History for the Limestone Source No. 1504605

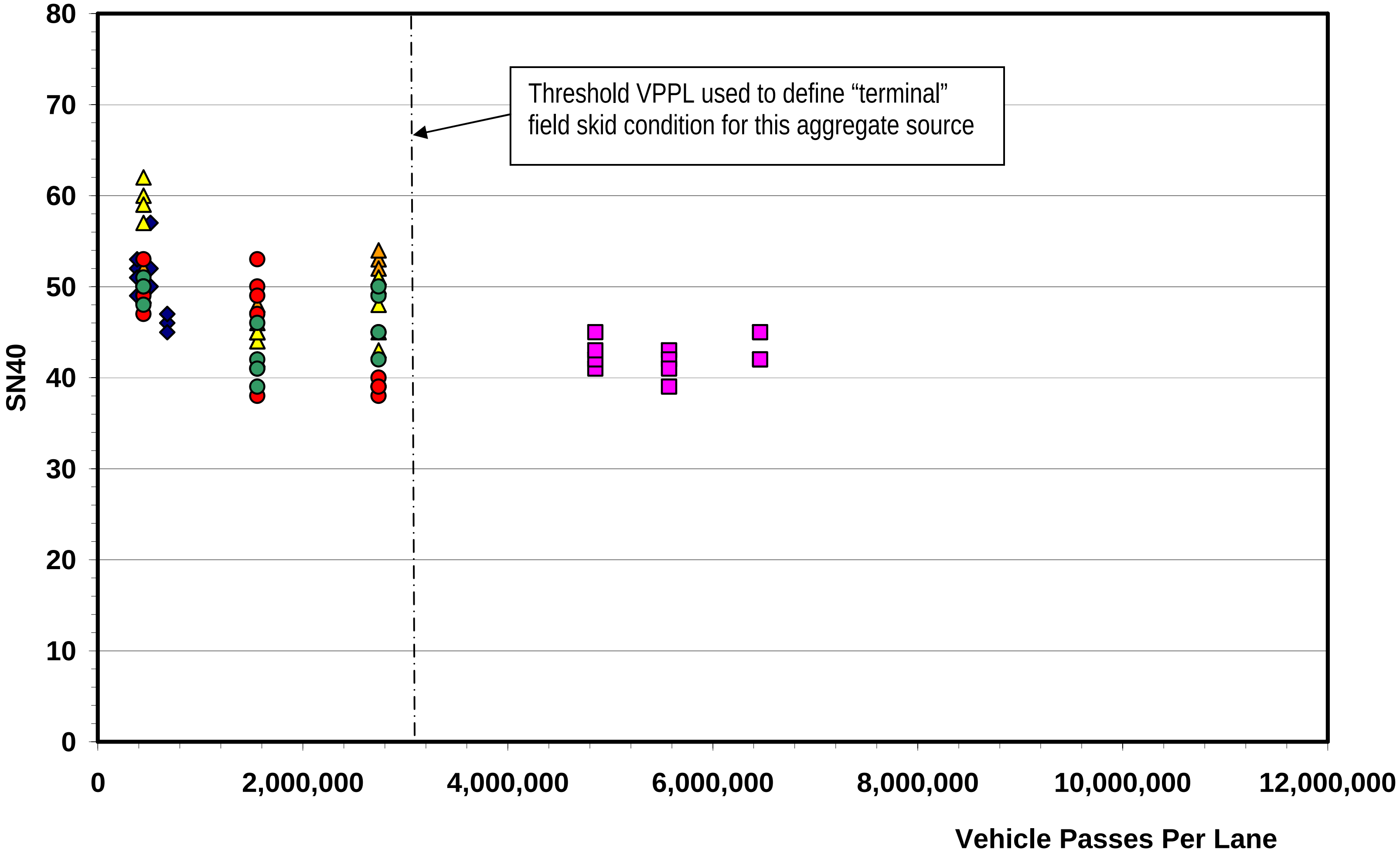


Figure 3.5: Field Skid Performance History for Igneous Source No. 50106

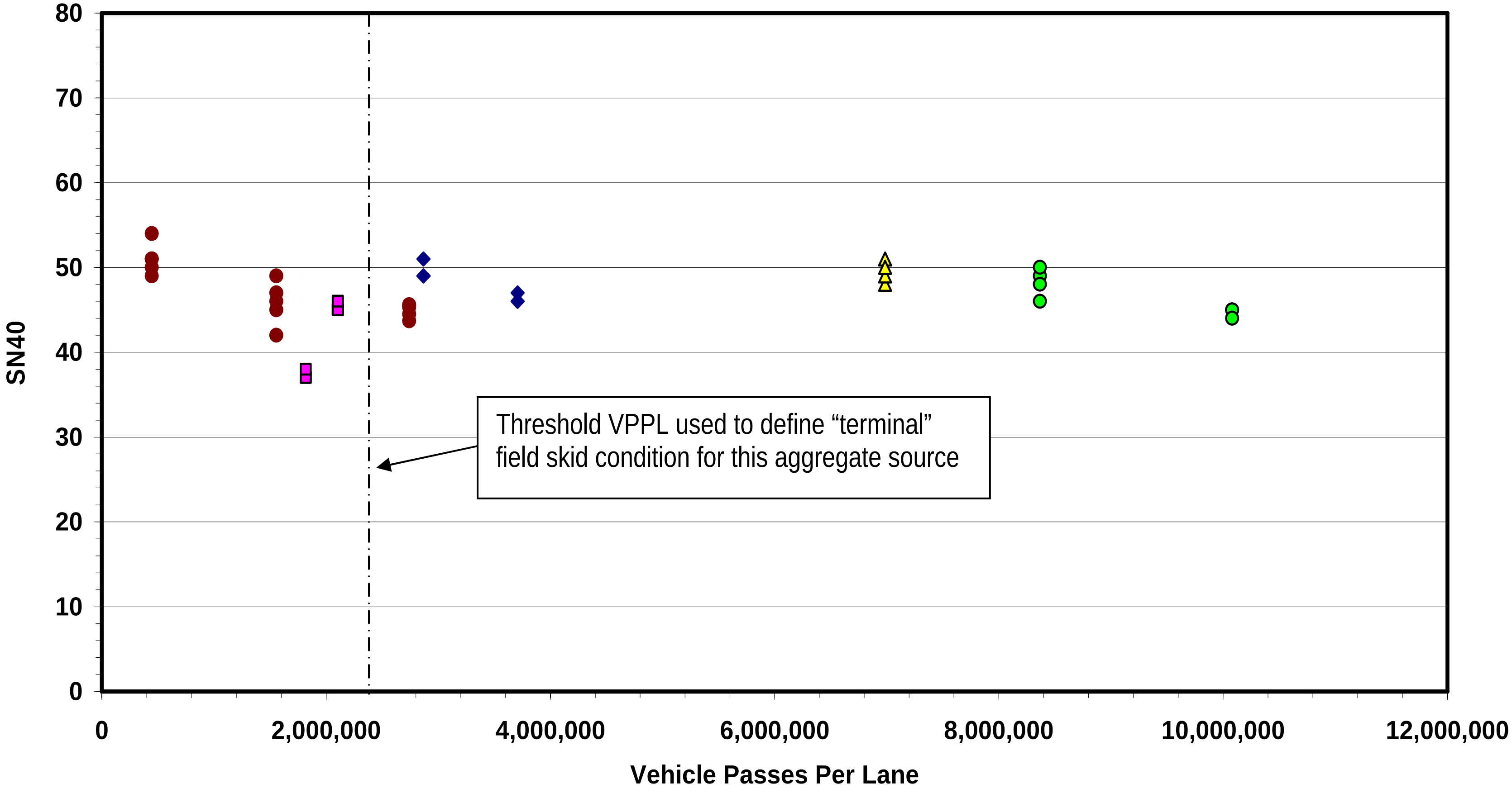


Figure 3.6: Field Skid Performance History for a Siliceous Gravel Source No. 50114

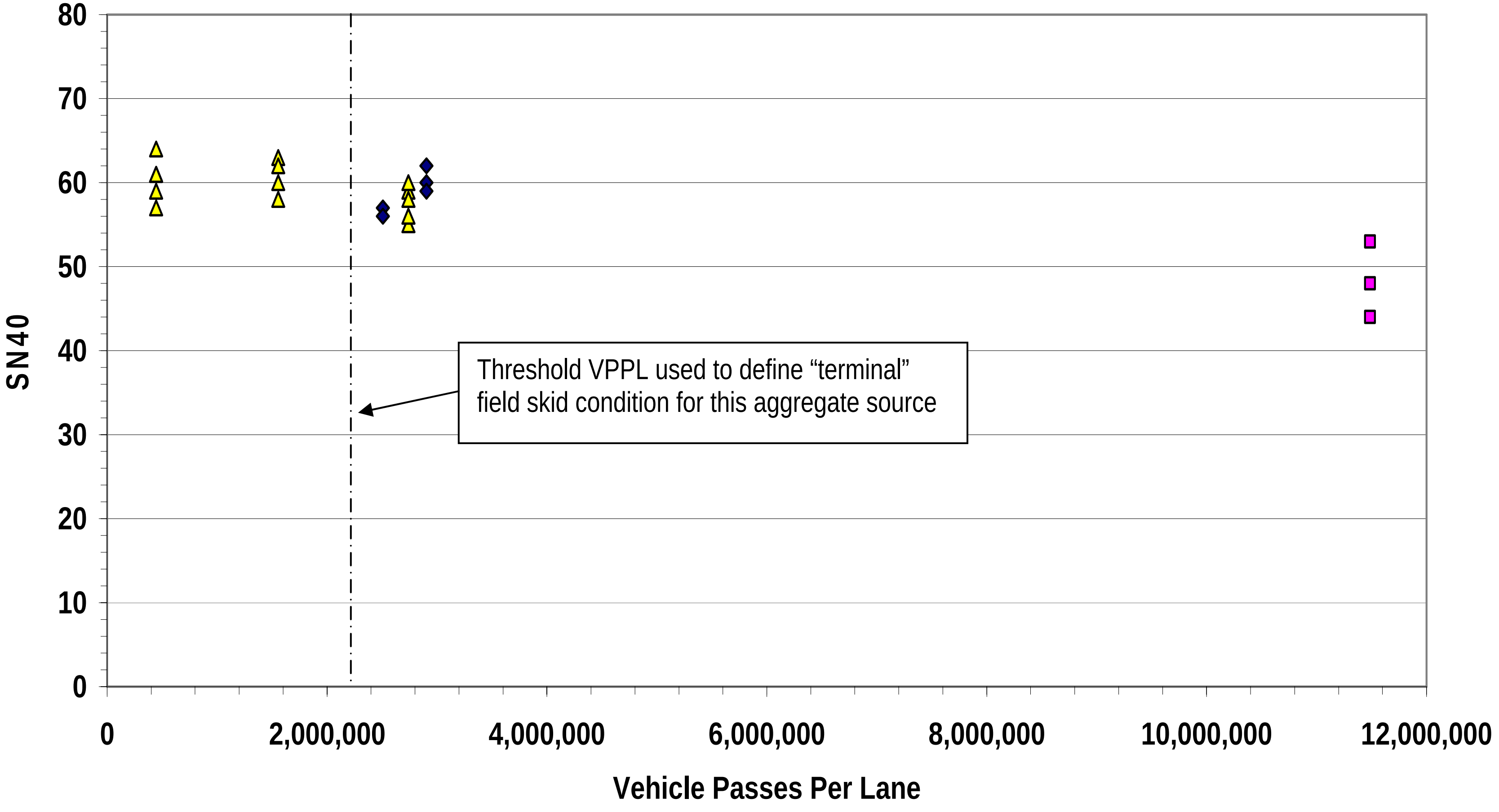


Figure 3.7: Field Skid Performance History for a Sandstone Source No. 50437

resistance number versus cumulative vehicle passes per lane (VPPL). They represent 2 limestone sources (Figures 3.3 and 3.4), 1 igneous source (Figure 3.5), 1 siliceous gravel (Figure 3.6) and 1 sandstone (Figure 3.7). To develop these skid performance history plots, data collected on different pavement sections that were constructed using the same bituminous coarse aggregate were combined. After review of the data trend in each plot, a threshold value of VPPL was selected as the minimum VPPL to achieve terminal condition. Skid numbers that fall below this critical threshold VPPL were not included in the analysis. As an example, if the limestone source represented by Figure 3.3 is considered, a VPPL of 2.9 million appears to be a reasonable estimate to be used as the threshold VPPL to achieve "terminal" conditions. All skid numbers measured after this threshold value had been reached were then considered as data that is independent of the transient changes that a pavement undergoes after its construction and therefore, a true reflection of the aggregate's field performance.

Measured skid resistance numbers were also reviewed with the objective of establishing skid numbers versus cumulative VPPL relationships for each type of aggregate before the pavement had reached "terminal" conditions. However, it was readily noticed that development of any meaningful relationship was very difficult because of the large scatter that existed in the data. For example, Fig. 3.3 above shows that, at a VPPL value of 1.5 million, the measured SN-values on different pavements constructed using aggregate from this source varied between 30 and 65. If data from different aggregate sources of the same type (i.e. limestone) were to be combined, then the scatter would be even larger. For this reason, the idea of developing skid numbers versus cumulative VPPL relationships was not pursued any further. Nevertheless, the following general observations could be made in the SN versus VPPL plots prepared for different types of aggregates.

1. Limestone sources can yield high skid numbers (typically between 50 and 60) on new pavements; However, data showed that the skid numbers deteriorated significantly with increasing VPPL; After the pavement has sustained about 2-3million vehicle passes, the skid number reached their terminal value; A difference of 20 was not uncommon between initial skid number and the terminal value.

2. The deterioration of SN-values with increasing VPPL observed in Sandstones, Igneous Aggregates, Siliceous Gravels and Synthetic aggregates was much smaller when compared with limestones. The change in skid numbers was 10 or less.

The data used in the development of field skid histories are summarized in Table 3.2

Skid Performance Histograms

In the next step, terminal skid number measurements available for different types of aggregate were divided into classes of 20-25, 25-30, 30-35, 35-40 ….. etc. The percentage of skid data points falling within each class was then calculated. Skid performance histograms developed in this manner were used to compare the performance of different types of aggregate types. Figure 3.8 through 3.12 represent histograms developed for sandstones, limestones, igneous material, siliceous gravel, and synthetic material respectively.

The contrasting skid resistance performance provided by different types of aggregates can be readily seen in these figures. It is clear that synthetic aggregates are far superior to any other types of aggregates in terms of their frictional behavior. The synthetic aggregates did not have any terminal skid numbers falling below 45. The sandstones and igneous materials performed quite well. These two types of aggregates did not have any terminal SN measurements below 35. Gravel sources and Limestones showed the greatest scatter. They included sources that performed well but also included other sources that performed poorly. The limestone category had the largest percentage of “poor performing” aggregate sources. The limestones had the weakest performance with 35% of their terminal skid numbers falling below 35. Only 8% of terminal skid numbers measured on gravel sources fell below the same threshold. These sources are likely to be carbonate gravels.

The above comparison leads to the conclusion that skid performance concerns are largely limited to aggregate sources that belong to the limestone category. The only other aggregate type that included some sources with questionable skid resistance performance was the gravel category. It may be suspected that gravel sources that include significant percentage of carbonate materials are among the poor performers.

Table 3.2 Field Skid Performance Data

Aggregate Source: Delta
Pit: Brownlee
Material Type: Sandstone
Production Code: 1402704

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
17,270,400	48	2,740,690	42		
17,270,400	47	2,740,690	39		
17,270,400	54	2,740,690	41		
445,454	42				
445,454	41				
445,454	41				
445,454	40				
445,454	42				
1,555,520	38				
1,555,520	39				
1,555,520	36				
1,555,520	36				
1,555,520	36				
2,740,690	38				
2,740,690	40				

Aggregate Source: Meridian
Pit: Apple, Oklahoma
Material Type: Sandstone
Production Code: 50437

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
2,508,462	57	445454	64		
2,508,462	56	1555520	60		
2,903,538	60	1555520	58		
2,903,538	62	1555520	63		
2,903,538	59	1555520	62		
11,487,490	44	2740690	59		
11,487,490	53	2740690	58		
11,487,490	48	2740690	60		
13,503,770	50	2740690	55		
13,503,770	50	2740690	56		
13,503,770	49				
445454	59				
445454	57				
445454	61				
445454	61				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Hanson					
Pit: Little River					
Material Type: Gravel					
Production Code: 50114					
Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
2,869,250	51	1,555,520	45		
2,869,250	49	1,555,520	47		
2,869,250	49	1,555,520	49		
3,708,750	47	2,740,690	44		
3,708,750	46	2,740,690	46		
3,708,750	46	2,740,690	45		
1,819,238	37	2,740,690	45		
1,819,238	37	2,740,690	46		
1,819,238	38	445,454	50		
2,105,763	45	445,454	48		
2,105,763	45	445,454	50		
2,105,763	46	445,454	47		
6,984,018	48	445,454	47		
6,984,018	49	1,555,520	44		
6,984,018	51	1,555,520	43		
6,984,018	50	1,555,520	46		
16,146,000	43	1,555,520	48		
16,146,000	42	1,555,520	45		
16,146,000	42	2,740,690	41		
16,146,000	42	2,740,690	39		
8,366,000	49	2,740,690	39		
8,366,000	50	2,740,690	40		
8,366,000	46	2,740,690	40		
8,366,000	48				
10,081,500	45				
10,081,500	45				
10,081,500	44				
10,081,500	46				
445,454	49				
445,454	51				
445,454	50				
445,454	51				
445,454	54				
1,555,520	46				
1,555,520	42				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Fordyce
Pit: Showers
Material Type: Gravel
Production Code: 2110904

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
5,990,750	40	1,178,400	38	2,740,690	32
5,990,750	40	1,178,400	38	2,740,690	34
5,990,750	40	1,178,400	37	2,740,690	31
5,990,750	39	445,454	51	445,454	47
2,635,750	32	445,454	53	445,454	46
2,635,750	34	445,454	47	445,454	43
2,635,750	33	445,454	50	445,454	42
2,635,750	34	445,454	50	445,454	43
3,204,500	31	1,555,520	40	1,555,520	42
3,204,500	31	1,555,520	39	1,555,520	42
3,204,500	33	1,555,520	38	1,555,520	41
6,618,393	38	1,555,520	43	1,555,520	41
6,618,393	39	1,555,520	39	1,555,520	41
6,618,393	41	2,740,690	29	2,740,690	40
1,178,400	36	2,740,690	31	2,740,690	39

Aggregate Source: Upper Valley
Pit: D. Garcia
Material Type: Gravel
Production Code: 2110905

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
7,194,970	37	445,454	39	445,454	54
7,194,970	40	1,555,520	41	1,555,520	45
7,194,970	39	1,555,520	38	1,555,520	43
4,509,510	34	1,555,520	41	1,555,520	46
4,509,510	36	1,555,520	41	1,555,520	49
1,886,625	41	1,555,520	40	1,555,520	44
1,886,625	40	2,740,690	34	2,740,690	35
1,886,625	39	2,740,690	38	2,740,690	40
2,497,500	38	2,740,690	33	2,740,690	38
2,497,500	39	2,740,690	35	2,740,690	37
2,497,500	37	2,740,690	34	2,740,690	41
445,454	43	445,454	53		
445,454	47	445,454	51		
445,454	41	445,454	52		
445,454	39	445,454	55		

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Granite Mt.
Pit: Sweet Home
Material Type: Igneous
Production Code: 50106

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
383,900	52	2,740,690	51	445,454	50
383,900	51	2,740,690	53	445,454	50
383,900	53	2,740,690	54	445,454	50
383,900	49	2,740,690	52	1,555,520	46
515,900	57	445,454	59	1,555,520	39
515,900	52	445,454	60	1,555,520	41
515,900	50	445,454	62	1,555,520	42
515,900	50	445,454	57	1,555,520	41
677,600	47	445,454	59	2,740,690	45
677,600	46	1,555,520	45	2,740,690	49
677,600	47	1,555,520	45	2,740,690	45
677,600	45	1,555,520	44	2,740,690	50
4,854,000	41	1,555,520	44	2,740,690	42
4,854,000	42	1,555,520	45	677,600	47
4,854,000	45	2,740,690	45	383,900	52
4,854,000	43	2,740,690	43	515,900	57
5,574,000	43	2,740,690	51	677,600	46
5,574,000	42	2,740,690	48	383,900	51
5,574,000	41	2,740,690	51	515,900	52
5,574,000	39	445,454	50	677,600	47
6,462,000	42	445,454	49	515,900	50
6,462,000	42	445,454	47	383,900	53
6,462,000	45	445,454	53	677,600	45
6,462,000	45	1,555,520	50	383,900	49
445,454	49	1,555,520	49	515,900	50
445,454	50	1,555,520	47	4,854,000	41
445,454	52	1,555,520	53	6,462,000	42
445,454	50	1,555,520	38	5,574,000	43
445,454	49	2,740,690	39	5,574,000	42
1,555,520	48	2,740,690	40	4,854,000	42
1,555,520	42	2,740,690	39	6,462,000	42
1,555,520	46	2,740,690	38	5,574,000	41
1,555,520	45	2,740,690	39	6,462,000	45
1,555,520	45	445,454	48	4,854,000	45
2,740,690	50	445,454	51	5,574,000	39

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Trans-Pecos
Pit: Hoban
Material Type: Gravel
Production Code: 619502

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
1,889,301	51	2,740,690	52		
1,889,301	50	2,740,690	52		
1,889,301	51	2,740,690	51		
445,454	54				
445,454	53				
445,454	53				
445,454	57				
445,454	54				
1,555,520	49				
1,555,520	50				
1,555,520	53				
1,555,520	52				
1,555,520	51				
2,740,690	54				
2,740,690	53				

Aggregate Source: Meridian
Pit: Creek Trap
Material Type: Igneous
Production Code:50438

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
16,739,839	48	2,740,690	45		
16,739,839	51	2,740,690	48		
16,739,839	50	2,740,690	46		
18,057,527	47	2,740,690	48		
18,057,527	46	2,740,690	48		
18,057,527	47				
445,454	46				
445,454	47				
445,454	46				
445,454	46				
445,454	46				
1,555,520	44				
1,555,520	46				
1,555,520	47				
1,555,520	42				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Hanson
Pit: Nbfls
Material Type: Limestone
Production Code: 1504603

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
7,182,400	46	445,454	57		
7,182,400	44	445,454	56		
7,182,400	46	445,454	55		
7,182,400	43	445,454	62		
7,541,520	40	445,454	62		
7,541,520	41	1,555,520	49		
7,541,520	41	1,555,520	53		
7,541,520	41	1,555,520	49		
8,029,280	35	1,555,520	49		
8,029,280	37	1,555,520	50		
8,029,280	32	2,740,690	45		
8,029,280	35	2,740,690	44		
5,529,150	41	2,740,690	43		
5,529,150	43	2,740,690	42		
5,529,150	42	2,740,690	44		
5,529,150	42				
5,808,000	43				
5,808,000	45				
5,808,000	44				
5,808,000	44				
2,620,560	37				
2,620,560	36				
2,620,560	36				
715,000	36				
715,000	38				
715,000	37				
715,000	37				
334,800	40				
334,800	35				
334,800	40				
334,800	40				
974,100	64				
974,100	61				
974,100	63				
974,100	62				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Vulcan
Pit: FM 1604
Material Type: Limestone
Production Code: 1501506

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
243,535	38	2,740,690	28		
243,535	39	2,740,690	28		
243,535	35	2,740,690	32		
243,535	38				
445,454	30				
445,454	31				
445,454	28				
445,454	30				
1,555,520	29				
1,555,520	29				
1,555,520	28				
1,555,520	29				
1,555,520	29				
2,740,690	31				
2,740,690	30				

Aggregate Source: Jobe
Pit: McKelligon (Dolo)
Material Type: Limestone
Production Code:2407201

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
5,441,331	30	1,555,520	32	1,555,520	40
5,441,331	31	2,740,690	28	2,740,690	35
5,441,331	29	2,740,690	30	2,740,690	34
4,695,502	28	2,740,690	30	2,740,690	34
4,695,502	26	2,740,690	25	2,740,690	34
4,695,502	28	2,740,690	26	2,740,690	33
445,454	21	445,454	40		
445,454	38	445,454	45		
445,454	37	445,454	44		
445,454	36	445,454	44		
445,454	33	445,454	41		
1,555,520	30	1,555,520	41		
1,555,520	25	1,555,520	39		
1,555,520	29	1,555,520	40		
1,555,520	34	1,555,520	38		

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Luhr
Pit: Tower Rock
Material Type: Limestone
Production Code: 50601

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
3,402,471	44	1,555,520	37		
3,402,471	47	1,555,520	35		
3,402,471	46	1,555,520	36		
2,826,060	40	1,555,520	36		
2,826,060	44	2,740,690	37		
2,826,060	42	2,740,690	39		
4,044,233	44	2,740,690	37		
4,044,233	42	2,740,690	39		
4,044,233	45	2,740,690	41		
445,454	47				
445,454	46				
445,454	44				
445,454	46				
445,454	48				
1,555,520	37				

Aggregate Source: Price
Pit: Clement
Material Type: Limestone
Production Code:708802

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
5,617,404	27	2,740,690	25		
5,617,404	27	2,740,690	26		
5,617,404	25	2,740,690	26		
445,454	41	5,617,404	27		
445,454	39	5,617,404	27		
445,454	40	5,617,404	25		
445,454	40				
445,454	41				
1,555,520	29				
1,555,520	28				
1,555,520	30				
1,555,520	33				
1,555,520	32				
2,740,690	28				
2,740,690	28				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Pit: Beckman Material Type: Limestone Production Code: 1501503					
Field Skid Numbers					
VPPL	SN40	VPPL	SN40	VPPL	SN40
445,454	53	2,740,690	38	8,989,500	38
445,454	49	2,740,690	38	8,989,500	40
445,454	52	2,740,690	41	8,989,500	40
445,454	55	2,740,690	39	4,411,641	33
445,454	55	2,740,690	41	4,411,641	34
1,555,520	45	445,454	47	4,411,641	35
1,555,520	45	445,454	45	8,173,550	37
1,555,520	46	445,454	44	8,173,550	38
1,555,520	44	445,454	44	8,173,550	37
1,555,520	43	445,454	45	8,173,550	37
2,740,690	48	1,555,520	32	9,353,300	32
2,740,690	36	1,555,520	36	9,353,300	34
2,740,690	38	1,555,520	35	9,353,300	36
2,740,690	38	1,555,520	34	10,109,550	37
2,740,690	41	1,555,520	35	10,109,550	39
445,454	42	2,740,690	33	10,109,550	37
445,454	44	2,740,690	31	10,109,550	39
445,454	41	2,740,690	30	10,460,450	36
445,454	44	2,740,690	32	10,460,450	38
445,454	42	2,740,690	28	10,460,450	37
1,555,520	48	8,991,450	36	10,460,450	39
1,555,520	47	8,991,450	36	613,800	38
1,555,520	45	8,991,450	34	613,800	38
1,555,520	44	8,991,450	37	613,800	39
1,555,520		4,532,048	28	613,800	39
2,740,690	42	4,532,048	26	5,649,800	39
2,740,690	41	4,532,048	27	5,649,800	43
2,740,690	46	2,180,338	37	5,649,800	43
2,740,690	34	2,180,338	40	5,649,800	41
2,740,690	46	2,180,338	44	6,863,400	38
1,555,520	46	4,997,900	36	6,863,400	43
1,555,520	46	4,997,900	41	6,863,400	38
1,555,520	45	4,997,900	42	6,863,400	37
1,555,520	45	4,997,900	40	3,472,600	32
1,555,520	44	8,989,500	41	3,472,600	34

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: **Pit: Beckman** **Material Type: Limestone** **Production Code: 1501503**					
Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
3,472,600	34	1,921,650	42		
3,472,600	34	1,921,650	42		
4,209,800	31	1,921,650	43		
4,209,800	32	1,989,500	42		
4,209,800	32	1,989,500	38		
4,209,800	32	1,989,500	39		
2,562,200	32	1,989,500	41		
2,562,200	32	2,154,000	60		
2,562,200	33	2,154,000	62		
2,562,200	33	2,154,000	60		
2,985,500	33	2,154,000	58		
1,949,500	37				
2,985,500	31				
1,949,500	36				
2,985,500	32				
1,949,500	39				
2,985,500	35				
1,949,500	38				
1,253,250	36				
1,253,250	36				
1,253,250	36				
1,253,250	44				
1,088,100	37				
1,088,100	39				
1,088,100	41				
1,088,100	40				
324,810	38				
324,810	37				
324,810	37				
324,810	38				
1,451,300	50				
1,451,300	62				
1,451,300	58				
1,451,300	58				
1,921,650	44				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Vulcan
Pit: Black
Material Type: Limestone
Production Code: 822107

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
10,333,198	23	2,740,690	22	2,740,690	28
10,333,198	26	2,740,690	27	2,740,690	26
10,333,198	28	2,740,690	28	2,740,690	26
445,454	38	445,454	36		
445,454	36	445,454	36		
445,454	38	445,454	34		
445,454	39	445,454	34		
445,454	36	445,454	38		
1,555,520	24	1,555,520	23		
1,555,520	25	1,555,520	21		
1,555,520	23	1,555,520	22		
1,555,520	26	1,555,520	21		
1,555,520	23	1,555,520	22		
2,740,690	28	2,740,690	27		
2,740,690	23	2,740,690	25		

Aggregate Source: TXI
Pit: Streetman
Material Type: Synthetic
Production Code:1817502

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
9,055,361	64	5,207,873	59	5,448,240	67
9,055,361	65	5,207,873	58	5,448,240	69
9,710,874	52	5,207,873	57	5,448,240	70
9,710,874	52	3,573,360	62	5,448,240	70
9,710,874	53	3,573,360	60		
10,111,143	61	3,573,360	50		
10,111,143	58	3,573,360	56		
10,111,143	59	3,632,160	67		
10,111,143	60	3,632,160	64		
4,673,581	59	3,632,160	61		
4,673,581	57	3,632,160	63		
4,673,581	58	5,360,040	48		
5,005,312	54	5,360,040	46		
5,005,312	54	5,360,040	46		
5,005,312	53	5,360,040	47		

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Colorado Matls.
Pit: Hunter
Material Type: Limestone
Production Code: 1504605

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
6,860,700	35	625,100	34	15,324,560	34
6,860,700	38	625,100	35	1,700,300	32
6,860,700	37	625,100	37	1,700,300	37
7,087,500	38	2,145,000	31	1,700,300	35
7,087,500	39	2,145,000	27	1,700,300	36
7,087,500	38	2,145,000	29	2,799,525	38
7,418,250	41	2,145,000	32	2,799,525	38
7,418,250	40	25,756,171	33	2,799,525	38
7,418,250	40	25,756,171	30	2,799,525	39
8,155,350	34	25,756,171	31	5,410,200	30
8,155,350	34	26,198,531	39	5,410,200	32
8,155,350	33	26,198,531	37	5,410,200	34
8,155,350	34	26,198,531	34	5,410,200	37
4,008,275	47	26,821,445	44	206,700	53
4,008,275	47	26,821,445	41	206,700	46
4,008,275	48	26,821,445	39	206,700	47
4,008,275	47	27,516,582	38	206,700	48
4,477,275	43	27,516,582	36	206,700	47
4,477,275	44	27,516,582	34	206,700	48
4,477,275	44	4,683,000	44	206,700	47
4,477,275	45	4,683,000	45	206,700	49
4,644,000	33	4,683,000	45	147,000	58
4,644,000	32	4,683,000	46	147,000	53
4,644,000	32	13,892,900	36	147,000	55
6,060,000	34	13,892,900	37	147,000	52
6,060,000	36	13,892,900	35	6,655,200	40
6,060,000	36	13,892,900	37	6,655,200	40
6,984,000	32	14,214,020	40	6,655,200	42
6,984,000	34	14,214,020	40	6,655,200	42
6,984,000	35	14,214,020	41	7,367,250	37
2,261,600	47	14,767,060	39	7,367,250	37
2,261,600	49	14,767,060	38	7,367,250	38
2,261,600	48	14,767,060	35	7,367,250	37
2,261,600	48	15,324,560	35	3,541,725	36
625,100	37	15,324,560	36	3,541,725	37

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Colorado Matls.
Pit: Hunter
Material Type: Limestone
Production Code: 1504605

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
3,541,725	35	699,200	45		
3,541,725	35	699,200	44		
3,944,525	27	1,354,100	32		
3,944,525	30	1,354,700	32		
3,944,525	29	1,354,700	32		
3,944,525	32	1,354,700	35		
2,140,925	46	578,200	36		
2,140,925	45	578,200	37		
2,140,925	46	578,200	37		
1,979,250	31	578,200	38		
1,979,250	32	289,800	53		
1,979,250	28	289,800	51		
1,979,250	30	289,800	51		
2,404,100	29	289,800	49		
2,404,100	29				
2,404,100	27				
2,404,100	28				
7,454,300	31				
7,454,300	31				
7,454,300	31				
7,454,300	30				
8,199,500	32				
8,199,500	34				
8,199,500	32				
8,199,500	32				
8,378,900	32				
8,378,900	32				
8,378,900	32				
8,378,900	32				
2,450,370	34				
2,450,370	33				
2,450,370	34				
2,450,370	35				
699,200	47				
699,200	46				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Hanson
Pit: Bridgeport
Material Type: Limestone
Production Code: 224902

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
3,867,250	30	2,464,400	38	3,420,000	29
3,867,250	30	1,589,000	36		
3,867,250	29	1,589,000	37		
3,867,250	28	1,589,000	35		
1,888,700	37	3,420,000	26		
3,232,000	37	3,420,000	26		
2,464,400	39	3,420,000	26		
3,232,000	37	3,420,000	26		
1,888,700	37	5,281,625	34		
2,464,400	39	5,281,625	32		
3,232,000	37	5,281,625	34		
1,888,700	38	5,281,625	34		
2,464,400	46	3,420,000	29		
1,888,700	35	3,420,000	29		
3,232,000	37	3,420,000	29		

Aggregate Source: Alamo
Pit: Weir
Material Type: Limestone
Production Code:1424603

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
3,573,360	46	5,448,240	33		
3,573,360	43				
3,573,360	46				
3,573,360	47				
3,632,160	46				
3,632,160	45				
3,632,160	45				
3,632,160	45				
5,360,040	35				
5,360,040	37				
5,360,040	32				
5,360,040	33				
5,448,240	36				
5,448,240	37				
5,448,240	31				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Vulcan
Pit: Smyth
Material Type: Limestone
Production Code: 1523205

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
3,573,360	60	127,600	74		
3,632,160	65	127,600	65		
3,632,160	51	2,800	73		
3,573,360	60	127,600	73		
3,632,160	49	127,600	73		
3,573,360	58	1,547,000	51		
3,632,160	56	1,547,000	55		
3,573,360	59	1,547,000	54		
5,448,240	50	1,547,000	56		
5,360,040	63	4,952,000	36		
5,448,240	48	5,648,000	37		
5,360,040	64	4,952,000	38		
5,448,240	45	5,648,000	39		
5,360,040	63	2,154,250	45		
5,448,240	49	2,154,250	45		
5,360,040	64	2,154,250	44		
127,600	64	2,154,250	43		
127,600	66	628,150	28		
127,600	66	628,150	43		
127,600	57	628,150	42		
127,600	62	406,450	29		
127,600	66	406,450	37		
127,600	62	406,450	39		
127,600	73	406,450	37		
127,600	72	2,820,300	55		
127,600	75	2,820,300	47		
127,600	75	2,820,300	54		
127,600	66	2,820,300	55		
127,600	66	127,600	66		
127,600	57	127,600	62		
127,600	62	127,600	75		
127,600	63	2,751,250	60		
127,600	59	2,751,250	61		
127,600	71	2,751,250	57		
127,600	72	2,751,250	62		

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Wright Matls.
Pit: Realitos
Material Type: Gravel
Production Code: 2106701

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
9,096,300	41	2,573,550	50		
9,096,300	41	2,573,550	54		
9,096,300	41	2,573,550	57		
9,096,300	42	2,573,550	51		
10,376,100	40	1,751,600	43		
10,376,100	40	1,751,600	43		
10,376,100	42	1,751,600	43		
10,376,100	41	1,751,600	43		
1,680,075	45	1,500,075	47		
1,680,075	44	1,500,075	46		
1,680,075	45	1,500,075	45		
1,680,075	45	1,500,075	45		
2,127,525	49	1,966,200	43		
2,127,525	47	1,966,200	43		
2,127,525	49	1,966,200	42		
6,519,540	57	2,474,700	45		
6,519,540	54	2,474,700	45		
6,519,540	62	2,474,700	45		
6,519,540	59	2,474,700	43		
7,121,700	53				
7,121,700	54				
7,121,700	55				
7,121,700	55				
7,812,640	57				
7,812,640	59				
7,812,640	60				
7,812,640	57				
4,142,220	46				
4,142,220	42				
4,142,220	47				
4,142,220	47				
4,579,760	42				
4,579,760	41				
4,579,760	44				
4,579,760	39				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Martin M
Pit: Creek Trap
Material Type: Igneous
Production Code: 50438

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
1,589,000	46				
1,589,000	47				
1,589,000	51				
1,589,000	46				

Aggregate Source: Hanson
Pit: Davis
Material Type: Igneous
Production Code: 50439

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
1,589,000	46				
1,589,000	47				
1,589,000	51				
1,589,000	46				

Aggregate Source: Vulcan
Pit: Kelly
Material Type: Limestone
Production Code: 218409

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
1,589,000	35				
1,589,000	35				
1,589,000	37				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: E.D. Baker **Pit: Creek Trap** **Material Type: Igneous** **Production Code: 50438**					
Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
1,553,116	51				
1,553,116	50				
1,553,116	52				

Aggregate Source: Vulcan **Pit: Tehuacana** **Material Type: Limestone** **Production Code: 914708**					
Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
13,789,295	38				
13,789,295	38				
13,789,295	38				
15,698,582	32				
15,698,582	31				
15,698,582	32				
Aggregate Source: Vulcan **Pit: Knippa** **Material Type: Igneous** **Production Code: 1523206**					
Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
29,923,367	41				
29,923,367	43				
29,923,367	43				
30,788,118	42				
30,788,118	48				
30,788,118	44				

Table 3.2 Field Skid Performance Data (continued)

Aggregate Source: Valley Caliche
Pit: Beck
Material Type: Gravel
Production Code: 2110901

Field Skid Numbers					
VPPL	**SN40**	**VPPL**	**SN40**	**VPPL**	**SN40**
13,290,000	37	1,461,000	41		
12,380,000	41	1,461,000	41		
13,290,000	37	1,461,000	41		
12,380,000	41	984,800	50		
11,263,000	39	984,800	50		
11,263,000	38	984,800	50		
6,380,500	36	984,800	50		
6,380,500	38				
6,380,500	40				
6,380,500	37				
5,482,500	36				
5,482,500	35				
5,482,500	36				
5,482,500	37				
1,461,000	41				

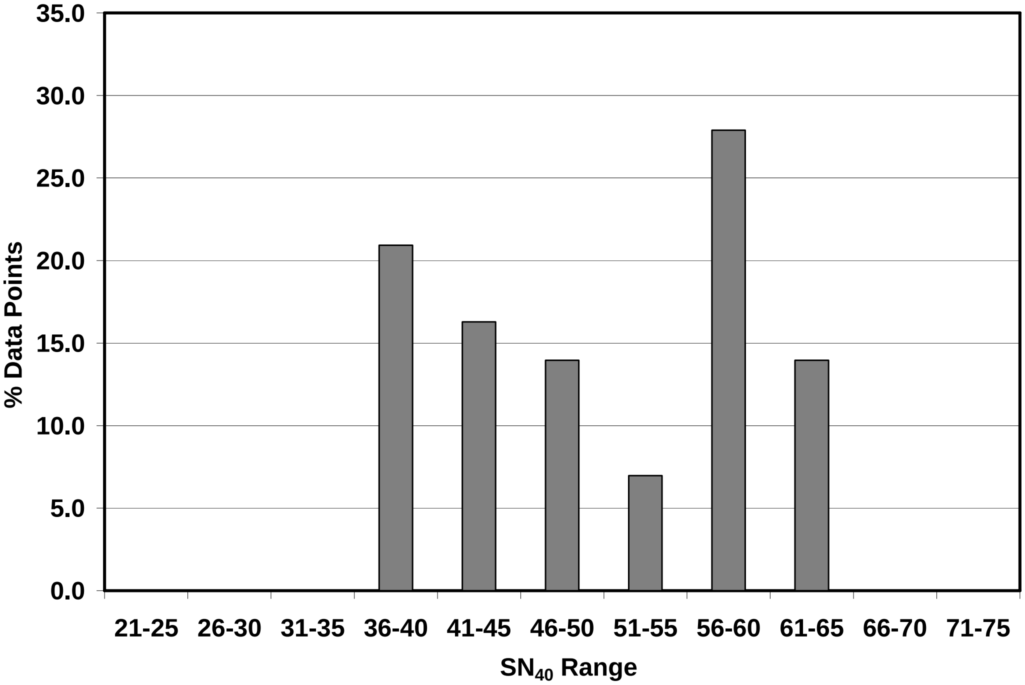


Figure 3.8 Skid Performance Histogram for Sandstone Aggregates

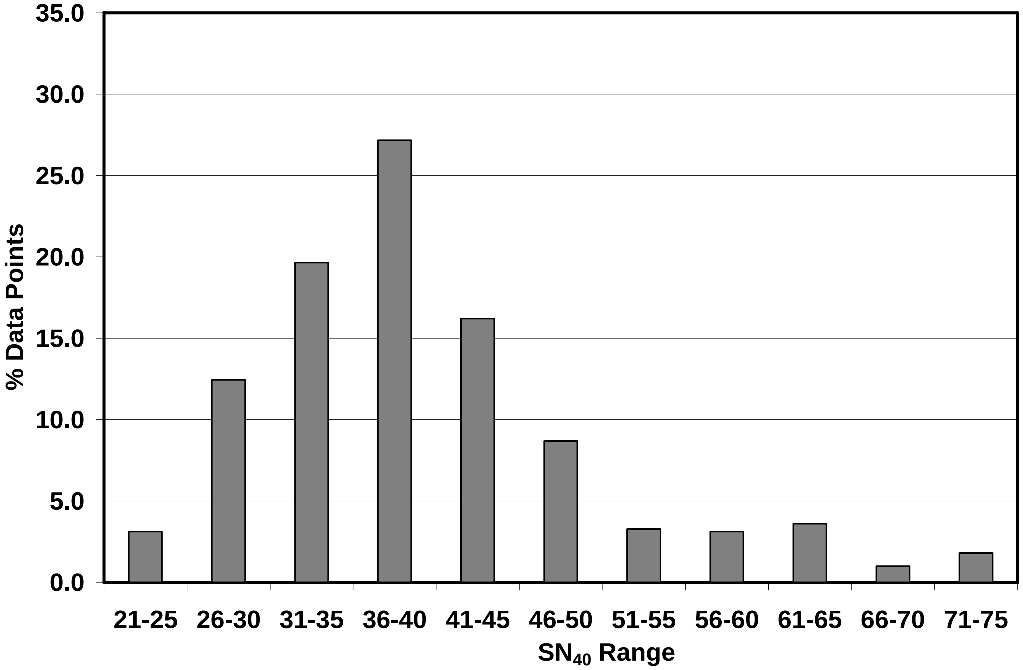


Figure 3.9 Skid Performance Histogram for Limestone Aggregates

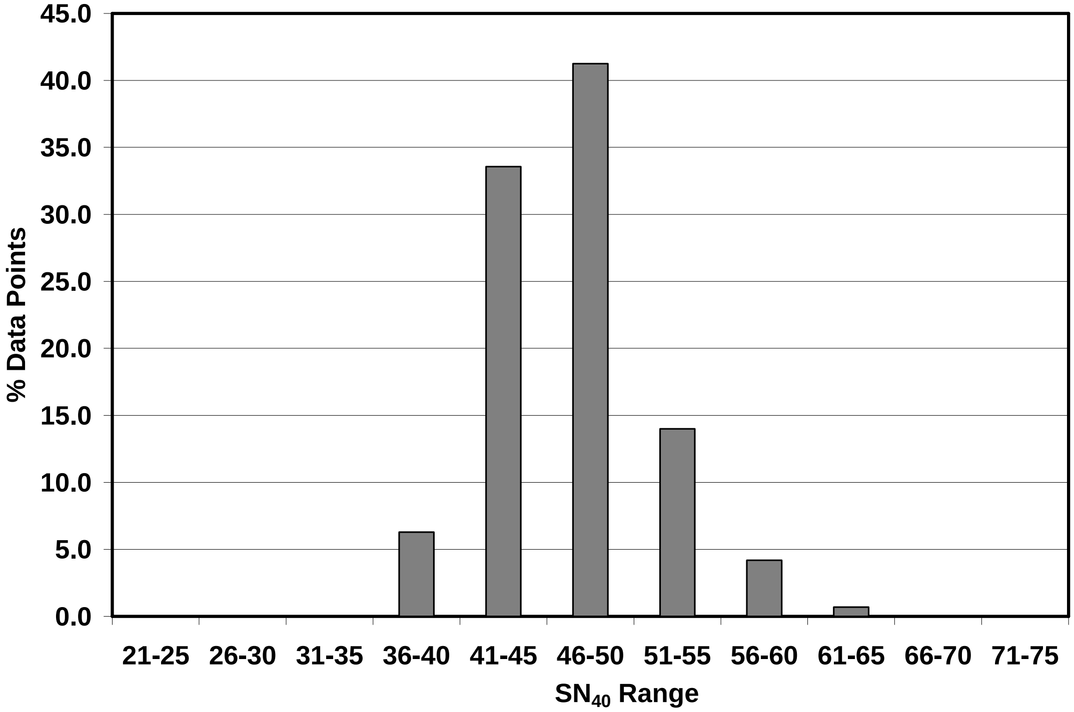


Figure 3.10 Skid Performance Histogram for Igneous Materials

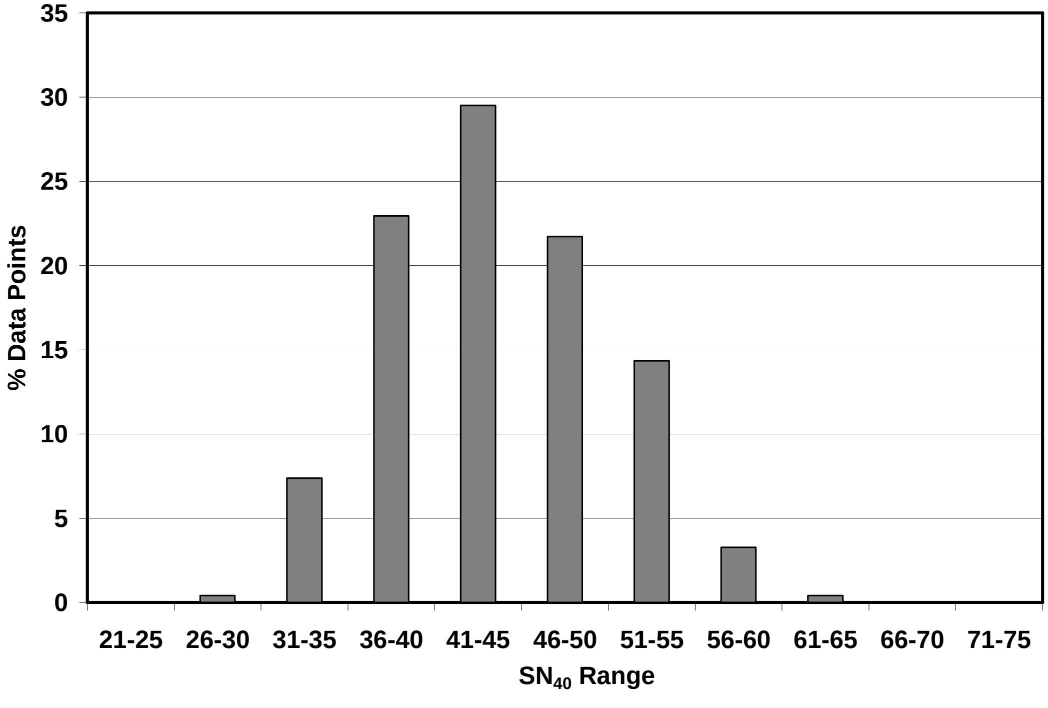


Figure 3.11 Skid Performance Histogram for Gravel Materials

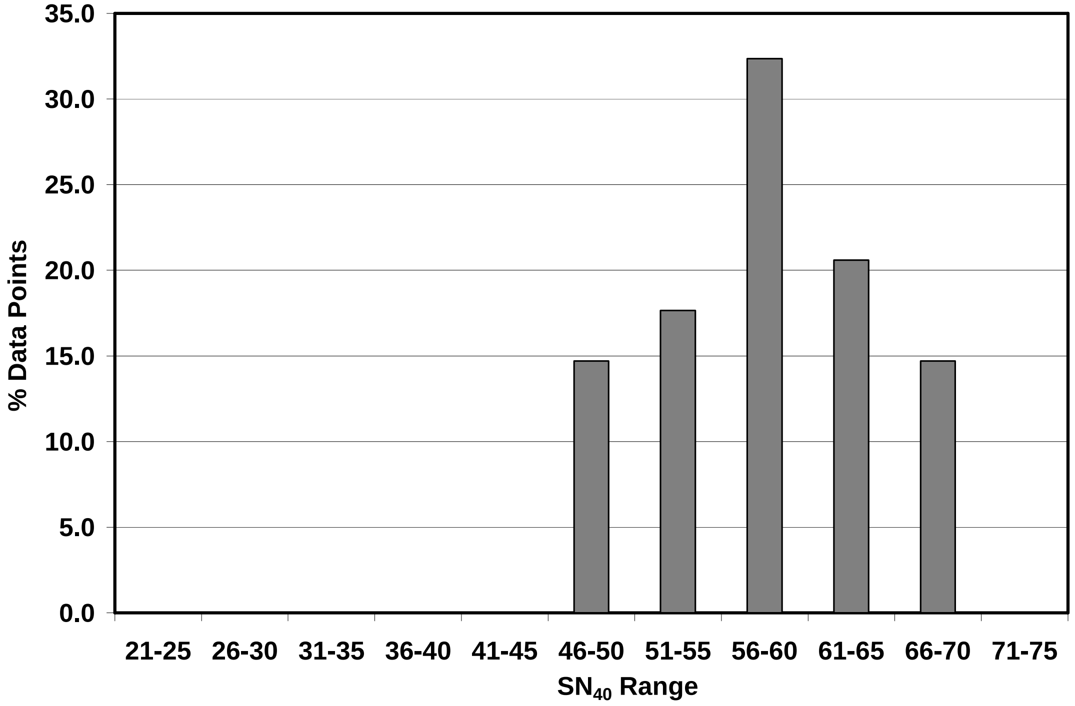


Figure 3.12 Skid Performance Histogram for Synthetic Materials

CHAPTER 4

DEVELOPMENT OF LAB -FIELD CORRELATIONS

OVERVIEW

Chapter 2 of this report examined the performance of TxDOT bituminous coarse aggregate sources in a number of lab test procedures used by TxDOT in its aggregate quality monitoring program. Chapter III reviewed their terminal skid resistance performance in the field. The next step in this research involved the development of correlations between the aggregate performance in the lab versus its performance in the field. The primary objective of this research task was to identify which lab tests provided the best correlation with field skid resistance performance of aggregates. Finally correlations were used as the basis for verification of TxDOT's WWARP aggregate classification system.

One of the difficulties the researchers encountered during this process was the lack of necessary laboratory data for the aggregate material for which terminal skid data was available. The missing lab data included Micro-Deval and Residual Polish Values. These tests were not in use at the time of construction of these test pavement sections. Therefore, these test parameters had to be "deduced" or "estimated" based on other information available for the same aggregate source. The procedures used in the estimation of MD and Residual PV values are described in Section 4.2 below. The number of sources for which MD and Residual PV values could be reliably determined was limited. The total number of aggregate sources for which complete and reliable set of lab and field data were available was 27.

ESTIMATION OF MICRO-DEVAL AND RESIDUAL POLISH VALUES

Estimation of Micro-Deval Test Values

TxDOT began using the Micro-Deval test method in its aggregate quality control monitoring program only recently. All of the pavement sections monitored in Project 0-1459 and many of the sections monitored in 7-3994 were constructed prior to the implementation of MD-test. Therefore, the material used in the construction of these test pavement sections had not been tested using MD-test. The only aggregate durability test that was used at that time was the 5-cycle MSS-test. Therefore, the MSS-test data was available for the aggregate source.

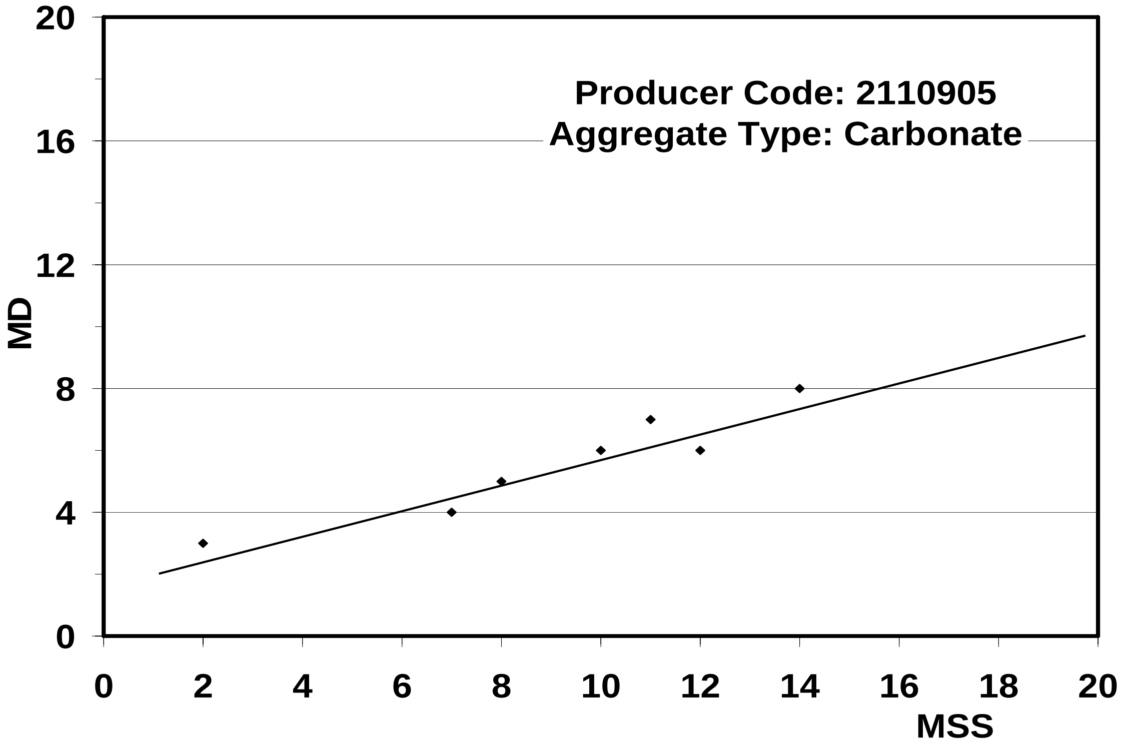
Fortunately, the TxDOT AQMP database described in Chapter II contained both MSS and MD-test data for the same aggregate sources based on tests conducted in 1998, 1999 and 2000. These data enabled the development of relationships between the MD and MSS tests for the aggregate sources in question. Once the MSS-MD relationships were developed, they were used as the basis for estimating the MD-value from the MSS-data. The estimated MD-values were then assumed to be representative of the material produced at that aggregate source at the time of construction of the pavement test section. Figure 4.1 demonstrates the above procedure for estimating MD-values.

Estimation of Residual Polish Values

The general procedure used in the estimation of Residual Polish Values was very similar to the one described in the section above. Residual polish value was introduced into the TxDOT AQMP based on recommendations from Project 7-3994. Therefore, the pavements sections monitored in 0-1459 and 7-3994 did not have Residual PV data for the materials used in test pavement construction. But they did have standard polish value data.

As a first step, the available data were reviewed with the objective of developing correlations between standard versus residual polish values. The Residual versus standard polish value scatter plot obtained for all aggregate sources tested at Texas Tech is shown in Figure 4.2 below. It suggests that reasonable estimates of the residual polish value could be obtained when the standard polish value is known.

Alternatively, the relationship between residual PV and standard PV could be developed on a source-by-source basis. Figure 4.3 shows two such examples of Residual versus Standard PV plots developed for 2 aggregate sources. The residual polish values are then deduced using the known values of standard polish value. This latter approach, which is similar to that used in the estimation of MD values, was used in the present analysis.



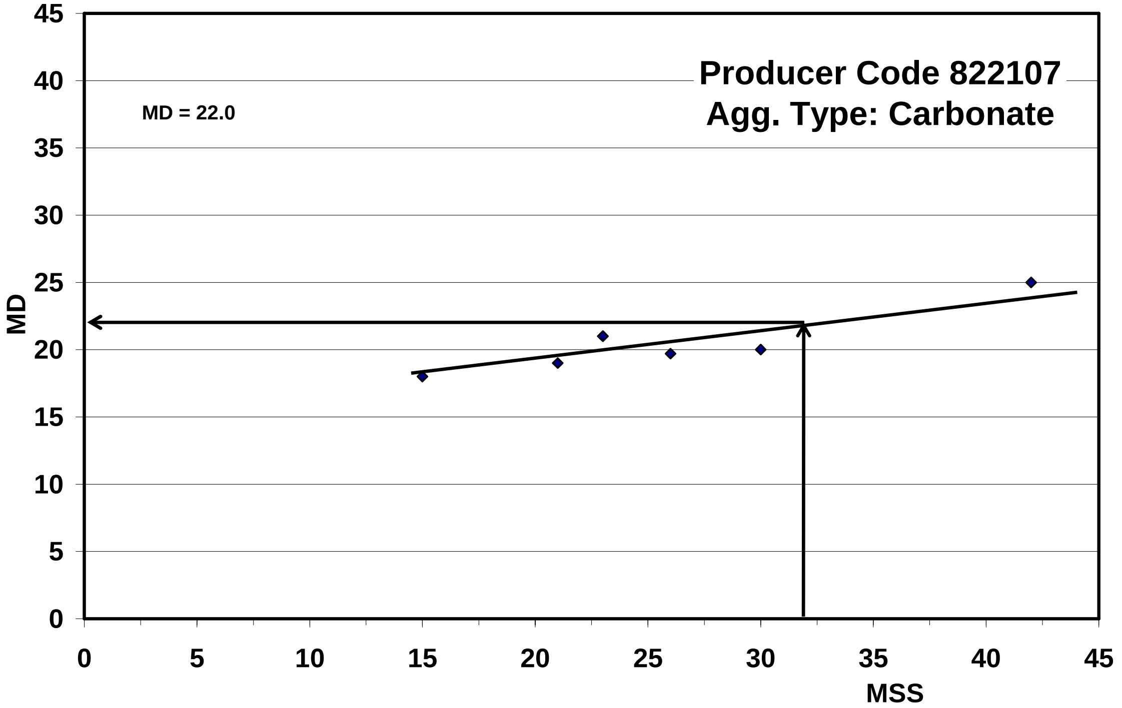


Figure 4.1 Estimation of MD-Value from MD-MSS Relationships for Two Aggregate Sources

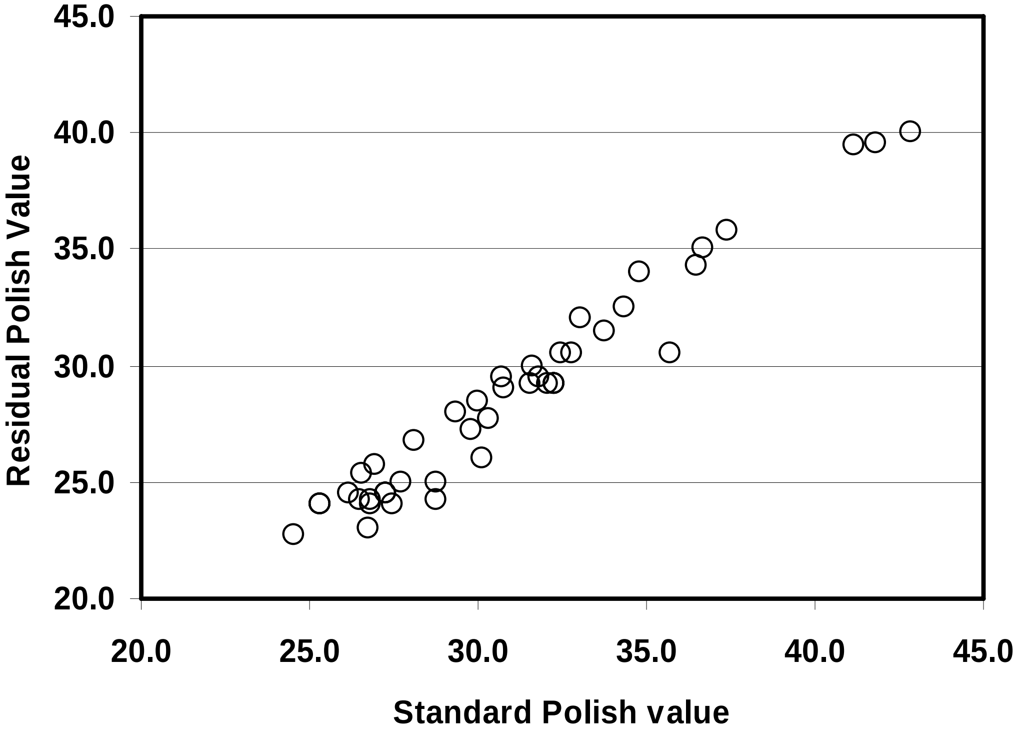


Figure 4.2 Relationship between Standard and Residual Polish Value

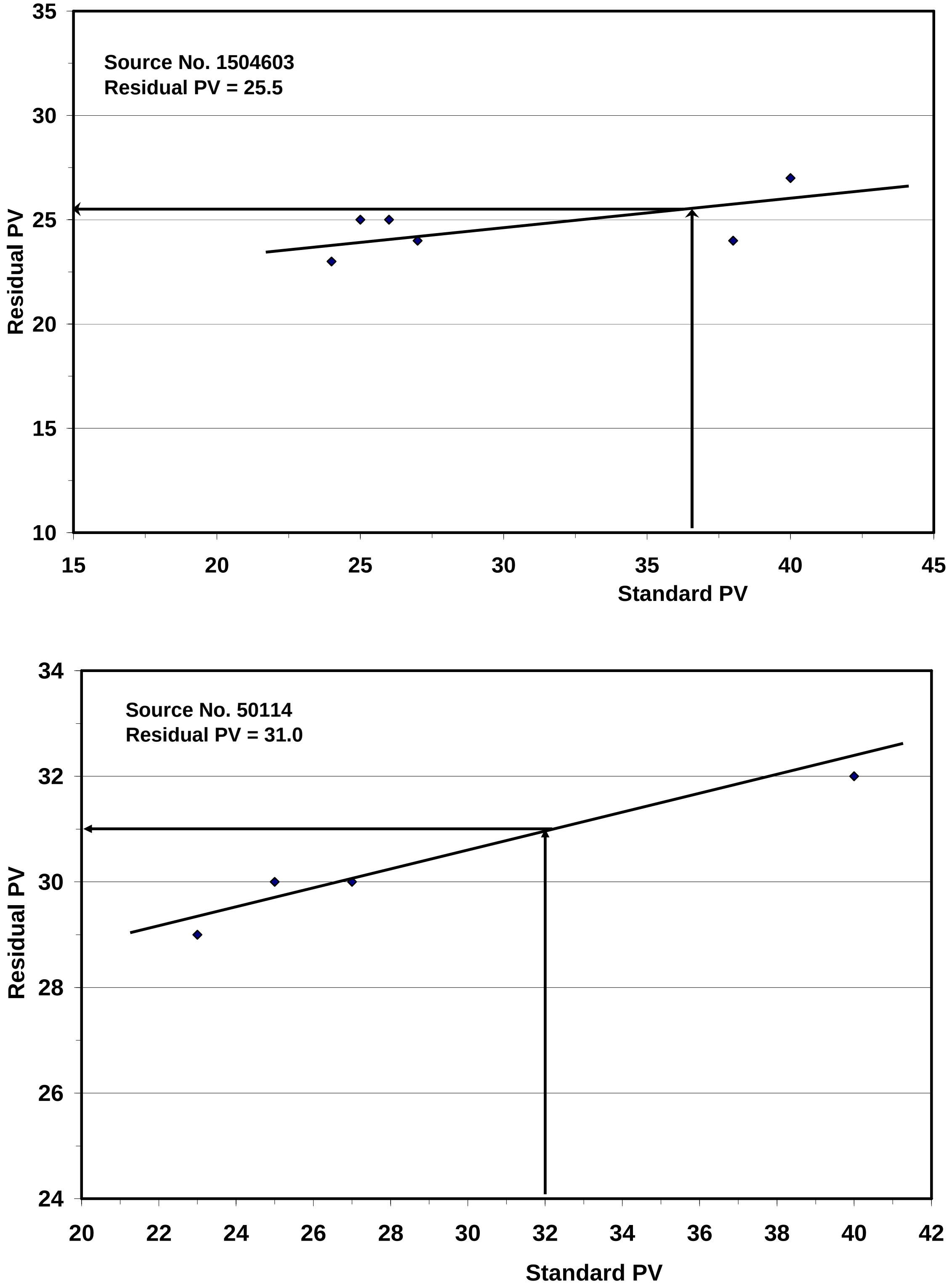


Figure 4.3 Estimation of Residual PV-Values from Residual PV-Standard PV Relationships for Two Aggregate Sources

Correlations between Aggregate Lab Performance and Field Performance

The next major task in this research project involved review of laboratory and field performance data for selected aggregate sources so that correlations between these could be developed. Field performance data consisted of terminal skid resistance measurements made with the locked wheel skid trailer. The procedure used in the analysis of the skid data was described in Chapter 3. However, for the purpose of lab-field correlations it was necessary to come up with a single parameter that represents the aggregate's performance in the field. For this purpose one could use the mean value of all skid measurements that represent terminal skid condition. However, the terminal skid data available for some aggregate sources showed larger scatter than others. As an example one may compare the two skid performance histories shown in Figure 3.4 and Figure 3.6. Tighter spread of data provides greater degree of confidence on the measured aggregate performance. Therefore, instead of using the mean value of the skid measurements, the lower quartile (or 25th percentile) was used in the present analysis. This number was calculated according Equation (4.1) below.

$$(TSN)_{25} = \overline{TSN} - 0.675\ \ (SD) \tag{4.1}$$

where:

$(TSN)_{25}$ = 25th Percentile of terminal skid number measurements

$\overline{(TSN)}$ = mean value of terminal skid number measurements

SD = standard deviation of terminal skid number measurements

The 25th Percentiles of terminal skid number measurements calculated for each of the 27 aggregate sources are shown in Table 4.1. The table also includes the laboratory parameters for each aggregate source.

In the next step, $(TSN)_{25}$ values are plotted against each of the laboratory parameters. Figures 4.4, 4.5, 4.6, and 4.7 show the relationship between the terminal skid number and the residual PV, percent MSS loss, percent MD loss and percent AIR respectively. The following conclusions can be made based on the review of these plots.

(a) One observation that can be made very easily is that carbonate aggregates (i.e. limestones and limestone-dolomites) showed the worst performance among all

Table 4.1 Laboratory and Field Performance Parameters for the 27 Sources Selected for Development of Correlations

Source	Pit	Material Type	Prod Code	Terminal Skid No.	Residual PV	%Loss MSS	%Loss MD	% AIR
Vulcan	Smyth	Carbonate	1523205	42.1	34.0	21.4	20.5	9.1
Hanson	Nbfls	Carbonate	1504603	38.7	25.0	9.1	16.0	3.2
Luhr	Tower Rock	Carbonate	50601	34.6	29.0	19.3	19.6	2.9
Alamo	Weir	Carbonate	1424603	34.7	30.0	20.3	24.0	4.8
Hanson	Bridgeport	Carbonate	224902	32.8	28.8	18.1	19.8	2.5
???	Beckmann	Carbonate	1501503	34.4	28.9	17.8	22.1	1.5
Vulcan	Fm 1604	Carbonate	1501506	26.8	28.6	18.6	19.2	3.9
Jobe	McKelligon(Dolo	Carbonate	2407201	27.5	27.1	6.5	10.8	14.6
Vulcan	Black	Carbonate	822107	24.0	27.0	26.1	20.5	1.0
Price	Clement	Carbonate	708802	25.6	30.2	25.5	22.4	2.4
Colorado Mtrls	Hunter	Carbonate	1504605	33.9	25.3	20.2	20.2	4.2
Vulcan	Kelly	Carbonate	218409	30.9	25.1	7.8	14.0	2.8
Vulcan	Tehuacana	Carbonate	914708	32.5	36.7	6.7	18.0	12.0
Meridian	Apple, OK	Sandstone	50437	47.0	36.0	9.3	8.0	98.3
Delta	Brownlee	Sandstone	1402704	47.1	39.0	8.0	11.0	63.3
Valley Caliche	Beck	Gravel	2110901	36.4	28.4	7.0	5.6	88.0
Fordyce	Showers	Gravel	2110904	35.6	28.3	2.9	3.0	88.6
Upper Valley	D. Garcia	Gravel	2110905	38.9	31.0	9.1	5.6	86.7
Wright Mtrls	Realitos	Gravel	2106701	43.3	26.5	1.5	1.9	97.1
Trans-Pecos	Hoban	Gravel	619502	45.7	35.0	6.8	6.0	97.4
Hanson	Little River	Gravel	50114	44.2	31.0	5.0	4.0	97.8
E.D. Baker	Johnson	Gravel	4118702	37.5	32.0	5.9	7.4	95.3
Meridian	Mill Creek Trap	Igneous	50438	46.9	35.0	2.0	7.0	95.3
Vulcan	Knippa	Igneous	1523206	41.9	32.5	5.4	7.8	96.2
Granite Mt	Sweet Home	Igneous	50106	41.3	29.0	3.0	4.0	95.7
Hanson	Davis	Igneous	50439	42.8	35.0	3.4	6.5	92.2
TXI	Streetman	Synthetic	1817502	52.8	50.0	2.3	17.4	97.7

Note: The residual PV values and % Loss MD values shown in this table are estimated parameters; they have been deduced through residual PV- standard PV and %Loss MD - %Loss MSS correlations developed for that specific aggregate source.

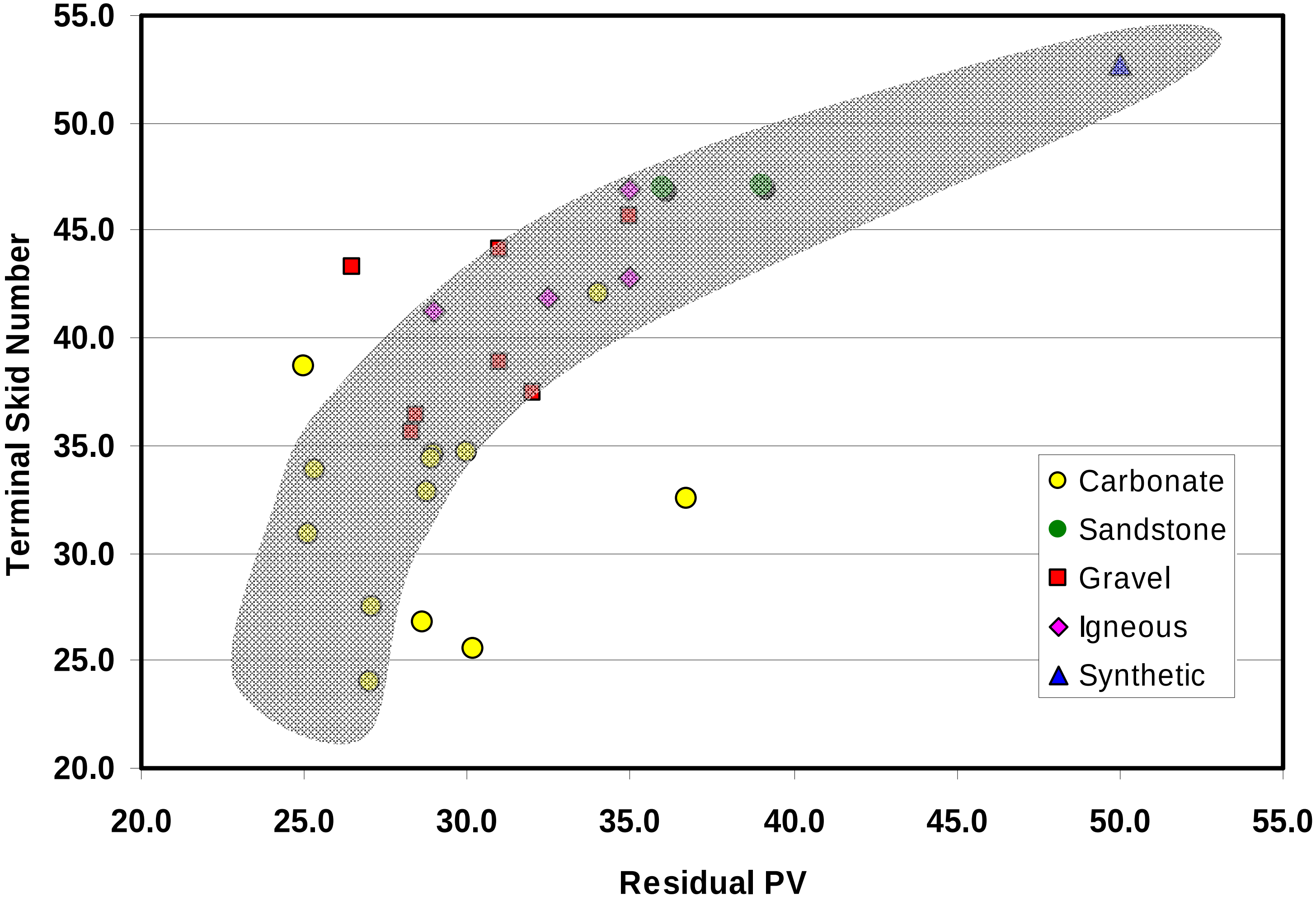


Figure 4.4 Relationship between Aggregate Residual PV and Terminal Skid Number

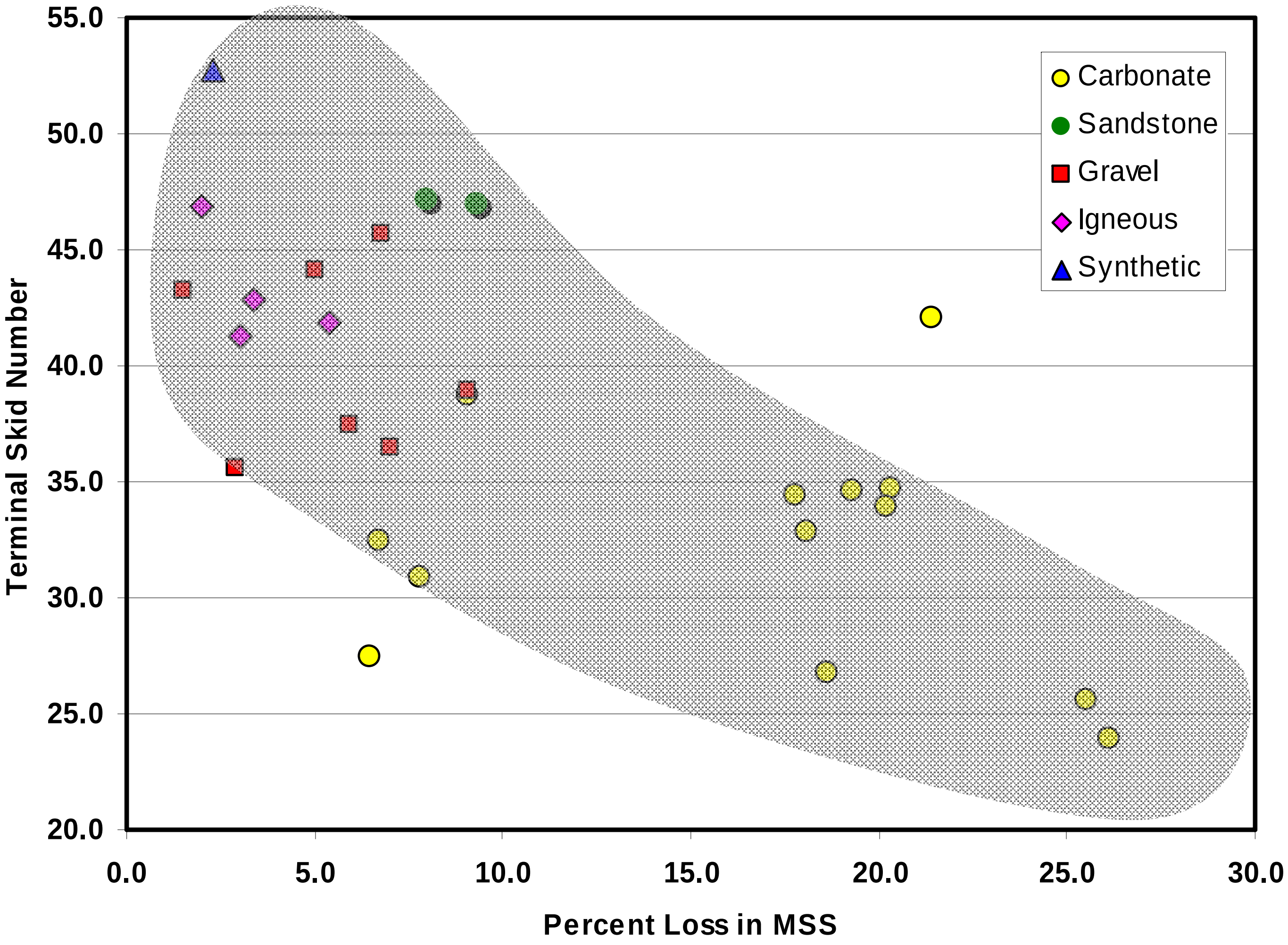


Figure 4.5 Relationship between Aggregate MSS Loss and Terminal Skid Number

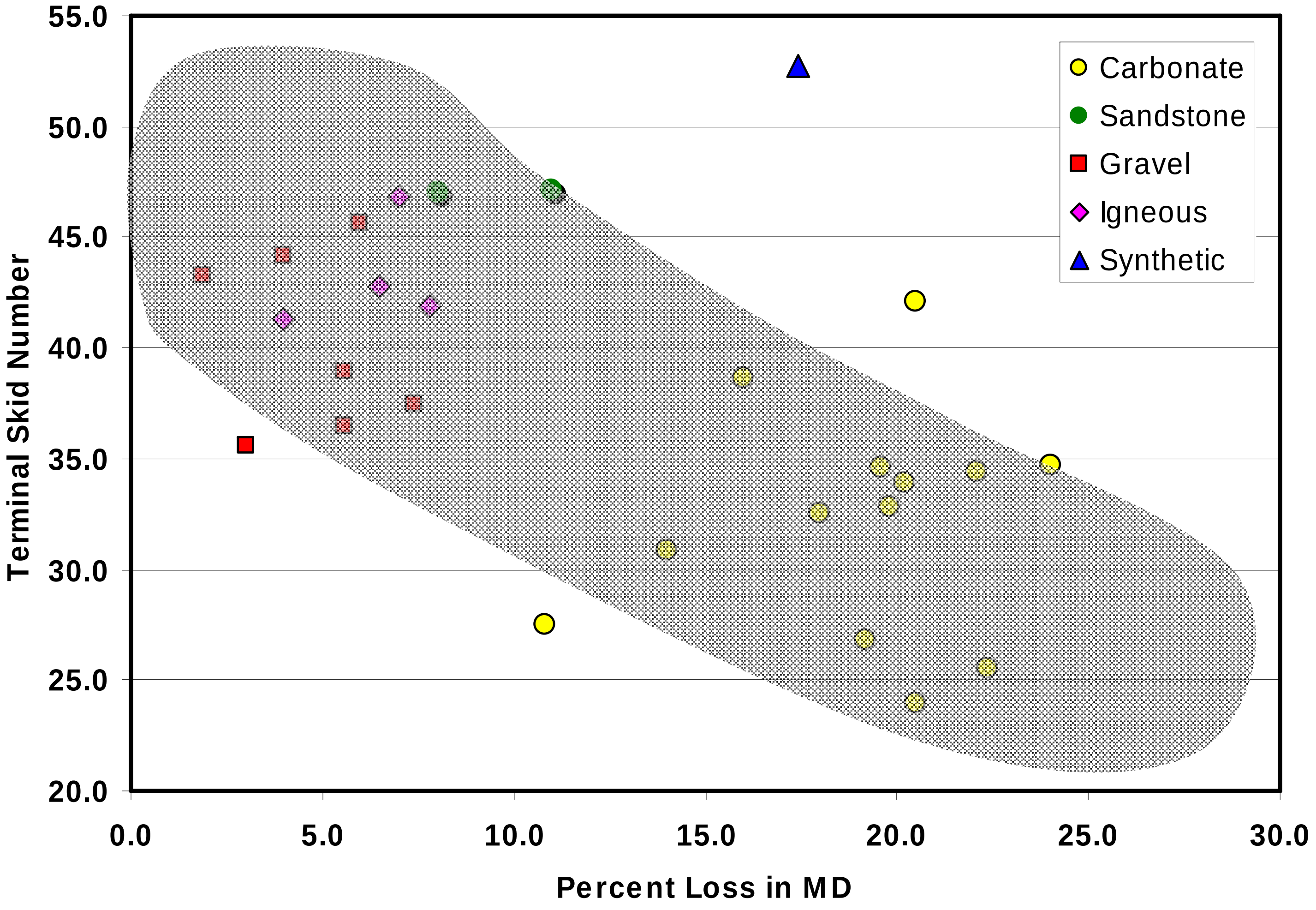


Figure 4.6 Relationship between Aggregate MD Loss and Terminal Skid Number

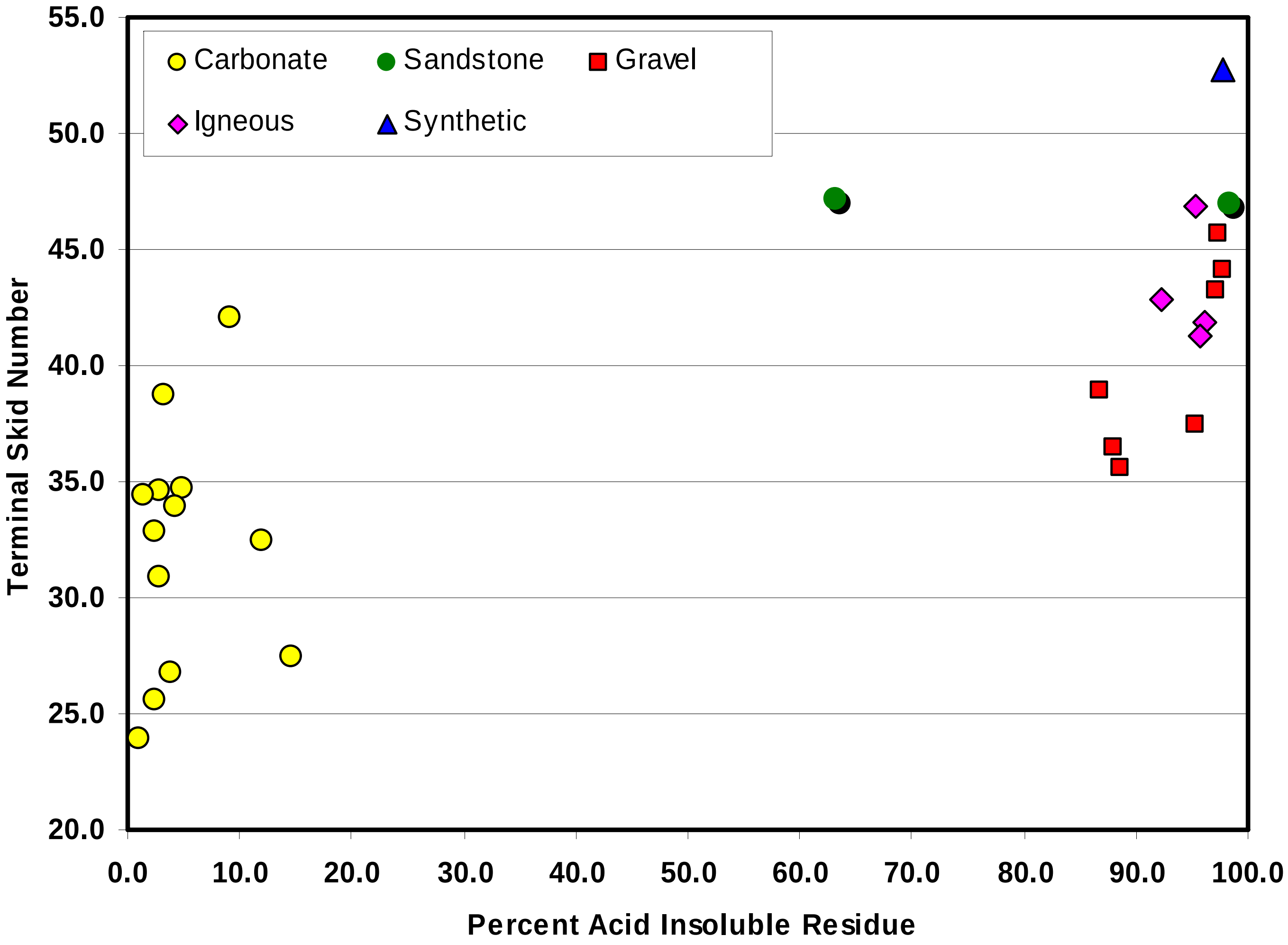


Figure 4.7 Relationship between Aggregate AIR and Terminal Skid Number

different types of aggregate. None of the other aggregate types showed *unsatisfactory* skid resistance behavior. If the different aggregate types are ranked based on performance synthetic aggregates will rank best, followed by sandstones, then igneous material, then gravel and finally carbonates.

(b) It is significant to note that among the 27 sources evaluated, 11 sources recorded TSN values of 35 or less. All 11 sources belonged to the carbonate category. Therefore this category requires special scrutiny.

(c) In the absence of aggregate petrography the AIR test can be used to separate this category of aggregates from others. None of the test parameters provide a tight correlation between aggregate lab performance versus field performance. This, however, should not be viewed as a limitation of the test method only. Poor reliability of field measurement of skid resistance also contributes significantly to the weak correlation.

(d) Although, tight correlations do not exist, terminal skid numbers show definite relationship with residual polish value, percent MSS loss and percent MD loss. They increase with increasing residual PV, and decreasing MSS and MD losses. Shaded region shown on each plot highlights these data trends.

(e) The limited data set suggests that “good performers” can be separated by using either AIR or MD loss. For example, all aggregate sources with AIR of at least 80% provided a terminal skid number of 35 or greater. Similarly, all aggregate sources with MD loss of 10% or less also provided a terminal skid number of 35 or greater.

(f) However, the same or an alternative threshold could not used to identify “poor performers.” For example, even the group of aggregate sources with AIR between 0-5% included some “satisfactory” and some “good performers.”

(g) Residual PV test showed particularly poor correlation with actual performance in the PV range of 25-30. The plot shows that this group included aggregate sources that can be considered “excellent performers” as well as “very poor performers.”

To verify the TxDOT’s aggregate classification procedure, the 27 aggregate sources were then categorized into excellent, very good, good, fair/poor categories based on their terminal skid number. Table 4.2 shows performance criteria used for the above categorization. It should be noted, however, that there is no direct correspondence between these performance categories and TxDOT WWARP classes A, B, C and D. Since the skid data were collected from in-service pavements, it is likely that all of these aggregate sources would either belong to TxDOT classification A or B.

Table 4.2 Aggregate Source Classification Based on Field Performance

Range of TSN	Aggregate Source Classification
TSN > 40	Excellent
35 < TSN < 40	Very Good
30 < TSN < 35	Good
TSN <30	Fair/Poor

TxDOT WWARP classifies aggregates based on the following: If AIR of the aggregate is 70 or greater and MSS is 25 or less, then the source is classified as A. If not the chart shown in Figure 4.8 is used. When these guidelines are used 13 out the 27 aggregate sources clarify as Class A aggregates based on AIR and MSS criteria. The remaining 14 sources are plotted on the classification chart. Also shown on this chart are the aggregate classification based on actual field performance according to Table 4.2. Finally, Table 4.3 compares the aggregate classification based on WWARP versus actual field performance for all 27 aggregates. The conclusions that can be made based on the review are as follows:

(a) As expected all 27 aggregate sources classify as either Class A or Class B material based on their MSS and Residual Values

(b) In general, use of Residual Value and MSS in combination is an improvement over the previously used procedure based on Polish Value only. The better performing materials do have high Residual PV and low soundness. Similarly, poor performing material have lower Residual PV and higher MSS loss.

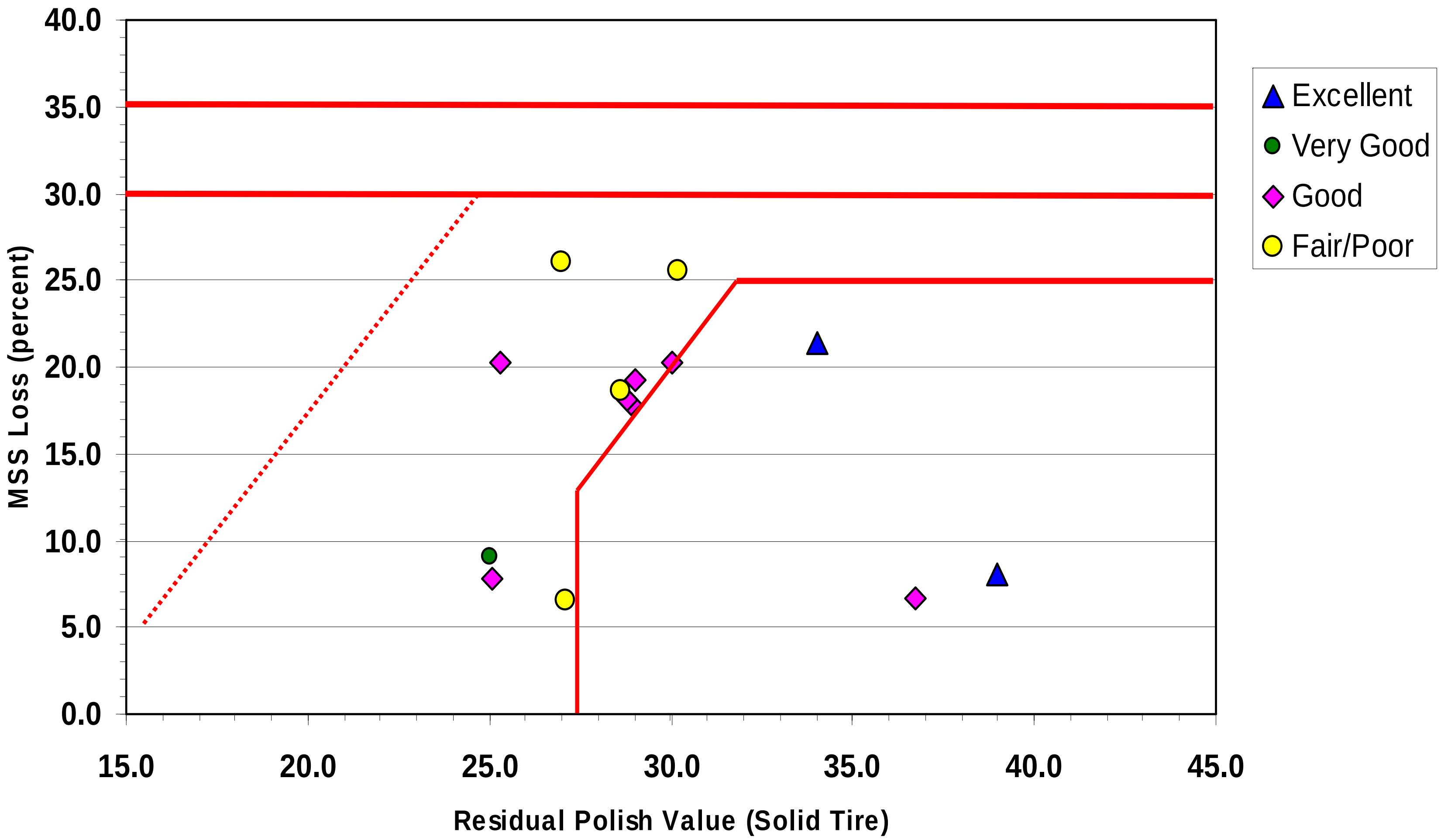


Figure 4.8 Comparison between Aggregate Source Field Skid Performance and Their TxDOT WWARP Classification

Table 4.3 Comparison of Aggregate Classification based on WWARP versus Actual Field Performance

Source	Pit	Material Type	Prod Code	Terminal Skid No. $(TSN)_{25}$	Classification based on Performance	Classification based on WWARP
Vulcan	Smyth	Carbonate	1523205	42.1	Excellent	A
Hanson	Nbfls	Carbonate	1504603	38.7	Very Good	B
Luhr	Tower Rock	Carbonate	50601	34.6	Good	B
Alamo	Weir	Carbonate	1424603	34.7	Good	B
Hanson	Bridgeport	Carbonate	224902	32.8	Good	B
???	Beckmann	Carbonate	1501503	34.4	Good	B
Vulcan	Fm 1604	Carbonate	1501506	26.8	Fair/Poor	B
Jobe	McKelligon(Dolo)	Carbonate	2407201	27.5	Fair/Poor	B
Vulcan	Black	Carbonate	822107	24.0	Fair/Poor	B
Price	Clement	Carbonate	708802	25.6	Fair/Poor	B
Colorado Mtrls	Hunter	Carbonate	1504605	33.9	Good	B
Vulcan	Kelly	Carbonate	218409	30.9	Good	B
Vulcan	Tehuacana	Carbonate	914708	32.5	Good	A
Meridian	Apple, OK	Sandstone	50437	47.0	Excellent	A
Delta	Brownlee	Sandstone	1402704	47.1	Excellent	A
Valley Caliche	Beck	Gravel	2110901	36.4	Very Good	A
Fordyce	Showers	Gravel	2110904	35.6	Very Good	A
Upper Valley	D. Garcia	Gravel	2110905	38.9	Very Good	A
Wright Mtrls	Realitos	Gravel	2106701	43.3	Excellent	A
Trans-Pecos	Hoban	Gravel	619502	45.7	Excellent	A
Hanson	Little River	Gravel	50114	44.2	Excellent	A
E.D. Baker	Johnson	Gravel	4118702	37.5	Very Good	A
Meridian	Mill Creek Trap	Igneous	50438	46.9	Excellent	A
Vulcan	Knippa	Igneous	1523206	41.9	Excellent	A
Granite Mt	Sweet Home	Igneous	50106	41.3	Excellent	A
Hanson	Davis	Igneous	50439	42.8	Excellent	A
TXI	Streetman	Synthetic	1817502	52.8	Excellent	A

(c) 15 out of 16 aggregate sources that were classified as Class A material based on WWARP yielded either “Excellent” (TSN>40) or “Very Good” (35<TSN<40) performance in the field. The only exception was the Vulcan Tehucana source that was rated “Good.”

(d) 10 out of the 11 aggregate sources that were classified as Class B material based on WWARP received “Good” (30<TSN<35) or “Fair/Poor”(TSN<30) rating based on actual field measured skid numbers. The only exception was Hanson-New Braunfels source that was rated “Very Good.”

(e) A final comparison between Micro-Deval Loss and MSS Loss for the two sources identified in (c) and (d) above show that Micro-Deval test would not have provided any better agreement.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

One of the major research tasks that was undertaken as a part of TxDOT Research Study 0-1707 involved a review of the aggregate classification system used by TxDOT as a part of its Wet Weather Skid Accident Reduction Program (WWARP). This review included the evaluation of conventional as well as new laboratory procedures for testing aggregates with respect to their frictional behavior. The conventional lab test procedures that were evaluated in this study are: Residual Polish Value test, 5-cycle Magnesium Sulfate Soundness (MSS) test, Micro-Deval (MD) test and the Acid Insoluble Residue (AIR) test. The evaluation of these conventional lab test procedure was undertaken by researchers at Texas Tech University. Other new lab test procedures, such Video Imaging, were studied by researchers at Texas Transportation Institute, Texas A & M University. This report only documents the research work completed by the Texas Tech research team. The study investigated the repeatability of each lab test procedure as well as the test method's ability to accurately predict aggregate field skid performance.

The aggregate skid resistance performance in the field is generally expressed in terms of skid numbers that are measured using the locked wheel skid trailer in accordance with ASTM E-274. The skid numbers (SNs) measured in this manner are sensitive not only the frictional characteristics of coarse aggregates used in pavement construction but also many other extraneous factors. Among these extraneous factors, pavement macrotexture, presence of distresses such as flushing/bleeding, rainfall, temperature have been found to have dominant influence on the measured skid numbers. The potential for contamination of skid measurements due to these extraneous variables can be minimized by constructing end-to-end test sections on the same roadway using a different aggregate in each of the test sections. By doing so, the mix design (macrotexture), climatic conditions, traffic conditions and construction variables can all be kept the same. However, to develop a large enough database, a large number of test sections must be built and tested. This plan, which was presented in the original research proposal, could not be implemented in this research project due to limitations in time and funding. Instead, skid data that were collected as a part of two other previous research studies (Project 0-1459 and Project 7-3994) were used for the purpose of lab-field performance correlations.   One of the drawbacks in the use of field skid data collected in previous research studies resulted from the absence of some of the more recent aggregate lab test parameters, namely residual polish values and % loss Micro-Deval values. Therefore, it was necessary to develop residual PV - standard PV correlations and % Loss MD - % Loss MSS correlations for each specific aggregate source and then estimate residual PV and % Loss MD based on these correlations. The conclusions and recommendations provided below must be viewed this in mind. It should also be noted that, although these previous research studies have monitored a large number of pavement sections, test sections with adequate skid performance histories and necessary aggregate laboratory data were limited to 27.

CONCLUSIONS

Among the different test methods evaluated, the two test procedures that specifically address skid resistance properties of pavement aggregates are the Polish Value test and the Acid Insoluble Residue test. The Micro-Deval test and the Magnesium Sulfate Soundness test may relate to skid resistance behavior indirectly because they have the capability to identify soft, absorptive materials that breakdown easily under traffic loads and thus cause loss of pavement macrotexture. The evaluation of different test methods with respect to repeatability showed that the Micro-Deval test was the most consistent among the four tests, followed by the polish value test, and then the MSS test and finally the AIR test. The poor repeatability of the AIR test is of special concern that deserves further study. This limitation in the AIR test may be overcome by either performing multiple tests or by using a larger sample size.

The analysis of field skid data clearly showed that the synthetic aggregates, sandstones and igneous materials consistently provided very good to excellent skid resistance. The gravel category was less consistent but nevertheless provided good overall skid resistance performance. It is suspected that gravel sources with significant amounts of carbonate material may have contributed to the variable performance seen in the gravel category. Among all different aggregate categories, the limestones and the dolomite-limestones showed the greatest variability. In other words some limestones and dolomite-limestones performed quite well while others performed very poorly. Nearly all of the very poor performers were found to be in this category. Since a very large fraction of the aggregate sources in Texas belong to this category, it is important to develop reliable methods of classifying these borderline materials as satisfactory or unsatisfactory.

The lab-field correlations showed that it was relatively easy to identify those aggregates that provided very good to excellent performance (i.e. terminal skid numbers > 35). For example, all sources with an AIR of no less than 80% provided terminal skid resistance of at least 35. These aggregate are also characterized by a MD losses of less than 8% or MSS losses of than 5%.   Among these three test methods the MSS test showed the least capability to separate excellent/very good aggregate sources when used by itself. The residual polish value test also showed better correlation near the high PV range than at the low PV range. None of the test methods provided tight correlations with the actual field performance. More importantly, none of the test methods proved to be effective in separating the poor performers from the satisfactory/good performers when used alone.

Combining two test methods (e.g. Residual PV and MSS) for the classification of aggregates appears to be a more effective means of classifying aggregate sources into Very Good, Good, Fair and Poor categories. The limited data set used in this study shows that the current WWARP aggregate classification has been generally successful in accomplishing this goal. In other words, nearly all aggregates that demonstrated Excellent to Very Good performance in the field were classified as Class A aggregate according to WWARP. Similarly, nearly all aggregate sources that showed Good to Fair/Poor performance in the field classified as Class B aggregates.

One area in which the WWARP procedure appears to have a limitation is in identifying those aggregates that show particularly weak performance. There were two sources that provided field TSN values of 26 and below. However, these two sources classify as Class B aggregates. Interestingly, these two sources were the only two sources that had MSS loss values larger than 25.0%.

RECOMMENDATIONS

The current test methods (Residual PV-MSS combination or Residual PV-MD combination) are effective in separating the excellent/very good aggregates from others.

However, they do not appear to be as effective in separating low end aggregate sources into good/satisfactory and poor/unsatisfactory categories. The limited data set evaluated suggests that the solution may be found by enforcing a stricter standard based on MSS loss to separate Class B and Class C aggregates.

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