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16 Abstract

Investigation of the reasons for poor performance of HMAC and seal coat surfaces in the Abilene District revealed that the pavement failure was due to high absorptivity of the aggregates used. The current requirement on the sulfate soundness (max. permissible 30%) has failed to identify and eliminate such absorptive, porous aggregates. The soundness tests performed in the district laboratories as well as tests performed in this study showed that the soundness loss for all the aggregates tested were well below the specifications. Review of available technical literature confirmed that although the sulfate soundness generally increases with increasing aggregate absorptivity, deviations from this general trend are not uncommon.

Additionally, the study reviewed technical literature available on the use of sulfate soundness as a predictor of field performance of aggregates. This review indicated that although more recent data suggest that for many aggregates there is a reasonably good correlation between sulfate soundness and aggregate performance in the field significant deviations from this general pattern are commonly found. The Abilene District aggregates which have performed very poorly in spite of low soundness are examples of such deviations. Based on the observations made above, it was concluded that the use of a specific fixed limit in aggregate soundness to disinguish between acceptable and unacceptable aggregates is not justified. The previous performance record of the aggregate are the best criteria to use in aggregate selection. The sulfate soundness test results should be properly interpreted in the light of other tests and field service records when the test is used for aggregate selection purposes. The present study also evaluated other test procedures such as L.A. Abrasion and freeze-thaw. None of these tests provided more definitive data that will be helpful in identifying the problem aggregates.

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LIMITATIONS ON THE USE OF AGGREGATE SULFATE SOUNDNESS FOR THE PREDICTION OF FIELD PERFORMANCE OF HMAC AND SEAL COAT PAVEMENT SURFACES

by

Priyantha W. Jayawickrama

Research Report No.

Conducted for

Texas Department of Transportation

by

Department of Civil Engineering

Texas Tech University

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SUMMARY

The present research study investigated the failure of the current aggregate evaluation procedures to identify poor quality aggregates that resulted in poor performance of HMAC and seal coat surfaces in the Abilene District. The tests performed in the study clearly showed that these aggregates were highly absorptive. At the present time the district does not use any specification limit on aggregate absorption. However, the current requirements on the sulfate soundness (max. permissible 30%) is expected to identify and eliminate such absorptive and porous aggregates. The soundness tests performed in the district laboratories as well as tests performed in this study showed that the soundness loss for all the aggregates tested were well below the specifications. Review of available technical literature confirmed that although the sulfate soundness generally increases with increasing aggregate absorptivity, deviations from this general trend are not uncommon. Additionally, the study reviewed technical literature available on the use of sulfate soundness as a predictor of field performance of aggregates. This review revealed that the documented information on the above aspect are somewhat contradictory. The more recent data, however, suggest that for many aggregates there has been reasonably good correlation between sulfate soundness and aggregate performance in the field. Careful examination of this data reveals that significant deviations from this general pattern has occurred in some aggregates. In other words some aggregates have performed very poorly in spite of their low soundness; others have shown good in-service performance in spite of high soundness. The Abilene district aggregates clearly belong to the first category. Based on the observations made above it is evident that the use of a specific fixed limit in aggregate soundness to distinguish between acceptable and unacceptable aggregates cannot be justified. The previous performance record of the aggregate are the best criteria to use in aggregate selection. The sulfate soundness test results should be properly interpreted in the light of other tests and field service records when the test is used for aggregate selection purposes. The present study also evaluated other test procedures such as L.A. Abrasion and freeze-thaw. None of these tests provided more definitive data that will be helpful in identifying the problem aggregates.

IMPLEMENTATION STATEMENT

Direct measurements of percent absorption of many of the local limestone aggregates available in Abilene district show that they are highly absorptive. The findings of the study confirm that there is a direct correlation between the absorptivity of these aggregates and the poor field performance that has been reported for these aggregates. Furthermore, the results obtained in the study clearly indicate that magnesium sulfate soundness test has failed to identify the absorptive nature of these aggregates and to predict their poor in-service performance. Therefore, special care must be taken in the interpretation of sulfate soundness test results for local aggregates. *The use of a specific fixed limit on aggregate soundness to distinguish between acceptable and unacceptable is not recommended.* None of the test methods investigated in the study appeared to be reliable predictors of aggregate field performance. *Whenever available, documented evidence on the previous in-service performance of the aggregates should be used in the selection of aggregates.* The study also collected and documented field performance of several aggregates that have been used in the Abilene district in the past. The data collected clearly show that white limestone aggregates from Yates-Parmelly and Massey-Richards sources have yielded poor to very poor performance in HMAC and seal coat surfaces. Based on the above evidence the use of these aggregates may be discontinued even though they meet the current sulfate soundness specifications.

This study, however, *does not* recommend that the use of sulfate soundness requirement be discontinued. Review of data available from many other districts indicate that specifications based on aggregate sulfate soundness have resulted in improved pavement performance. Most engineers agree that the use of sulfate soundness requirement has helped to reduce the amount of fines and deleterious substances in the aggregate and thereby improve aggregate quality.

DISCLAIMER

The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENTS

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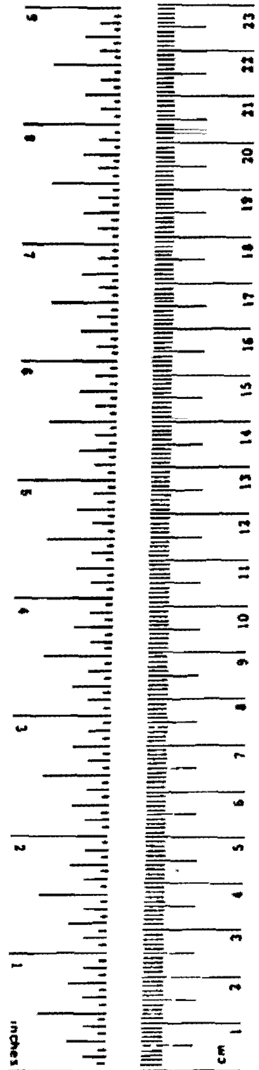
METRIC CONVERSION FACTORS

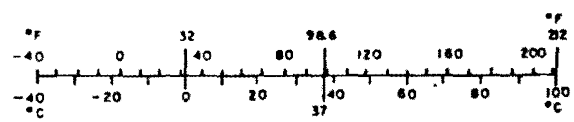
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Chapter 1
INTRODUCTION

Problem Statement

The Abilene District has experienced a great deal of problems with the aggregates that are locally available for use in the preparation of hot mix asphalt concrete and seal coat paving mixes. The aggregates collected from many of the local sources are described as soft, porous, absorptive materials. These aggregates present many problems during construction and result in poor performance of the pavements. First of all, because of their absorptive nature the aggregates tend to retain a lot of moisture preventing proper adhesion between the aggregate and the asphalt binder. Therefore special care has to be exercised to ensure that the material is thoroughly dry before it can be mixed. With some aggregates, the temperature had to be 75° F or higher in order to be able to carry out mixing operations satisfactorily. Furthermore, because of high absorptivity, these aggregates required high asphalt contents and resulted in a mix with poor laying capability. Secondly, many of these aggregates are so soft that they easily generate fines during handling. Usually, the fines in the material are removed during the preparation of the material. However subsequent stockpiling and hauling operations generated sufficient fines in some materials to cause poor adhesion between the aggregate and the binder in the mix.

The problems associated with the in-service pavements surfaces constructed using these aggregates are manyfold. In many instances further absorption of the asphalt binder into the aggregates resulted in a dry mix. This, in turn caused cracking of the mat. In a number of projects severe aggregate loss was evidenced within a short time after the highway was opened to traffic. This phenomenon was even more pronounced during the winter and is believed to be due to the poor adhesion between aggregate and the binder. The aggregates, sometimes appeared to leave a powdery coating and "popout" from the mix leaving small pits on the pavement surface.

The specification requirements used by the district in the selection of aggregates include the 4-Cycle Magnesium Sulfate Soundness Loss (30% maximum acceptable) and Los Angeles Abrasion Wear (35% maximum allowable) in addition to other specification requirements (such as gradation, polish value etc). There is no specification limit on the percent absorption of the aggregate. Generally, it is believed that the sulfate soundness test will identify the undesirable aggregates that are porous and too absorptive. Surprisingly, all of the local aggregates have consistently performed well in the soundness test in spite of their absorptive behavior which was evident during handling, mixing and placing operations. Typically the soundness losses recorded for these materials ranged between 10-25%. Therefore none of the above material is rejected based on the current specification limits. An even more interesting observation was that a particular aggregate type (Massey-Richards Blue Limestone) which showed little signs of high absorptive behavior during handling operations did not meet the soundness test requirement. Consequently, the producer had to move the crushing operations to another location in search of a harder material which would satisfy soundness loss requirements. The aggregates obtained from the second source (Massey-Richards White Limestone) was able to meet the soundness requirements but has been found to be an absorptive material which has presented problems during mix preparation and resulted in poor in-service pavement performance. Based on the experience with the local aggregates described above, the engineers in the district have little confidence on the use of soundness test as an aggregate evaluation method. The present study investigates the correlation between the in-service performance of the local aggregates, their absorptive behavior and the performance in the soundness test.

Objectives and Scope of the Study

This research study was initiated with the objective of evaluating the typical aggregates found locally within the Abilene District. The contradictory behavior that has been reported for these materials in terms of their performance in soundness loss versus their absorptivity is investigated with particular emphasis. A total of four(4) aggregates that are presently used in the District were subjected to a detailed laboratory study.

Additionally, the in-service performance of the pavements constructed in the recent times are evaluated based on the data collected from the district.

Research Approach

The research approach to accomplish the objectives stated above included the following tasks.

Task 1: Literature Review

Task 1 of the research project involved collection and review of pertinent technical literature. In this task particular emphasis was placed on the correlation between in-service performance of both HMAC and seal coat surfaces and the soundness loss for aggregates used. The finding from the literature review are presented in chapter 2 of this report.

Task 2: Laboratory Investigation

In task 2 four different types of aggregates that are currently being used in the Abilene District were selected and a series of tests were conducted for complete characterization of this material. The tests included: Gradation, Absorption, 5-cycle Mg-sulfate soundness loss, Los Angeles Abrasion and Freeze Thaw tests. A detailed account of the laboratory study and the results obtained are given in Chapter 3.

Task 3: Collection of Field Performance Data

Subsequently, each of the aggregates selected were examined with regard to their performance in the in-service pavement surfaces. This task was completed in collaboration with District Engineers Office in Abilene. A questionnaire was prepared and sent to various engineers in the district. A final assessment of each aggregate type was made based on the responses received from the engineers and other technical personnel who have had experience in dealing with these aggregates in the field. The details of the above data collection process and the results are presented in Chapter 4 of this report.

Task 4: Data Analysis

The final task of this research study involved the analysis of data collected during the previous phases of the project. The data from literature, the laboratory study and the field performance study were all analyzed and critically reviewed in this task. A complete discussion of the data analysis efforts are presented in Chapter 5.

Task 5: Conclusions and Recommendations

The final chapter of this report summarizes the conclusions that were arrived at based on the findings of this study. It also lists the recommendations for implementation.

Chapter 2
LITERATURE REVIEW

A number of research publications and technical reports dealing with the sulfate soundness test and its suitability as an aggregate selection method were collected and reviewed. The findings from this literature survey are summarized in the present chapter. The first part of this chapter deals with general considerations; such as the test procedure, the mechanisms that cause particle break up during the test and reproduceability of the test results etc. However, the above discussion is limited to a brief review. A more comprehensive treatment of the soundness method can be found in Refs. 1-4. The emphasis in this chapter is placed on the correlation between the soundness loss of aggregates and their actual, observed field performance. Among the technical literature that address this particular aspect of soundness test, reports from three independent studies that were previously conducted on Texas aggregates were identified. The findings from these studies are discussed in detail.

Sulfate Soundness Test

The sulfate soundness test consists of alternate immersion of a carefully graded and weighed test sample in a solution of sodium or magnesium sulfate and oven drying it under specified conditions. The accumulation and growth of salt crystals in the pores of the aggregate particles is thought to produce disruptive internal forces similar to the action of freezing water. Loss is measured after a specified number of cycles in terms of the amount of the sample that will pass a sieve smaller than the size upon which it was originally retained. Although a number of theories have been proposed regarding the mechanism by which the sulfate test disrupts the particles none of these has received universal acceptance *(Refs. 2,3,5-7)*. It is probable that a combination of actions is involved, including not only the pressure of salt crystal growth but also the effects of heating and cooling, wetting and drying, and pressure due to migration of solution through pores. The relative importance of these disruptive effects varies with the structure of the aggregate being tested.

Reproduceability of Soundness Test

Subsequent to the introduction of the soundness test as ASTM test Method C-88, the test procedure has undergone a number of revisions. Many of these have been aimed at improving the *within-laboratory* and *laboratory-to-laboratory* reproduceability, an objective which has only been partially realized. The following variables have been identified as the possible reasons for the poor reproduceability of soundness test results. *(Refs. 2,6,7,8 and 9).*

1. Amount of salt in the solution, which is affected by the method of preparation and temperature

2. Purity of the salt

3. Efficiency of drying oven

4. Length of drying time

5. Type of sample container since it affects ease of drying

6. Technique of sieving in the preparation of the samples and measurement of loss.

Early data secured before the test procedure was closely controlled, indicated very poor reproduceability of sulfate tests on the same material within laboratories as well as from laboratory to laboratory *(Refs. 2,6)*. It appears that refinements during intervening years have helped to improve the reproduceability of the test method to some extent. The statistics presented in Table 2.1 were obtained from a series of 5-cycle Sodium and Magnesium sulfate tests conducted in triplicate on 36 fine aggregates and 56 coarse aggregates *(Ref. 10)*. They show the amount of variability that typically exists between soundness loss results obtained from independent tests conducted within the same laboratory on the same aggregate type. Table 2.2 presents similar data corresponding to single operator as well as multi-laboratory tests as given in the current ASTM standards, i.e. ASTM Method C-88. The large variations found in the results obtained in different

Table 2.1 Reproduceability of Soundness Test

Type of Test	Standard Deviation	Coefficient of Variation (per cent)
Coarse Aggregate:		
5-cycle magnesium sulfate soundness	1.1	14.5
5-cycle sodium sulfate soundness	1.1	12.4
Fine Aggregate:		
5-cycle magnesium sulfate soundness	0.4	3.9
5-cycle sodium sulfate soundness	0.3	6.0

Reference 10 (Bloem, 1963)

Table 2.2 Precision Indexes for Sulfate Soundness Test (ASTM)

	Coefficient of Variation(%)	
	Single Operator	Multi-Laboratory
Sodium Sulfate Soundness	24	41
Magnesium Sulfate Soundness	11	25

Reference 11, (ASTM C 88-83)

laboratories may have resulted from differences in test procedures. These experiences suggest that not only are the results of the above test limited to a *rough* indication of aggregate soundness but also any comparison between results obtained from different tests is not warranted unless such tests are conducted using identical techniques.

Correlation between Aggregate Soundness Loss and Their Field Performance

The usual purpose of soundness test is to evaluate the ability of an aggregate to resist the destructive effects of freezing and thawing. Therefore it is appropriate to examine the degree to which correlation exists between soundness loss and in-service performance against freeze-thaw effects. In this regard much of the information available is focused on the use of soundness test for evaluation of aggregates used in the preparation of concrete mixes rather than asphalt concrete mixes. Bloem *(Ref.1)*, after reviewing a number of reports dealing with the correlation between soundness loss-field performance, concludes that *"there is little or no support, either theoretical or experimental, for the assumption that the sulfate soundness test simulates exposure to freezing and thawing in concrete or provide a reliable indication of field performance ."* The growth of sulfate crystals in aggregate pores is not analogous to the development of pressure by an advancing front of freezing water. According to Verbeck and Landgren *(Ref. 12) "the mechanism of disruption in sulfate soundness is different and such test results should have only rough and uninterpretable empirical correlation with concrete performance."* Bloem emphasizes on the need for engineering judgement in the interpretation of soundness test results and cautions against the use of inflexible arbitrary limits on the soundness loss which can lead to rejection of good materials and acceptance of materials with poor field performance. The PCA (Portland Cement Association) publication entitled *"Design and Control of Concrete Mixtures" (Ref. 13)* agrees that the results of the soundness test can be misleading and recommends the use of actual in-service field performance data for aggregate evaluation purposes whenever such data is available. Some investigators have recommended the use of a simple absorption test in preference to the more complicated soundness test *(Refs. 14,15)*.

The data available on the correlation between soundness loss and field performance for aggregates used in the asphaltic concrete mixes is more limited. The reports from three separate studies that investigated Texas aggregates with regard to their performance in the test as well as in the field were located and reviewed. The following sections discuss the findings of these research studies.

(A) Departmental Research Study by McCall, District 6, 1976 *(Ref 13)*:

This study was initiated with the objective of finding a solution to the rapid disintegration of the hot mix asphalt concrete surfaces on I-10 in Pecos and Reeves counties, in district 6. A total of sixteen hot mix asphalt concrete projects were included in the study. Early deterioration and cracking that occurred in many of these projects were suspected to be due to the poor quality of the aggregates used in mix preparation. Many of these aggregates showed very high absorption rate and required near maximum asphalt contents. In projects where such aggregates were used deterioration and cracking of the surface occurred within periods ranging from less than a year to thirty months after placement. On projects where aggregates with lower absorption rates were used, the pavement surface showed less deterioration and better serviceability.

Three different kinds of tests were carried out on all aggregate types to determine they will be able identify the poor quality aggregates. These tests were Los Angeles Abrasion Test (Tex-410-A), Wet Ball Mill Test (Tex-116-E) and 4-cycle Magnesium Sulfate Soundness Test (Tex-441-A). Based on the results of these tests it was concluded that the first two tests, Los Angeles Abrasion and Wet ball mill failed to pinpoint the high absorbancy and low durability of the aggregate. It was also found that the fourth cycle of the soundness test was able identify the inferior material. Based on the findings of this study a new specification limit of maximum permissible soundness loss of 25% was introduced. Since the introduction of this new specification, a noticeable improvement in the performance of the pavement surfaces was observed. Additionally, there was a saving of 1-1½ percent asphalt use on these projects.

The above study report also presented data on how the serviceability, crack length and the service condition of each pavement section declined with increasing sulfate soundness of the aggregates. This information is summarized in Figures 2.1, 2.2 and 2.3. These figures show a general trend of decreasing pavement performance with increasing soundness loss. However, not all the pavement sections have followed this general trend.

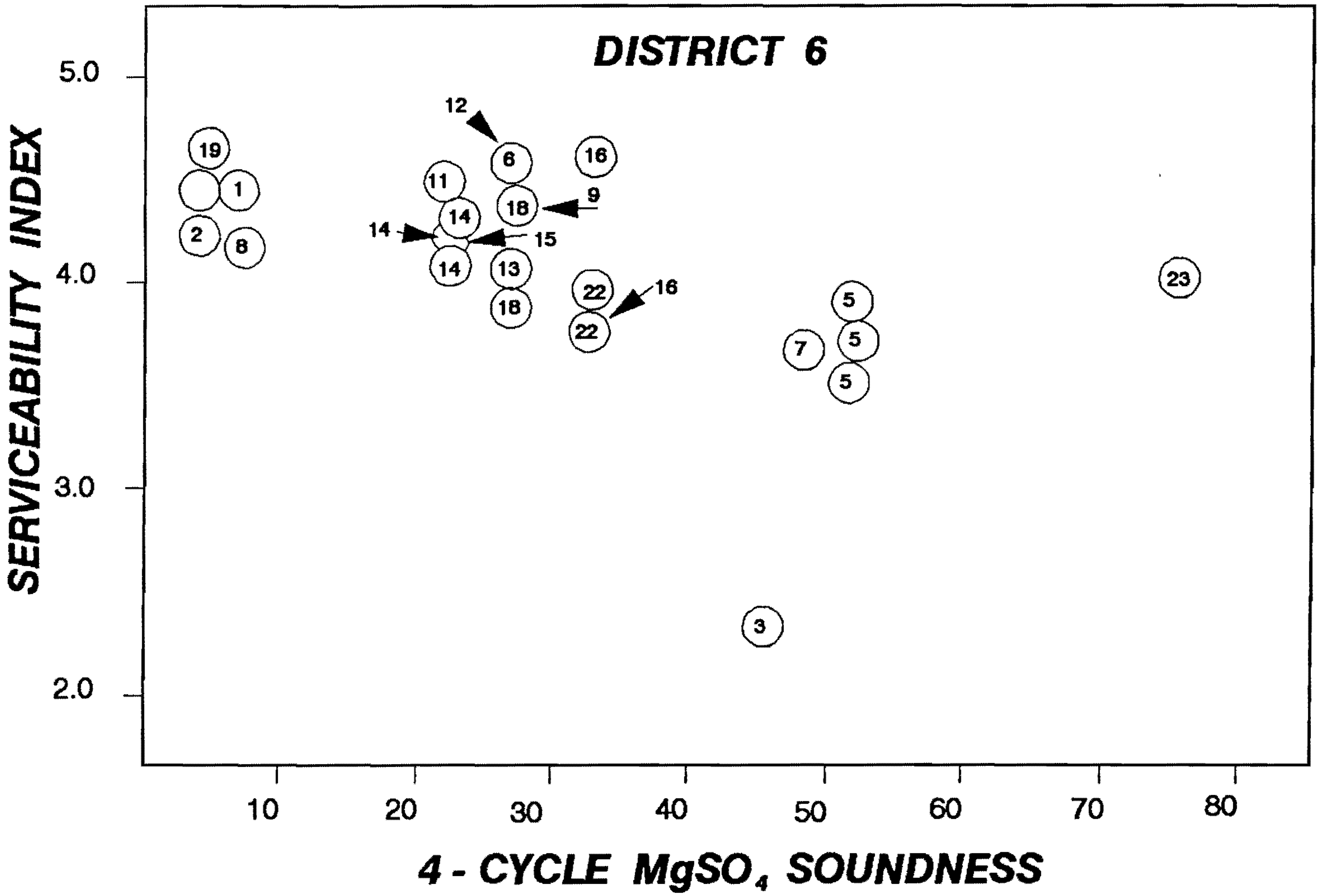


Figure 2.1 Serviceability versus Percent Soundness Loss

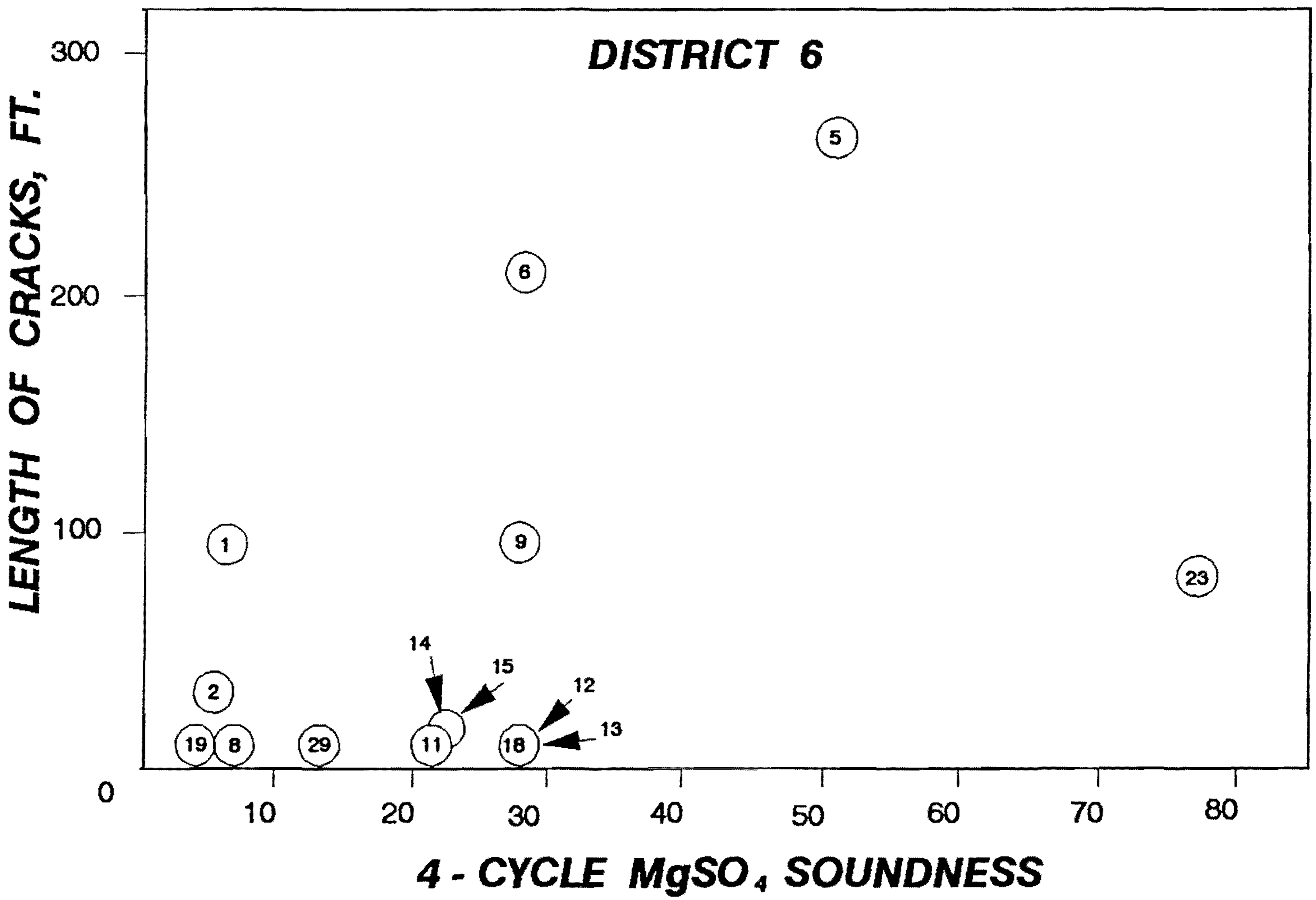


Figure 2.2 Crack Length versus Percent Soundness

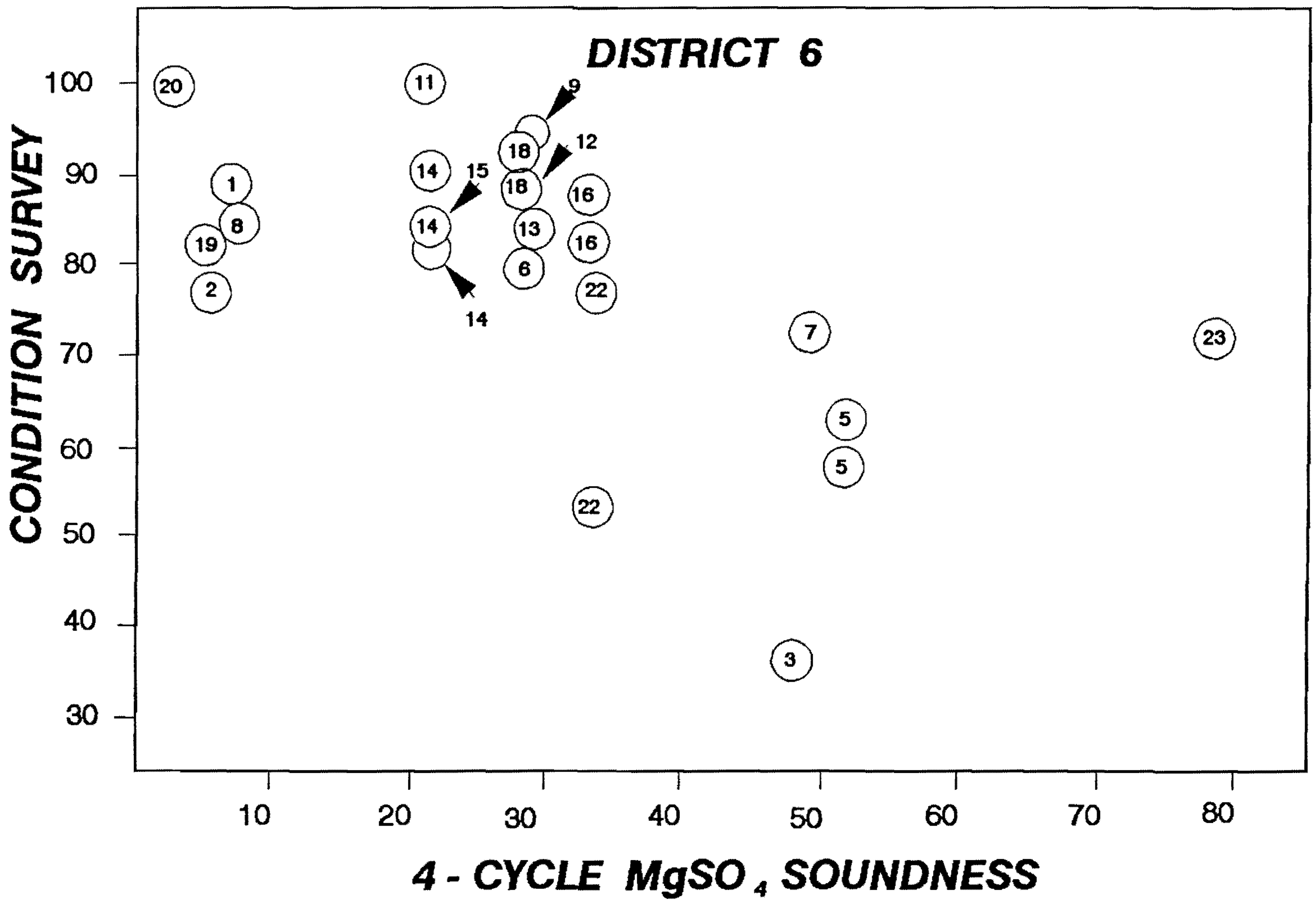


Figure 2.3 Condition Survey versus Percent Soundness

For example project no. 23 shows significant deviation from this general trend. In this case the pavement performance has been remarkably good in spite of the very high soundness loss of the aggregates used.

(B) Texas Transportation Institute Study (Gandhi and Lytton, 1984) ***(Ref. 17)***

The above study was undertaken with the objective of investigating the procedures used in the selection of aggregates for asphalt concrete mixtures. The study was conducted in two separate phases. In Phase I of the study, a literature review and a survey of current practices used in different states was carried out and utility decision analysis was performed to determine the most suitable scheme for a given state. In Phase II, a field and laboratory data collection program was undertaken to determine which of the aggregate examination procedures correlated well with field performance. A total of 32 different aggregate types, 16 from Texas and the remaining from other states were collected for this purpose. As objective data regarding field performance of all these aggregates were not available, a methodology was used to evaluate performance subjectively in the form of a deterioration rate constant,K. This subjective evaluation utilizes the estimates made by highway department laboratory engineers regarding the in-service performance of the pavement surface with respect to cracking, ravelling, rutting etc. The use of such an approach was justified by first demonstrating that deterioration rate constants obtained by using subjective evaluation matched closed with those obtained from objective evaluation for the Texas pavement sections for which both types of data were available. After determining the deterioration rate constants they were correlated with laboratory test values, petrographic examinations and climatic variables using statistical regression analysis. From this analysis the tests or examinations that are the best predictors of aggregate field performance were determined.

The independent and dependent variables included in the statistical analysis are listed in Table 2.3. The statistical analysis method first considers all the variables in the regression model and then selectively eliminates the independent variables that are not significant. The above regression analysis process resulted in several of the variables being excluded from the final model. This indicates that the excluded variable is not a good predictor of the pavement performance. On the other hand, tests that remain

Table 2.3 Listing of Dependent and Independent Variables in the Regression Analyses

A. Dependent Variables (Field Performance)	B. Independent Variables (Laboratory Tests)	
1. General Rating of Aggregate, R	1. Water Absorption (ABS)	
2. Deterioration Rate Constant for Serviceability Index, K_1	2. L.A. Abrasion (LA)	
	3. Soundness (SO)	Aggregate Tests
3. Deterioration Rate Constant for Pavement Rating Score, K_2	4. Sand Equivalent Value (SE)	
	5. Crushed Particles (CR.PART)	
4. Deterioration Rate Constant for Rutting, K_3	6. Marshall Stability (MSTAB)	
5. Deterioration Rate Constant for Ravelling, K_4	7. Tensile Strength (TS)	Tests on Asphalt Mixes
	8. Tensile Strength Ratio-1 (TR-1)	
6. Deterioration Rate Constant for Alligator Cracking, K_5	9. Tensile Strength Ratio-2 (TR-2)	
	10. Tangent Modulus (TM)	
7. Deterioration Rate Constant for Transverse Cracking, K_6	11. Resilient Modulus (MR)	
	12. Powder Coatings (POWDER)	Petrograhic Evaluations
	13. Film Coatings (FILM)	
	14. Hardness (HARD)	
	15. Chemical Character (CH)	
	16. General Quality of Rock (GQ)	
	17. Normal Annual Rainfall (RF)	
	18. Normal Minimum Temperature (MT)	
	19. No. of Wet Days (WD)	Climatic Factors
	20. No. of Freeze Days (FD)	

within the model are thus indicated as the best tests to be used for aggregate selection. In order to identify those test values which were best correlated with field performance a sensitivity analysis was performed. The sensitivity is calculated as the ratio of the percent change in deterioration rate constant to a 10 percent change in the test variable. From this analysis, the tests were ranked in the order of importance for each performance criterion. These sensitivity numbers are shown in Table 2.4. Examination of the sensitivity numbers listed in Table 2.4 reveals that out of 7 pavement performance criteria, five included the soundness loss of the aggregate in the final regression model. The models for alligator cracking and transverse cracking did not include the above variable. This means that pavement performance with regard to alligator and transverse cracking was not significantly affected by the aggregate soundness. Among the five pavement performance criteria that included aggregate soundness, four listed it as the least important test parameter. The remaining pavement performance criterion, had a total of 9 variables in the regression model and the soundness was ranked seventh with a

Table 2.4 Results of Sensitivity Analysis (Gandhi and Lytton, 1984)

Performance	Ranking of Tests or Properties	Sensitivity*
1) General subjective performance rating of the aggregate, R	1) TR-1 (Tensile Strength Ratio, Vac. Sat/Dry, Lottman Test)	0.87
	2) TS (Tensile Strength, Dry, Lottman Test)	0.64
	3) TM (Tangent Modulus, Dry, Lottman Test)	0.58
	4) TR - 2 (Tensile Strength Ratio, Thermally Conditioned/Dry, Lottman Test)	0.55
	5) M STAB (Marshall Stability)	0.46
	6) MR (Resilient Modulus, Dry)	0.46
	7) SO (Soundness)	0.16
	8) POW (Dust Coatings)	0.14
	9) ABS (Water Absorption)	0.09
2) Present serviceability index (PSI) or Roughness of the pavement, K_1	1) MR	1.33
	2) TR - 1	1.05
	3) TM	0.97
	4) CH (Chemical Character)	0.93
	5) TS	0.77
	6) POW	0.62
	7) TR - 2	0.57
	8) ABS	0.15
	9) SO	0.14
3) Pavement Rating Score (PRS), K_2 (Rating of overall performance of the pavement)	1) MR	3.65
	2) CR, PART	3.42
	3) TM	2.37
	4) CH	1.65
	5) TR - 2	1.52
	6) POW	0.90
	7) SO	0.39

Performance	Ranking of Tests or Properties	Sensitivity*
4) Rutting, K_3	1) HARD (Hardness of Rock)	1.25
	2) CH	1.01
	3) MR	0.49
	4) TS	0.43
	5) GQ (General petrographic quality of rock)	0.22
	6) SO	0.09
5) Raveling, K_4	1) TS	1.44
	2) CH	0.93
	3) POW	0.49
	4) FILMS (Coating on Particles)	0.46
	5) SO	0.26
6) Alligator Cracking, K_5	1) C.P.	1.69
	2) GQ	1.28
	3) MR	0.78
	4) TR - 2	0.65
	5) CH	0.53
7) Transverse Cracking, K_6	1) HARD	1.67
	2) CH	1.15
	3) TR - 1	1.03
	4) TS	0.51
	5) POW	0.13
	6) TR - 2	0.11

* Sensitivity is defined as a ratio of the percentage change in K for a 10 percent change in the test property.

sensitivity number of 0.16. Based on the results of the above analysis the investigators concluded that soundness loss of the aggregates used was not a reliable indicator of the field performance of the asphalt concrete surface mix. Therefore they recommended that aggregates should not be rejected on the basis of soundness test alone and if a certain aggregate source is considered marginal on the basis of the test a decision regarding its suitability is best made on the basis of previous experience with regard to its field performance.

(C) Center for Transportation Research Study (Papaleontiou, Meyer and Fowler, 1987)

The above research study conducted by Center for Transportation Research at University of Texas is the most recent of the three studies reviewed. The objectives of the study were to investigate if the soundness test is a valid measure of durability, and to determine the most appropriate parameters for the test considering aggregate type, pavement type, region and traffic. Additionally, this research study investigated possible relationship between the soundness test and other material tests for the purpose of identifying an alternative test which is more nondiscriminating, simpler to perform, and one with more consistent results that provides equivalent information on pavement performance.

A total of 41 aggregates (14 limestones, 12 sandstones, 13 siliceous gravels, and 2 synthetic lightweight) from 33 quarries in Texas, Oklahoma, and Arkansas representing the most common or problem materials used by Texas districts were selected for the study. These materials were subjected to a series of laboratory tests including specific gravity, absorption, freeze-thaw, Los Angeles Abrasion, aggregate durability index, a modified procedure for the Texas wet ball mill (called Texas degradation) and the 4-cycle soundness test. Statistical analysis was used to determine repeatability of methods and develop models describing the relationship between the soundness test and other tests.

The behavior of 8 aggregate sources evaluated in the laboratory was assessed in several Texas districts by examining their performance in selected HMAC and seal coat projects. This field evaluation included examination of hot mix and seal coat surfaces for specific forms of distress that result from poor aggregate quality such as cracking of the mat, and splitting, crushing, dissolving or shelling of the aggregates. The method used in field performance evaluation was subjective and similar to that used in the TTI study described previously except that, in this study the emphasis was on those distress types that are directly related to aggregate quality.

Several important conclusions were drawn from the results of this study. Some of the conclusions which have a special relevance to the present research project are as follows.

1. CTR study identified the 4-cycle soundness test as the best among seven laboratory methods in predicting performance of aggregates in HMAC and surface treatments. The use of the soundness test was recommended to eliminate soft, absorptive, weakly cemented limestone and sandstone aggregates which crack, crumble, split, shell and wear readily during construction or in service due to traffic and environment. Los Angeles Abrasion, wet ball mill and decantation tests did not identify the problem aggregates. The study reported that there was strong evidence that the Los Angeles Abrasion test permits the use of unacceptable materials and recommended that use of the above test be discontinued.
2. The aggregates used in seal coats, which are more exposed to weathering and subjected to higher wheel stresses were found to be more susceptible to disintegration than aggregates used in hot mixes. As a result the recommended soundness limit for seal coat aggregates was more stringent (lower) than that for HMAC. Recommended limits were 25 percent for seal coat and 30 percent for HMAC.
3. Most districts have experienced improved road performance after implementing the soundness limits on aggregates. A state wide survey conducted as part of the study revealed that specification limits used in districts were linked with material availability and price. Four districts in central and west Texas (Brownwood, San Angelo, Abilene and Odessa) stated that a 25 percent limit on seal coats would create material shortage and/or raise price. Three districts (Brownwood, Abilene and Corpus Christi) reported that they will be affected by a 30 percent soundness limit on aggregates used for HMAC.

4. The statistical analysis between results from soundness test and other tests revealed that Texas Degradation Test provided the best correlation whereas Los Angeles and Freeze-Thaw Tests showed poorest correlation.

Chapter 3
EXPERIMENTAL STUDY

Four aggregate types that are currently being used for hot mix and seal coat preparation in the Abilene District were selected for a detailed laboratory study. This chapter describes this laboratory testing program. The selected aggregates are; Massey-Richards Blue Limestone, Massey-Richards White Limestone, Yates-Parmelly White Limestone and Clements-Garden City Yellow Limestone. The first of these three aggregates were chosen because the experience with their field performance was not consistent with their sulfate soundness test results. The fourth aggregate type, i.e. Clements-Garden City limestone was included in the testing program not because of a specific problem but as a reference material. This aggregate has provided better service than most other aggregates available in this local area.

The tests that were performed on the selected aggregates included; gradation, aggregate absorption, 5-cycle magnesium sulfate soundness, Los Angeles abrasion and freeze-thaw tests. Among these tests, the magnesium sulfate soundness test was performed in four replication for each type of aggregate so that the repeatability of this test procedure can be established. The following sections discuss each of the above test procedures and the results obtained.

(a) Aggregate Gradation

The aggregate gradation tests were conducted to characterize the material supplied. The tests were performed according to Texas Standard Specifications (Tex-401-A). The test procedure is not described here but is included in this report as *Appendix A* for the sake of completeness. The results obtained are presented in Tables 3.1 through 3.4 for the four aggregate types.

(b) Aggregate Absorption

The problems associated with the aggregates that were used in this study have

Table 3.1 Gradation Test Results: Massey-Richards Blue Limestone, Type "D"

DRY SIEVE ANALYSIS		
Sieve Requirements	Lab Results	Specifications
Passing 1/2"	100	100
Passing 3/8"	96.9	85-100
Passing 3/8",Retained on #4	55	21-53
Passing #4,Retained on #10	32.6	11-32
Total Retained on #10	90.7	54-74
Passing #10,Retained #40	4.7	6-32
Passing #40,Retained #80	1.3	4-27
Passing #80,Retained #200	1.6	3-27
Passing #200	1.7	1-8
Pan		---

Table 3.2 Gradation Test Results; Massey-Richards White Limestone, Type "D"

DRY SIEVE ANALYSIS		
Sieve Requirements	Lab Results	Specifications
Passing 1/2"	100	100
Passing 3/8"	81.37	85-100
Passing 3/8",Retained on #4	73.37	21-53
Passing #4,Retained on #10	5.83	11-32
Total Retained on #10	97.76	54-74
Passing #10,Retained on #40	.10	6-32
Passing #40,Retained on #80	.11	4-27
Passing #80,Retained on #200	.5	3-27
Passing #200	1.5	1-8
Pan		---

Table 3.3 Gradation Test Results: Yates-Parmelly White Limestone, Type "D"

DRY SIEVE ANALYSIS Sieve Requirements	Lab Results	Specifications
Passing 1/2"	100	100
Passing 3/8"	99.9	85-100
Passing 3/8",Retained on #4	78.8	21-53
Passing #4,Retained on #10	12.4	11-32
Total Retained on #10	91.3	54-74
Passing #10,Retained on #40	.5	6-32
Passing #40,Retained on #80	.5	4-27
Passing #80,Retained on #200	2.0	3-27
Passing #200	5.7	1-8

Table 3.4 Gradation Test Reslts; Clements-Garden City Yellow Limestone, Type "D"

DRY SIEVE ANALYSIS Sieve Requirements	Lab Results	Specifications
Passing 1/2"	100	100
Passing 3/8"	94.5	85-100
Passing 3/8",Retained on #4	68	21-53
Passing #4,Retained on #10	20.3	11-32
Total Retained on #10	93.8	54-74
Passing #10,Retained on #40	3	6-32
Passing #40,Retained on #80	1.1	4-27
Passing #80,Retained on #200	1.3	3-27
Passing #200	.8	1-8
Pan		---

been attributed to their high absorptivity. Therefore, a series of tests were performed to measure the aggregate absorption in the laboratory. These tests were conducted according to Texas Standard Test Method Tex-201-F. The test procedure is included in this report as *Appendix B.* The results obtained from the absorption tests are shown in Table 3.5. Examination of this data reveals that the three problem aggregates have very high absorption rates. The absorption of the reference material i.e. Clements-Garden City limestone was noticeably lower than the others. These data are further examined later in this report in Chapter 5 under the section "Analysis of Data and Discussion of Results."

(c) 5-cycle magnesium sulfate soundness test

The current specifications used by the district in the selection of aggregates include a 30% permissible loss in the 4-cycle soundness test. However, the above specification is likely to be upgraded to require 5-cycle soundness test in the near future. For this reason the testing completed in the present study included 5-cycle tests instead of 4-cycle tests. The soundness test is often criticized for poor reproduceability of results. Therefore, the test was performed in four(4) replications for each aggregate type so that the reproduceability of the test results for the local aggregates can be investigated. The test method used is Tex-411-A with 5 cycles of alternate immersion and drying. The test procedure is found in *Appendix C.* The results of this series of tests are presented in Table 3.7. Chapter 5 includes a detailed discussion of these results.

(d) Los Angeles Abrasion Test

The aggregate selection specification used in the Abilene District include a maximum permissible loss of 35% in the Los Angeles abrasion test in addition to the limit on soundness loss. Therefore, L.A. abrasion test was included in the laboratory test program. The tests were conducted according to Texas Standard specifications (Tex-410-A). The test procedure is included in this report as *Appendix D.* The results of the Los Angeles abrasion tests are shown in Table 3.6. A discussion of these results appears in Chapter 5.

Table 3.5 Results of the Absorption Tests

ABSORPTION TEST

Sample Name	Absorption, %
Vulcan Materials Massey-Richards Blue	4.4
Yates-Parmelly "D" Aggr	5.8
Clements Source Garden City	2.9
Vulcan Materials Massey-Richards White	4.2

Table 3.6 Results of the Los Angeles Abrasion Test

LOS ANGELES ABRASION

Identification	Total Percent Loss After 500 Revolutions
Vulcan Materials Massey-Richards Blue	34.5%
Yates - Parmelly "D" Aggr	39.0%
Clements Source Garden City	27.7%
Vulcan Materials Massey-Richards White	29.4%

Table 3.7 **Results of the 5-cycle Magnesium Sulfate Soundness Tests**

Magnesium Sulfate Soundness Test

Set #	Clements Source	Yates-Parmely "D" Aggr.	Vulcan Mtls. Massey Richards Blue	Vulcan Mtls. Massey Richards White	Sp. Gr. of Solutions
1st	18.26	13.39	12.48	19.98	1.397
2nd	17.49	16.18	12.75	21.80	1.395
3rd	14.65	20.29	13.06	19.64	1.301
4th	15.91	18.01	14.85	18.51	1.301
Average Loss After 5 cycles	16.58	16.97	13.29	19.98	

(d) Freeze-Thaw Tests

The primary objective of this study was to investigate the failure of magnesium sulfate soundness test to identify poor quality aggregates. The soundness test uses an indirect approach to create the same disruptive forces that will be generated by water freezing within the pores of the aggregates. The freeze-thaw test accomplishes the same objective by using a more direct approach. This test is not routinely done because of the time and cost involved. In the present test program, a series of 50-cycle freeze-thaw tests were performed so that the results from two independent aggregate durability tests can be compared. The results of the freeze-thaw tests were further examined to determine whether these test results are better predictors of aggregate performance in the field. The test method used is Tex-432-A and is included in *Appendix E* of this report. The results of this test series is shown in Table 5.8.

Table 3.8 Results of Freeze-Thaw Tests

50 CYCLES FREEZE/THAW

Source	Grade	Actual Loss, %	Weighted Loss, %	Total Weighted Loss, %
Clements Source				
Garden City	3/8"	9.7	.5	
	# 4	5.9	4.0	
	#10	2.0	.4	
				4.9
Vulcan Materials				
Massey-Richards Blue	3/8"	32.2	*9.0	
	# 4	16.3	9.0	
	#10	12.1	3.8	
				21.8
Vulcan Materials				
Massey-Richards White	3/8"	9.1	1.9	
	# 4	1.7	1.2	
	#10	1.7	.1	
				3.2
Yates-Parmelly				
"D" Aggr	# 4	2.8	2.0	
	#10	1.0	.2	
				2.2

* Weighted loss assumed to be same as for sieve #4 as percent retained on 3/8" sieve was less than 5%

Chapter 4

FIELD PERFORMANCE OF AGGREGATES

One of the major tasks in this research study involved the collection of in-service performance data on selected aggregates. Several different methods have been used by previous researchers to accomplish the above task. The departmental research study conducted by McCall(1976) used crack length measurements, results of condition surveys and serviceability indexes to characterize the performance of each pavement. In each of these methods the pavement performance is expressed in terms of a number which may be in the form of an index or a rating score. These numbers representing pavement performance are used in subsequent analysis. The second research study described in Chapter 2 (i.e. TTI study by Gandhi and Lytton) was primarily based on estimates made by highway department laboratory engineers regarding the in-service performance of the pavement surface with respect to cracking, ravelling, rutting etc. These subjective evaluation data were then transformed into "pavement deterioration rate constants." These numerical values were used to represent pavement performance in all subsequent statistical analyses. The third research study conducted by Papaleontiou, Meyer and Fowler (1987) at CTR, made no attempt to develop quantitative measures of pavement performance. Such qualitative measures are were not needed in this research study because it did not involve any analyses on pavement performance data. In the above study the researchers made visual examination of specific distress types that are associated with poor aggregate quality and made a qualitative pavement evaluation based on the above distress types. The present research study used a similar approach. Based on the information gathered by communication with engineers in the Abilene district and review of available literature the following distress types were identified as distress resulting from the use of unsound, absorptive aggregates.

(a) Cracking of the mat due to drying of the mix caused by high absorption of the aggregate

(b) Aggregate splitting, cracking, and disintegration into small pieces

(c) Dissolution of aggregates

(d) "Shelling"; or aggregate removal leaving the outer coat in the binder

(e) Cluster of small pits on the surface due to loss of aggregate or "popouts"

Data on pavement surface performance were collected through telephone communications with engineers who have had experience on the use of these aggregates and by using a questionnaire. The questionnaire that was used in the field performance data collection process is included in *Appendix F.* The following sections summarize the information collected regarding the in-service performance of each aggregate type selected for this study. This discussion is presented in two separate parts. The first part deals with aggregates used in hot mix asphalt concrete and the second with aggregates used in surface treatments. It must be also noted that the data collected included information on three additional aggregate types which were not included in the laboratory tests in this research study. These aggregates are white limestone from Anderson source, crushed caliche from Cox source and white limestone from Booth source.

Aggregates Used in Hot Mix Asphalt Concrete

The responses received for the questionnaire included descriptions of the field performance of the following aggregates: white limestone from Massey-Richards source, yellow limestone from Clements-Garden City source, white limestone from Anderson source and white limestone from Booth source.

(a) White Limestone from Massey-Richards Source

Massey-Richards White Limestone was used in a number of HMAC projects including the recent projects completed on IH-20 in Taylor County (August 89) and SH-70 in Nolan County (July 90). The aggregates from this source are described as soft, porous and very absorptive material. Percent absorption for this material is recorded as 5-6% based on tests done in the district laboratory. The 4-cycle magnesium sulfate soundness loss was 18-20% which was well below the specification limit. L.A. Abrasion loss was 28%. Polish value for this material was recorded as 37%. The information collected during the survey did not indicate any particular problem during construction. However in many of the HMAC projects, severe cracking was observed soon after construction. The cracks were sealed within the first six month period after construction. The pavement surface deteriorated rapidly due to continued crack growth.

(b) Yellow Limestone from Clements-Garden City Source

Clements-Garden City limestone was used in number of HMAC projects including projects 69-1-37 and 68-8-38 on US-87 in Howard County both constructed in July 90. The material is described as not very absorptive. According to data available in the district laboratory absorption for this material is 4.0%, sulfate soundness loss 18-20%, L.A. Abrasion wear 30% and Polish value 35%. The absorptivity measured for this material in the present research study is 2.9% which is lower than the absorptivity given above. There were no reports of difficulties during construction with this aggregate. The pavement surfaces have shown no evidence of cracking due to drying or aggregate disintegration.

(c) White Limestone from Anderson Source

This aggregate was used in hot mix construction project 53-7-31 on US-84 in Scurry County completed in December 1990. The laboratory testing conducted prior to the project provided the following information. Sulfate soundness 13%, L.A. Wear 30% and Polish Value 30%. There was no reliable test data on absorption. However the absorption was estimated to be approximately 5-6%. This particular aggregate was not included in the current research project. Experience with the use of this aggregate did not report any problems during or immediately after construction. Several problems were noted during the first six months. These occurred primarily in the section of the pavement that was constructed during the latter part of the project. These construction operations took place in late fall where the daytime temperatures were 50-70 degrees. The pavement surface did not appear satisfactory because of high absorbancy and a segregated mix. Therefore an emulsion was applied to the surface. At the time information was being collected for this study the above maintenance work was just completed.

(d) <u>White Limestone from Booth Source</u>

White Limestone from Booth source was used in the HMAC project 5-8-68 on IH-20, Mitchell County in June 1989. The laboratory data available on this material are as follows: absorption 4-5%, sulfate soundness 18%, L.A. Abrasion Loss 37% and Polish Value 43%. No distress were identified immediately after construction. However cracks appeared within 6-10 months after the construction during the first winter. One year after the construction was completed a hot asphalt rubber seal coat was applied on the main lanes to help seal the cracks. The cracks reappeared within two years since the original construction.

Aggregates used in Surface Treatments

The information on field performance of following aggregates used in seal coat projects were available; white limestone from Yates-Parmelly source and crushed caliche from Cox source. The second aggregate, crushed caliche was not included in the detailed laboratory investigation undertaken as a part of the present research study.

(a) <u>White Limestone from Yates-Parmelly Source</u>

Yates-Parmelly limestone was used in a large number of seal coat construction projects. Among them are: project 663-1-17 and project 663-2-4 on FM-707 in Taylor county. These projects were completed in the summer of 1990. According to the information provided in the questionnaires Yates-Parmelly limestone has the worst performance record out of all the aggregate types used in pavement construction work. This aggregate is described as soft, porous and highly absorptive and as a result has to be dried before adequate adhesion between the aggregate and the binder could be achieved. The aggregate created a lot of fines during stockpile handling, and hauling operations and during rolling on chip seal applications. The district laboratory data on this material is as follows: Percent absorption 5-6%, 4-cycle sulfate soundness loss 18%, L.A. Abrasion Loss 35% and Polish Value is 39%. The field experience with the Yates-Parmelly aggregate also showed rapid deterioration under traffic. The traffic created dust out of any excess or loss aggregate. The problems were even more pronounced during winter. In cases where maintenance fog sealed the pavement aggregate loss was low. It was also noted that powdering was most severe during the initial few months. Subsequent aggregate loss was low.

(b) Crushed Caliche from Cox Source

This aggregate was used in project 1361-3-20 on SH-208 in Scurry county completed in August 1990. The district laboratory data on the material were as follows: sulfate soundness 12%, L.A. wear 28%, Polish Value 36%. Data on absorption was not available. The construction in the above project included scarifying existing surface and then adding 8 inches of new base course with a two course surface treatment. no cracking or loss of aggregate was observed until the time the data was collected for the study.

It should also be noted at this point that no field performance data were available on Maasey-Richards Blue limestone. This material did not meet the soundness test requirement and therefore was never used in pavement construction. Consequently the producer moved the crushing operations to another source in search of a better quality material.

Chapter 5

ANALYSIS OF DATA AND DISCUSSION OF RESULTS

This chapter discusses analyses performed on the data that was collected from both the experimental and the field performance studies conducted under this research project. The discussion on the results of data analyses is presented in two separate sections. The first section of this chapter deals with analysis of laboratory data and the second section deals with the analysis of field performance data. As described in Chapter 3, the laboratory investigation involved testing of four(4) different types of aggregates that are currently being used in the Abilene District in the preparation of HMAC and Seal Coat paving mixes. The data collected from the laboratory testing included:

(a) 5-cycle Mg-Sulfate Soundness Loss(%)
(b) Freeze-Thaw Loss(%)
(c) Los Angeles Abrasion Loss(%)
(d) Absorption(%)
and (e) Aggregate Gradation

The analysis of the this data is discussed below.

Repeatability of Soundness Test Results

The suitability of soundness test for the evaluation of aggregate durability has often been questioned because of the poor repeatability of the test results. The above shortcoming of the soundness test has been addressed in a number of research studies *(Refs. 2, 6-9)*. ASTM standard test method C-88 which describe soundness test comments that " *since the precision of this test method is poor, it may not be suitable for outright rejection of aggregates without confirmation from other tests more closely related to the specific service intended.*" In order to establish the repeatability of soundness test results for those specific types of aggregates used in the Abilene District the 5-cycle soundness test was performed in 4 replications for each aggregate type. The variability between the percent soundness losses corresponding to the 4 trials of a given aggregate type was then expressed in terms of coefficient of variation(%). The coefficients of variation (CV%) calculated for each of the aggregates investigated in this study are given in Table 5.1.

These Coefficients of Variation (CV%) determined for aggregate samples from Abilene District may be compared with values reported in literature. Of particular significance here is the findings made in TxDot research study 3-9-85-438 where a total of 41 aggregate types representative of material used in different parts of the state were subjected to a detailed study. The findings of the above research study with regard to reproduceability of sulfate soundness test results are summarized in Table 5.2. A review of this data reveals that there is significant variability in the Coefficients of Variation determined for different types of aggregates. The coefficient of variation obtained varies from a minimum of 2% to a maximum value of 50%. This indicates that the soundness test results have been quite consistent for some types of aggregates whereas they have shown large variations for others. The guidelines provided in the ASTM standards *(Test Method C-88, Ref. 11)* describing Soundness Test of aggregates is as follows.

	Coefficient of Variation (%)	
	Single Operator	Multi-laboratory
Sodium Sulfate Soundness	24	41
Magnesium Sulfate Soundness	25	11

A comparison of the coefficients of variability obtained in this study with data reported in the two other references above it can be concluded that the aggregates investigated in this study, on a relative basis, have performed quite consistently in the soundness tests. With the exception of the Yates-Parmelly limestone, all of the other aggregates have yielded coefficients of variation less than the average value provided in ASTM standards as a guideline.

At this point it should also be pointed out that although that some of the

Table 5.1 Variability of Soundness Test Results

Aggregate Description	Average Soundness Loss(%)	No. of Tests Performed	Standard Deviation	Coefficient of Variation, CV(%)
Massey-Richards; White Limestone	19.98	4	1.365	6.8
Massey-Richards; Blue Limestone	13.29	4	1.070	8.1
Yates-Parmelly; White Limestone	16.97	4	2.918	17.3
Clement-Garden City; Yellow Limestone	16.58	4	1.615	9.7

Table 5.2 Repeatability of Soundness Test Results;
Findings from Research Study No.3-9-85-438

Aggregate No.	Avg. Soundness Loss (%)	No. of Observations	Standard Deviation	Coefficient of Variation(%)
30	1.9	3	0.59	31
25	2.2	3	0.72	33
18	2.9	4	1.46	50
16	8.4	3	1.51	18
15	9.1	3	0.20	2
41	10.0	3	0.69	7
26	14.4	2	1.27	9
8	17.1	2	4.10	24
7	29.3	3	3.81	13
37	36.1	4	2.45	7
40	39.0	3	4.37	11
13	46.0	2	1.63	3
5	63.5	3	2.65	4

aggregates used in the study has been tested previously in District-8 laboratories no attempt is made include such data in the present analysis. Such a comparison between the test results obtained from the two laboratories was considered inappropriate for the following reasons. Firstly, District-8 laboratory used 4-cycle test whereas tests performed for this research study were 5-cycle soundness tests and hence no direct comparison was possible. Secondly, although the material was obtained from the same source they were not collected during the same time period and therefore, the samples probably did not represent the same material.

Soundness Loss(%) - Absorption Relations

Because of the dependance of the absorption and sulfate soundness tests on the amount of permeable pore space in the aggregates it is reasonable to expect a positive correlation between the results of these two types of tests. In other words, it may be expected that as absorption increases, there will be corresponding increase in the loss in the soundness test. In fact, it is generally assumed that specification of a maximum allowable soundness loss limit would eliminate more porous, absorptive aggregates. A preliminary examination of the results obtained for the Abilene District aggregates indicated clearly that they were highly absorptive. However, their soundness losses, which are reported in Table 3.7 were all within low to moderate range. Thus, it appears that these materials deviate from the usual behavior observed for most other aggregates. Hence, this particular observation was subjected to further investigation. Consequently, the data obtained in the present study was compared with information available in literature with regard to correlation between Soundness Loss and Absorption. A number of research reports that have addressed this particular issue were located *(Refs. 19,20)*. The most complete and comprehensive documentation of the Soundness Loss - Absorption Correlations is found in Ref.20 by Mather (1947). In this study a total of 409 aggregate samples were tested and analyzed. The aggregates used in the study by Mather were collected from the New England, North, and Middle Atlantic States. The mineralogical and lithological composition of the material tested included; quartz sands, granitic sands, shales and sandstones, schists and gneisses, limestones, manufactured quartzite and dolomite sands. The data recorded as the soundness loss and absorption for each of 409 aggregate samples were not presented in the article. However, the distribution of this data were presented in the form of frequency distributions. This data was reproduced and are shown in Figures 5.1 and 5.2. Figure 5.1 summarizes the absorption data. The aggregate absorption varied in the range from 0.1% to 3.8% the mean absorption being 1.21%. The standard deviation was 0.760%. In order to compare aggregate samples from Abilene District with these data, they are superimposed in the same figure. It can be immediately recognized that three(3) of the Abilene District Aggregates are more absorptive than any other aggregate used in the Mather study. The only exception is the reference material, Clements-Garden City aggregate which had a relatively lower absorption but still ranked among the top 10%. Figure 5.2 shows the distribution for the 5-cycle Mg-Sulfate Soundness Loss values. The range for Soundness Loss was between 0.2% to 34.2% with a mean value of 7.86%. The standard deviation for this data is 5.449%. Once again data from the present study are plotted on the same figure for comparison. This comparison indicates that Abilene district aggregates have higher soundness losses than most other aggregates used in the Mather study. However, they do not fall within the category of aggregates with extremely high soundness loss although such a result could be expected based on their percent absorption values. The percentile rankings of the soundness loss of Abilene District range within 81.2% to 89.7%. The next step in the analysis was to examine Soundness Loss-Absorption relations for these aggregates. The following regression equation was proposed by Mather based on the analysis performed on the results obtained for all 409 aggregates.

$$\text{Soundness Loss}(\%) = 5.78\ (\text{Absorption}\%) + 0.86 \quad \ldots\ldots\ldots\ldots (5.1)$$

$$\text{Coefficient of Determination, } r^2 = 0.65$$

This relationship is plotted in Figure 5.3. It was not possible to include individual data points in this plot to indicate the amount of scatter because such data was not available. However, the coefficient of determination of 0.65 may be used to get an idea of the amount of scatter that was present in the data. It is significant to note that all of the Abilene District aggregates lie to the right of the regression line in the gray shaded

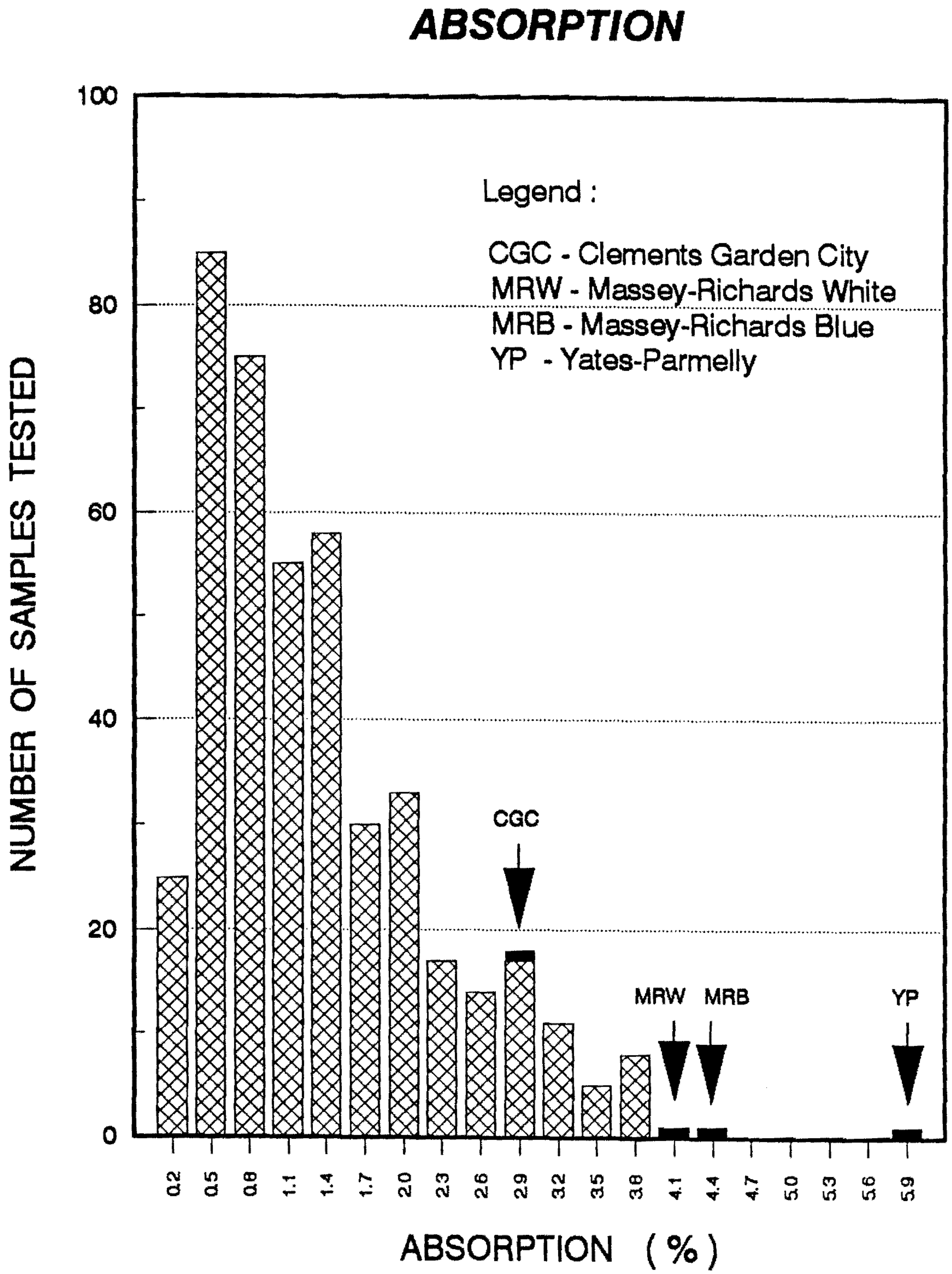


Figure 5.1 Frequency Distribution for Aggregate Absorption *(Ref. 20, Mather,1947)*

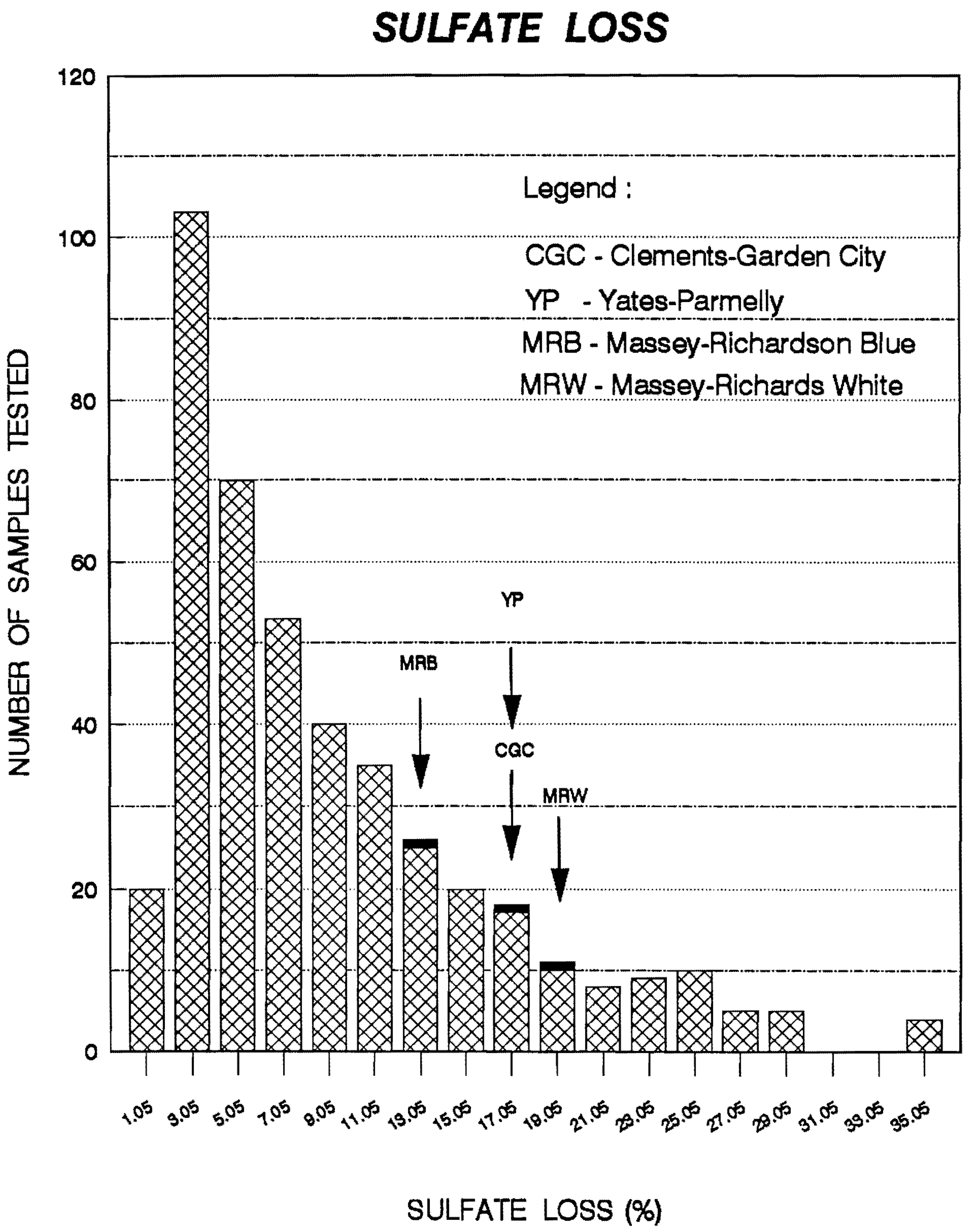


Figure 5.2 Frequency Distribution for Sulfate Soundness *(Ref. 20, Mather 1947)*

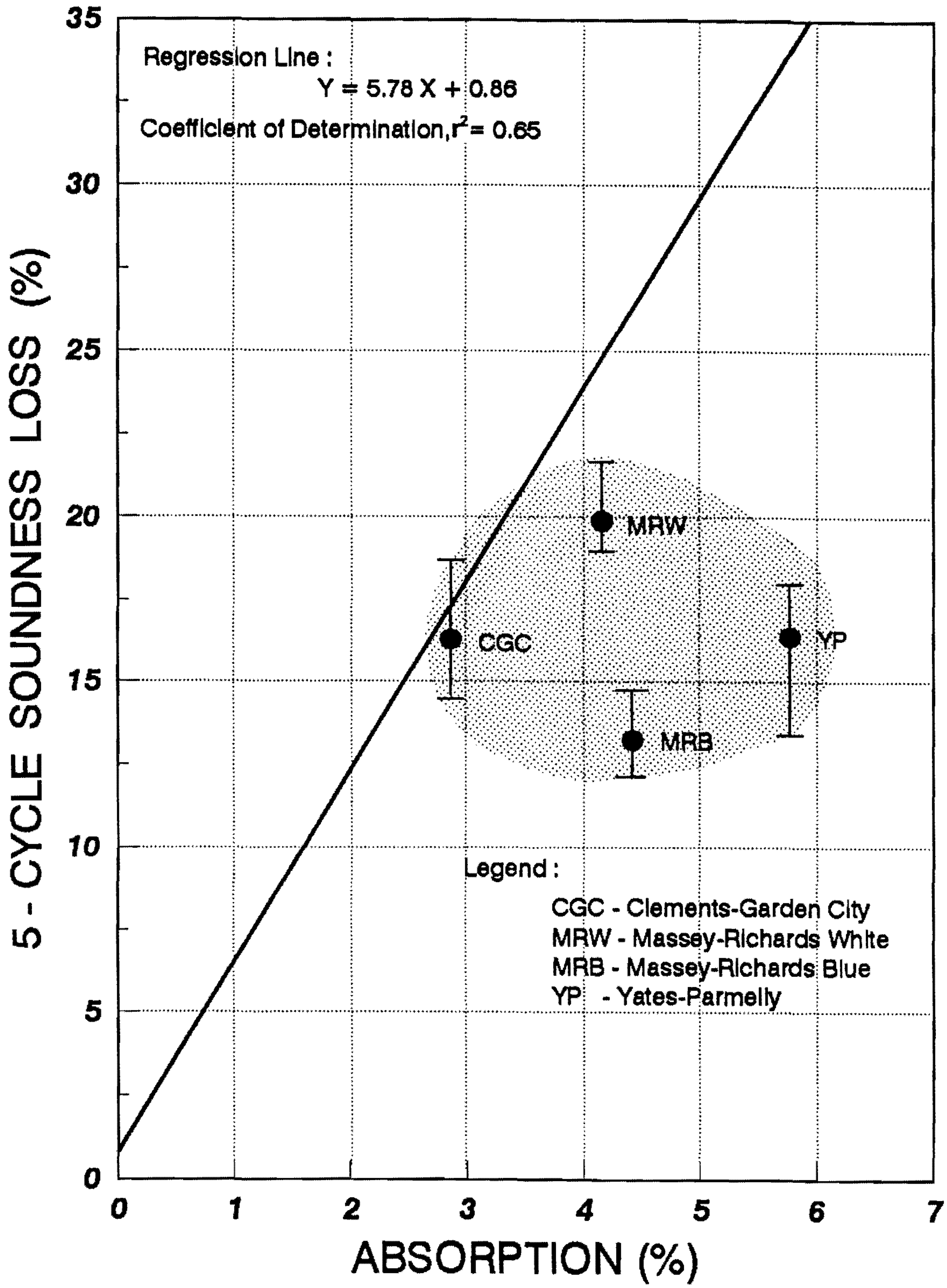


Figure 5.3 Correlation between Sulfate Soundness and Absorption

area. Clements-Garden City aggregate, however, lies quite close to the line. From these observations it is apparent that 3 of the aggregates being used in the Abilene District deviate from the general trend that has been established for other aggregates. The Clements-Garden City aggregate does not show such deviation.

Comparison with Aggregates from Other Parts of Texas

Subsequently, data collected for the Abilene District aggregates were compared with those reported from TxDot research study 3-9-85-438. Such a comparison will be particularly beneficial because it would enable one to make an assessment of the local aggregates in reference to other materials used throughout the state. The data extracted from research project 3-9-85-438 for this comparison are presented in Table 5.3. These materials included Limestones, Sandstones and Siliceous Gravels. Figure 5.4 shows the frequency distribution for aggregate absorption data. It can be immediately seen that the three Abilene aggregates; Massey-Richards White, Massey-Richards Blue and Yates-Parmelly are among the aggregates with highest absorption. In fact these three are among the seven(7) aggregate types with highest absorption among a total of 42 aggregate types (i.e. they are among the top 16%). It is interesting to note that these are also the aggregates which have caused problems during the mix preparation and construction. The fourth aggregate type i.e. yellow limestone from Clements-Garden City source did not cause similar problems but was included in the study as a reference material. This aggregate, as is apparent from Figure 5.4 ranks among those aggregates with medium absorption. The low absorption aggregates that are included in the first columns of the frequency distribution diagram are primarily siliceous gravels. From these observations it is quite evident that the poor performance reported for the MRB, MRW and YP aggregates are directly associated with their high absorptivity values. A comparison of their soundness losses with those recorded for materials from other parts of the state shows an entirely different picture. This data is shown in Figure 5.5. It is important to note at this point that the soundness loss data used for this comparison were obtained from District-8 laboratories. These data are summarized in Table 5.4. It was not possible to include the soundness test results from the current study in the analysis because the present test program included 5-cycle soundness loss tests. The

Table 5.3. Summary of Data from TxDot Study 3-9-85-438

Agg No.	Aggregate Type	4-Cycle Soundness (% Loss)	Absorption (%)	Spec Grav	Freeze Thaw (% Loss)	Los Angeles (% Loss)	PV
1	Cr. Limestone	52.2	3.3	2.47	15.4	30	39
2	Cr. Limestone	6.1	0.8	2.66	2.6	21	28
14	Cr. Limestone	7.6	1.9	2.54	1.7	27	29
17	Cr. Limestone	17.0	3.6	2.47	3.1	28	41
20	Cr. Limestone	39.0	2.2	2.56	14.9	30	37
26	Cr. Limestone	15.3/13.5	2.7	2.52	10.3	21	42
28	Cr. Limestone	1.7	0.8	2.70	1.1	21	27
29	Cr. Limestone	17.1	4.3	2.32	1.9	31	36
30	Cr. Limestone	2.3/2.1/1.2	1.4	2.52	4.3	16	33
37	Cr. Limest Strat #1	36.5/39.4/34.5/34.0	2.9	2.51	9.8	-	-
38	Cr. Limest Strat #2	40.1	8.4	2.16	1.0	-	-
39	Cr. Limest Strat #3	6.0	2.9	2.49	1.5	-	-
40	Cr. Limest Strat #4	43.6/34.9/38.6	3.9	2.45	21.1	-	-
41	Cr. Limestone	9.6/9.6/10.8	3.6	2.40	1.9	31	36
3	Cr. Sandstone	13.3	2.6	2.49	3.9	26	47
5	Cr. Sandstone	65.8/64.1/60.6	3.9	2.26	3.1	28	-
6	Cr. Sandstone	18.5	-	-	3.0	26	47
7	Cr. Sandstone	31.6/24.9/31.4	5.5	2.30	23.7	-	-
8	Cr. Sandstone	14.2/20.0	2.9	2.48	3.0	26	47
10	Cr. Sandstone	6.1	3.2	2.25	1.9	26	46
12	Cr. Sandstone	67.1	5.1	2.32	13.8	29	45
13	Cr. Sandstone	47.7/45.4	3.3	2.31	0.8	25	43
18	Cr. Sandstone	4.9/2.6/2.8/1.4	2.3	2.49	1.4	27	36
19	Cr. Sandstone	8.5	1.3	2.58	2.8	29	39
27	Cr. Sandstone	43.9	3.7	2.24	-	-	-
31	Cr. Sandstone	2.5	1.2	2.58	1.1	25	41
9	Cr. Flint Gravel	1.8	0.7	2.59	0.7	20	26
15	Cr. Gravel	9.1/8.9/9.3	1.0	2.57	2.1	16	29
16	Pea Gravel	7.3/7.7/10.1	2.1	2.59	6.7	22	-
21	Pea Gravel	5.2	1.4	2.61	4.1	24	-
22	Gravel	5.9	1.6	2.60	9.2	25	-
23	Gravel	2.4	1.2	2.63	5.2	25	-
24	Pea Gravel	6.8	2.2	2.60	6.7	24	-
25	Gravel	2.6/2.7/1.4	1.4	2.63	4.5	22	-
32	Cr. Silic Gravel	3.7	0.7	2.65	1.9	26	33
33	Cr. Silic Gravel	8.6	1.0	2.61	5.2	31	30
34	Cr. Silic Gravel	4.7	1.2	2.60	2.0	23	34
35	Cr. Silic Gravel	1.3	0.8	2.57	0.7	19	34
36	Cr. Silic Gravel	2.9	0.5	2.67	1.4	22	27
4	Lightweight	-	4.8	1.55	3.4	12	43
11	Lightweight	-	10.1	1.39	2.4	26	48

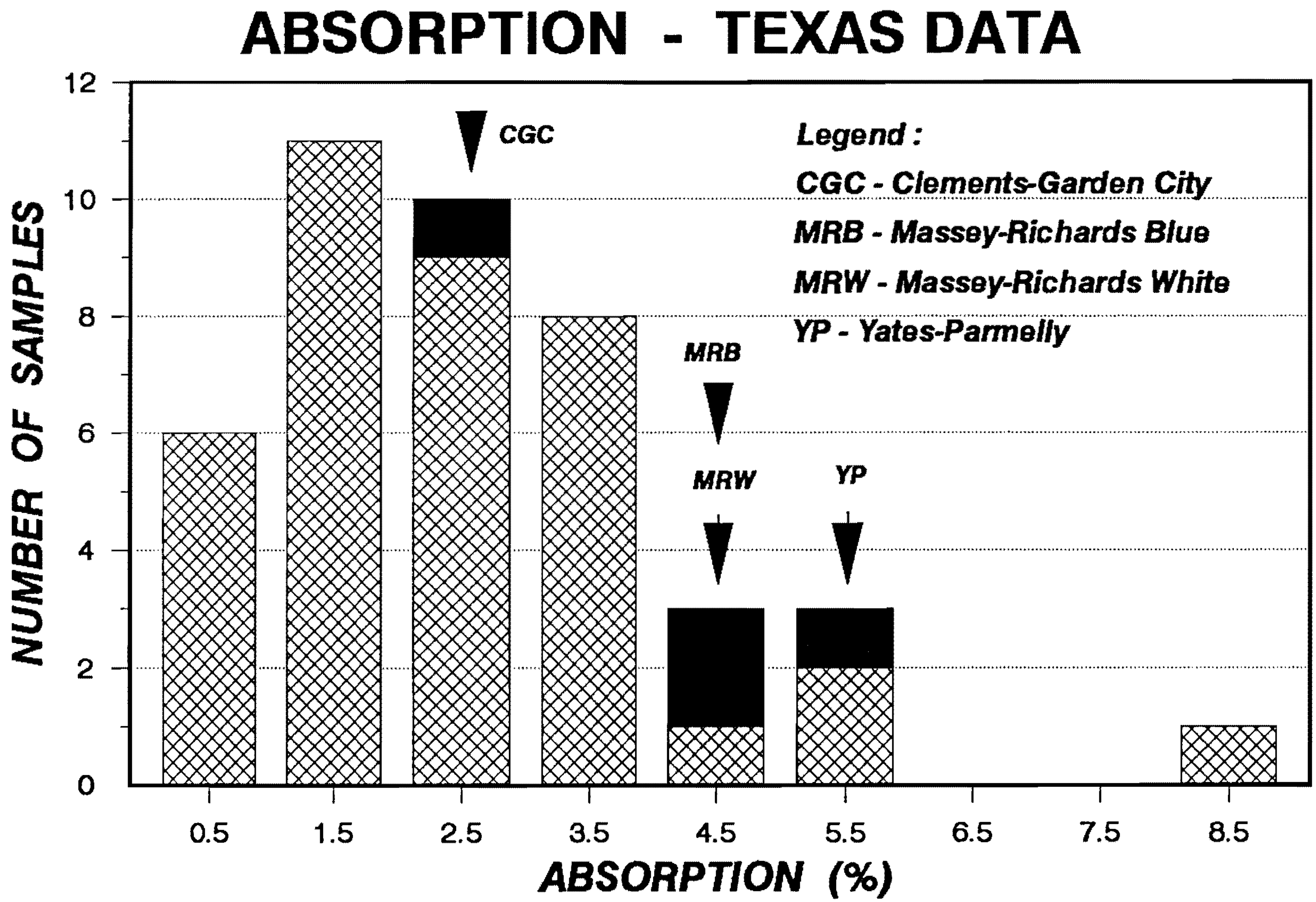


Figure 5.4 Frequency Distribution for (%)Absorpton of Texas Aggregates

SOUNDNESS LOSS - TEXAS DATA

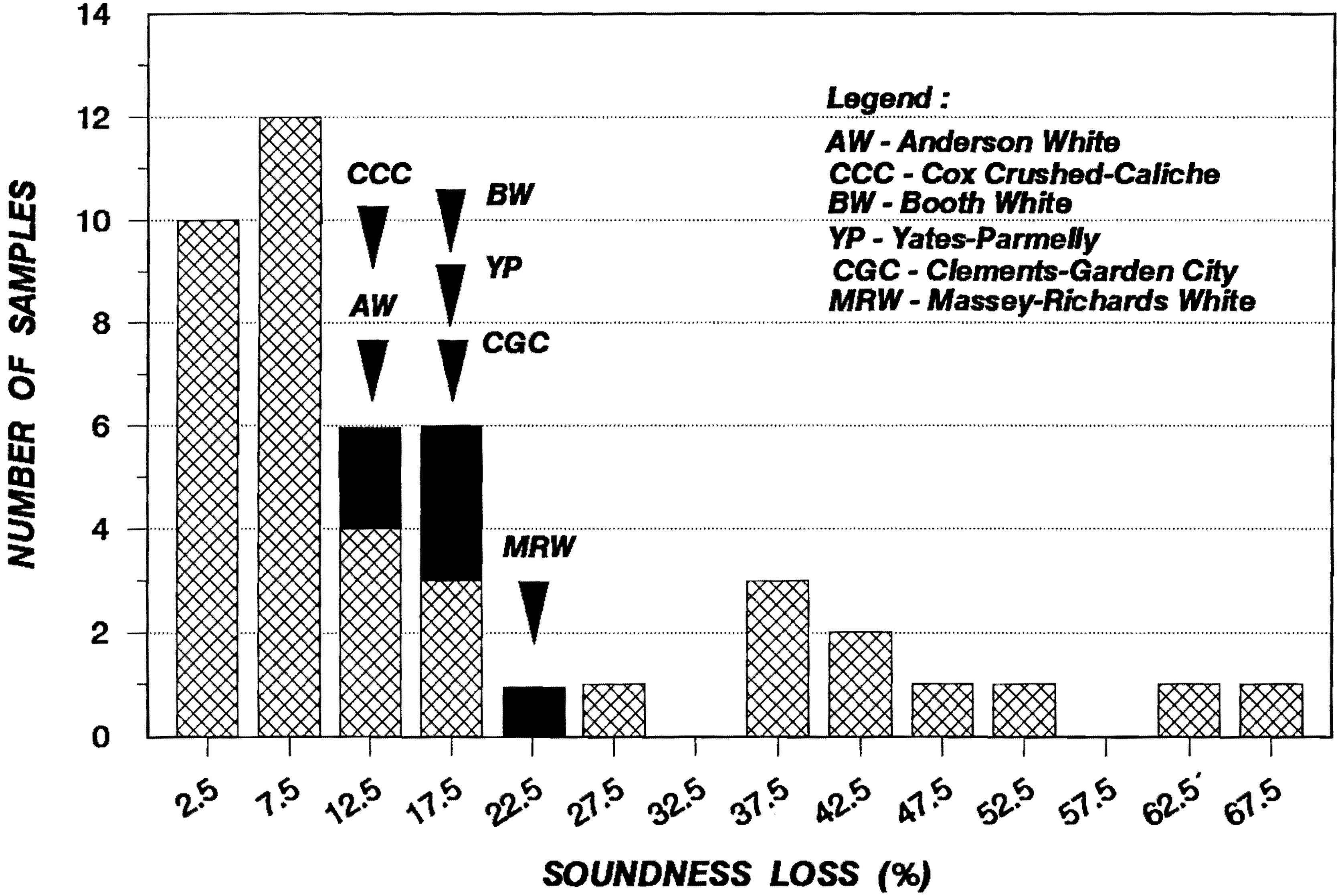


Table 5.4 Aggregate Properties Based on Data Collected from District-8 Laboratories

Description of Aggregate	Aggregate Sources	Range for % Soundness Loss (4 - Cycle Test)	% Absorption	Los Angeles Wear	Polish Value
White Limestone	Massey - Richards	18 - 28	5	28	37
White Limestone	Yates - Parmelly	18	5 - 6	30 - 35	-
Yellow Limestone	Clements - Garden City	18 - 20	4	30	35
White Limestone	Anderson	13	5 - 6	30	31
White Limestone	Booth	18	4 - 5	37	43
Crushed Caliche	Cox	12	-	28	36

testing completed for research study 3-9-85-438 as well as testing routinely performed in District-8 laboratories use 4-cycles. According to the figure none of the Abilene District aggregates show excessively high soundness losses. Considering that the first two classes with lowest soundness loss values represent siliceous gravels, it appears reasonable to classify Abilene District aggregates among materials with moderate soundness loss. Therefore, for the aggregate types investigated in this study, it may be concluded that the soundness loss has shown little correlation with aggregate absorption or with field performance. Figure 5.6 and Figure 5.7 show similar distributions for Los Angeles Abrasion Loss data and Freeze-Thaw Loss data. According to these plots Los Angeles Abrasion Loss has shown good correlation with observed field behavior whereas the Freeze Thaw does not show any correlation whatsoever.

The next step in the data analysis was to examine the Soundness Loss(%) versus Absorption(%) relation obtained for the Texas data. Figure 5.8 shows this relationship. The linear regression equation obtained from these data was:

4-cycle Soundness Loss(%) = 7.76 (Absorption%) - 1.82 ....(5.2)

Coefficient of Determination, r^2 = 0.46

The plot of Soundness Loss(%) versus Absorption(%) (Figure 5.8) shows significant scatter in data. This is also apparent in the low coefficient of determination, r^2 which is 0.46 as opposed to r^2 = 0.65 in the Mather study. The solid line represents the overall trend in data. The scatter in data indicates that although it is generally assumed that sulfate soundness loss is closely associated with absorptivity of the aggregate there can be significant deviations from such overall trends. The aggregates used in the Abilene District appear to be good examples of this. In Figure 5.8 they are seen clustered within the shaded area. Figure shows other aggregate types that show equally large deviations. It is interesting to note that both analyses, the first one based on data from study by Mather and the second based on data from study 3-9-85-438 show identical trends in the deviations shown by Abilene District aggregates. In both cases the data points representing Abilene aggregates lie *below* the regression line for the overall trend. In other words these aggregates yield much lower soundness loss values in comparison to most other aggregates with similar absorptivity.

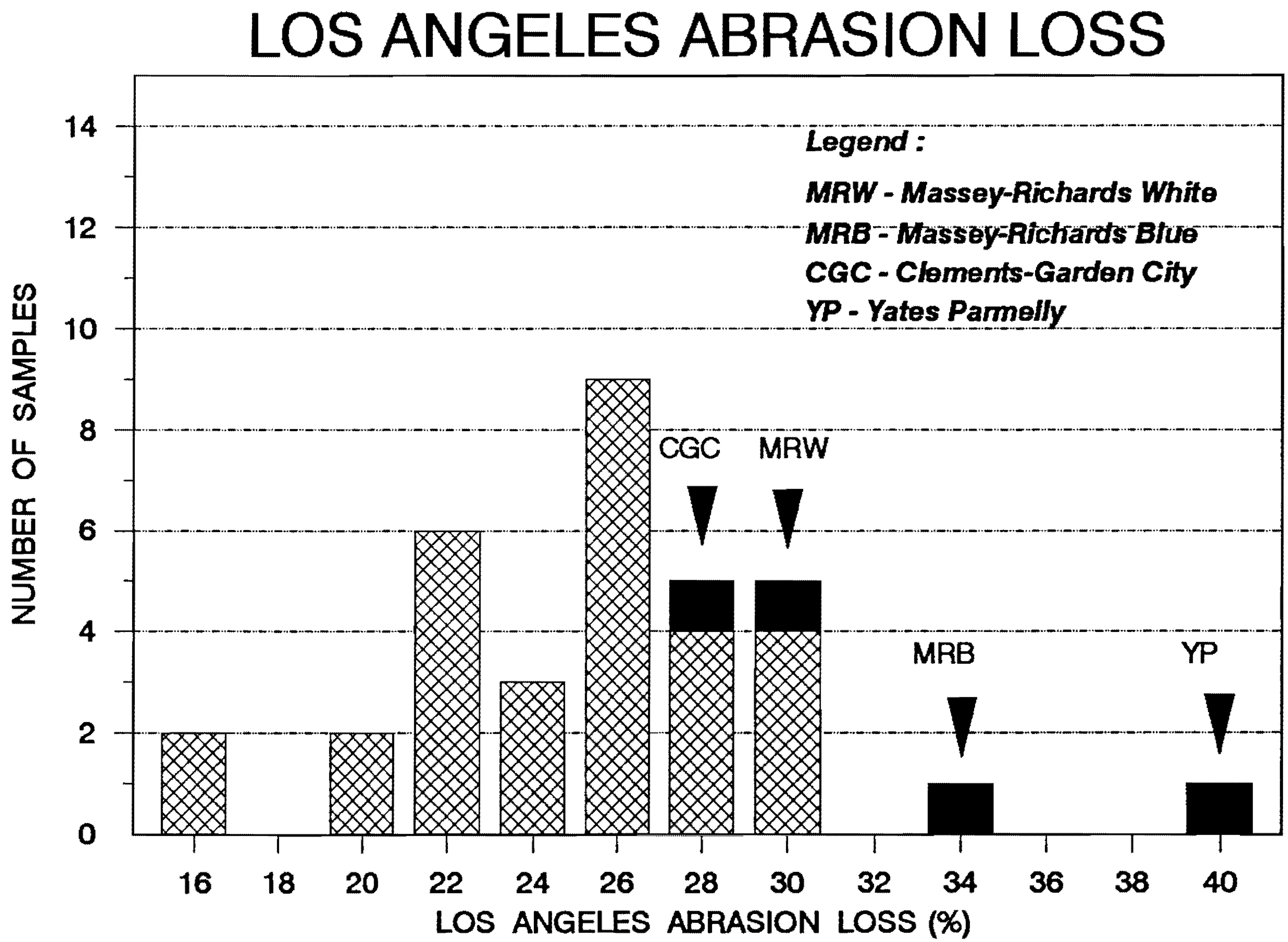


Figure 5.6 Frequency Distribution for Los Angeles Abrasion Loss of Texas Aggregates

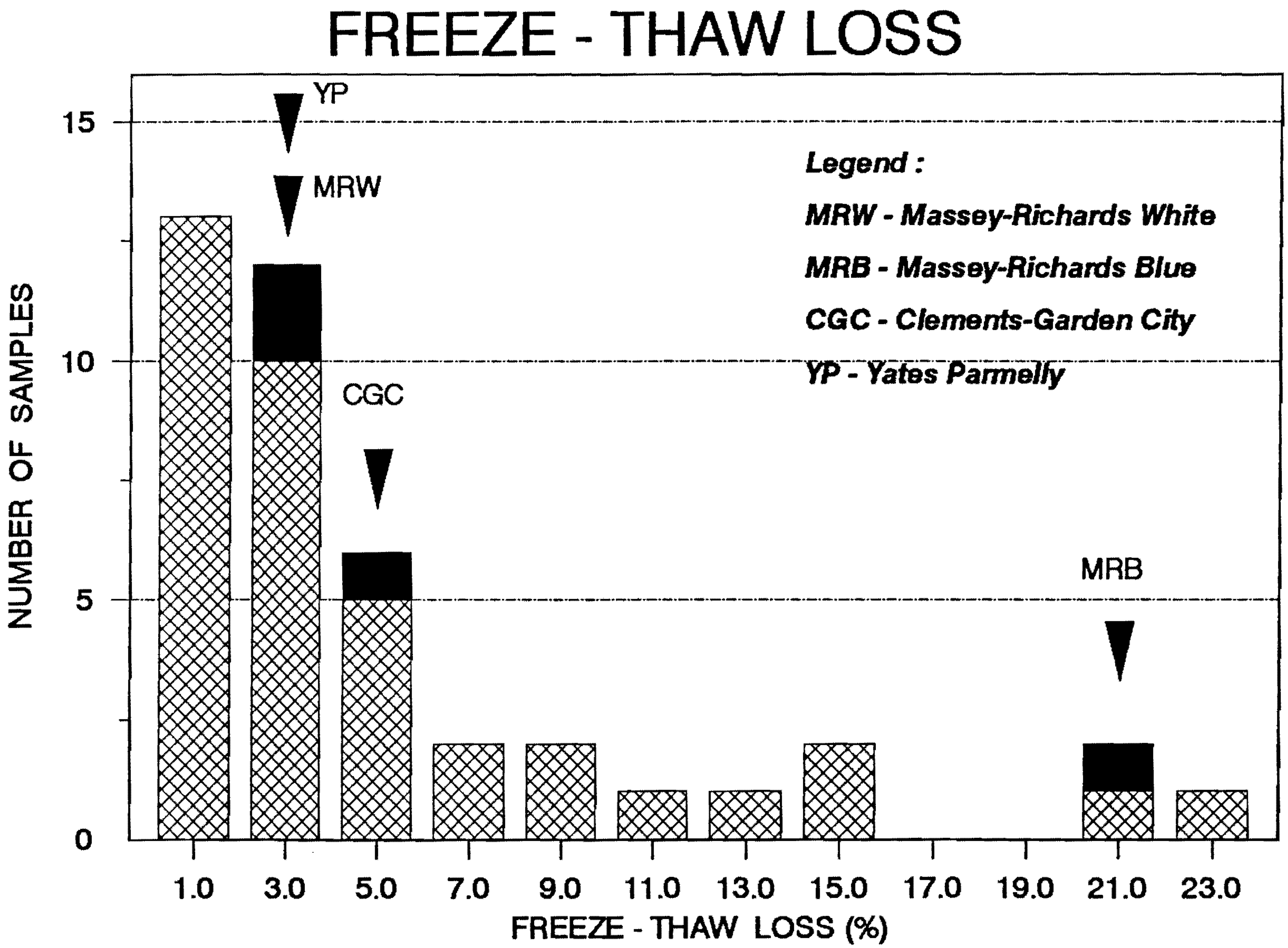


Figure 5.7 Frequency Distribution for Freeze-Thaw Loss of Texas Aggeregates

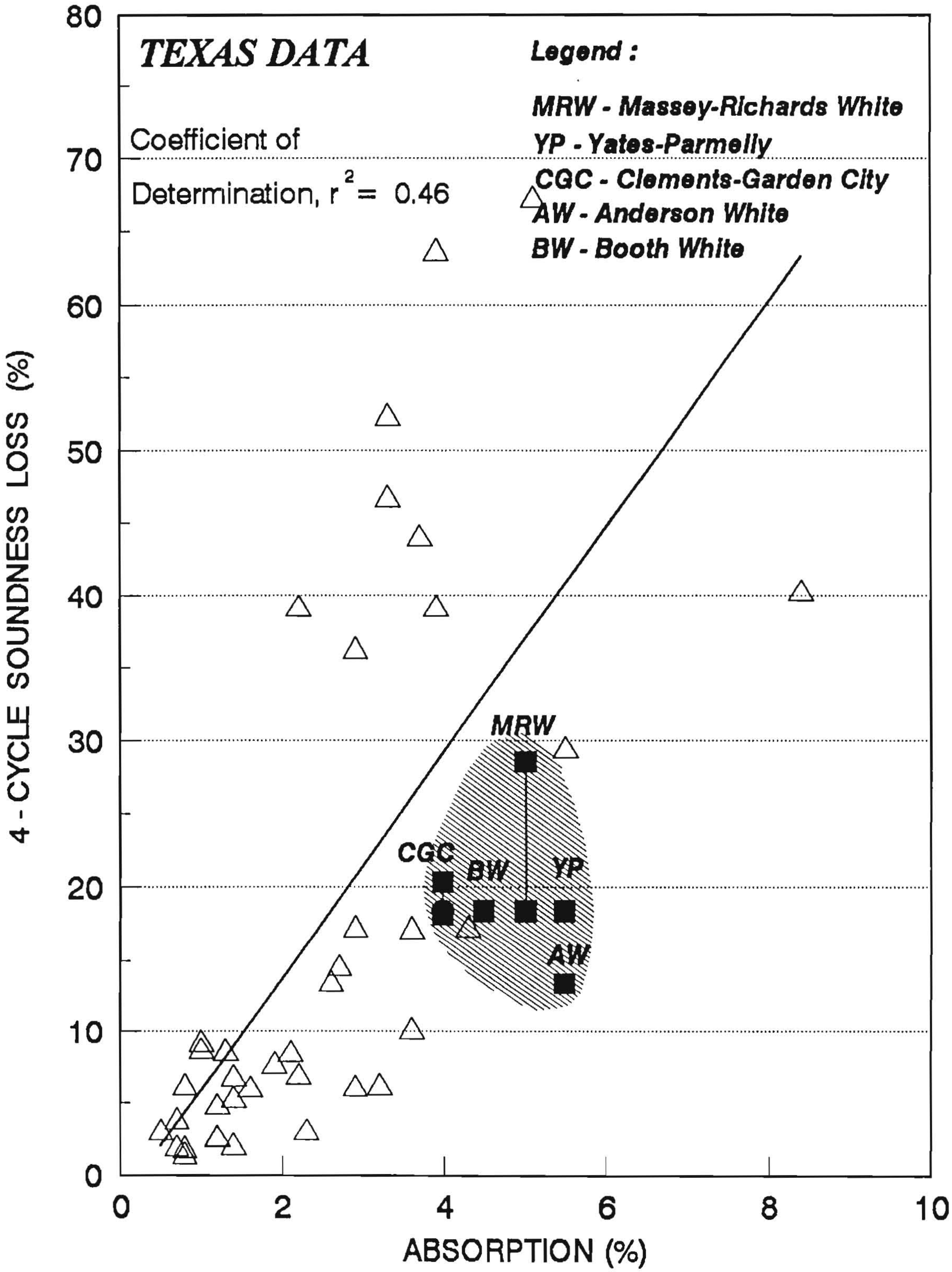


Figure 5.8 Correlation between Sulfate Soundness and Absorption of Texas Aggregates

Analysis of Field Performance Data

The next stage in the data analysis process involved the examination of the field performance data collected during this study to determine how they compared with performance data reported for other locations in Texas. Accordingly, the performance data base developed during TxDot research study 3-9-85-438 was used as the basis for comparison. The data from study 3-9-85-438 are summarized in Tables 5.5 and 5.6. In both research studies the in-service pavement performance was based on specific types of distress that are associated with poor aggregate quality. The specific distress types used in the evaluation were discussed in chapter 4 of this report. It is also important to note that at the present time there is no established method for the measurement of these specific distress types and as a result the evaluation of the pavements was of a subjective nature.

The evaluation of the in-service pavements in this the present study was accomplished using the same criteria as in the research study 3-9-85-438 with special effort to maintain same standards. However, since the evaluation was carried out by independent groups some discrepancy can be expected because of the subjective nature of the method of evaluation. In the final research report from study 3-9-85-438 the results of the field evaluations were presented in descriptive form. For the analysis purposes in this study the field performance of various pavement sections were classified as: Very Good, Good, Fair, Poor and Very Poor. Subsequently, the pavement sections used in the previous study (3-9-85-438) were identified with one the above performance categories based on the descriptive evaluations available. The results were then plotted against the Soundness Loss(%) values reported for each type aggregate. These plots of Pavement Performance versus Soundness Loss(%) obtained for HMAC surfaces and Seal Coat surfaces are shown in Figures 5.9 and 5.10 respectively.

The notation used in identifying the pavement sections in Figures 5.9 and Figure 5.10 is as illustrated in the following example: e.g. 15-IH37-3,6,8 represents Interstate Highway 37 in District 15 constructed using aggregate nos. 3,6 and 8. It should also be noted that the soundness values of aggregates that appear on the above figures may not correspond directly with those values reported in Table 5.3. The reason for this is that sometimes the same aggregate number has been used to identify a material when it came

Table 5.5 Field Performance of Selected HMAC Projects (Study 3-9-85-438)

Aggregate Number	District	County	Highway Number	ADT	Total Traffic	Construction Date	Roadway Condition
29, 41	11	Angelina	US69	11,400	14,364,000	11/83	extensive agg. wear, few popouts
29, 41	11	Angelina	SH147	640	844,800	9/83	extensive agg. wear, few popouts
29, 41	11	Angelina	US59	16,000	9,600,000	9/85	extensive agg. wear, few popouts
29, 41	14	Travis	US290	60,700	40,608,300	7/85	no surface deterioration
29, 41	15	Bexar	SH16	14,400	—	—	no surface deterioration
29, 41	14	Williamson	US183	28,800	21,880,000	4/85	good condition, few popouts
3, 6, 8	15	Bexar	IH37	15,000	—	—	no signs of deterioration
3, 6, 8	15	Bexar	IH37	8,900	—	—	no signs of deterioration
3, 6, 8	14	Travis	Loop 360	18,000	29,034,000	12/82	good condition, few popouts
3, 6, 8	15	Bexar	Loop 410	14,500	—	—	no signs of deterioration
13	16	Nueces	IH37	35,000	48,300,000	6/83	cracking, many popouts, agg. breaking
13	16	Neuces	US277	10,000	5,400,000	9/85	surface deter., agg. breaking, popouts
13	16	Neuces	SH44	9,500	6,555,000	4/85	some popouts, fairly good condition
13	16	Neuces	SH358	34,000	58,140,000	6/82	cracking, many popouts, agg. breaking
26	7	Tom Green	US67	3,000	990,000	6/86	no signs of deter. except few popouts
26	7	Tom Green	US67	3,000	6,300,000	7/81	no signs of deter. except few popouts

Table 5.6 Field Performance of Selected Seal Coat Projects (Study 3-9-85-438)

Aggregate Number	District	County	Highway Number	ADT	Total Traffic	Construction Date	Roadway Condition
29, 41	11	Angelina	Loop 36	1,100	1,573,000	6/83	severe agg. wear, crushing, 90% embedment
29, 41	11	Angelina	SH7	1,400	1,932,000	6/83	severe agg. wear, crushing, shelling
29, 41	14	Williamson	US79	9,320	6,235,080	7/85	agg. wear, many particles, crushed
3, 6, 8	14	Williamson	US79	9,810	20,895,300	7/81	very good condition, few breaks
12	13	DeWitt	SH72	1,300	858,000	6/85	some shelling, few breaks and popouts
12	13	Fayette	SH95	820	541,200	6/85	severe agg. loss, many popouts and breaks
12	13	Lavaca	SH111	1,400	924,000	6/85	severe agg. loss, popouts, agg. breaking, 20% patching
12	13	Lavaca	US90-A	2,100	1,386,000	6/85	many agg. broken, agg. wear, 90% embedment
5, 27	16	Nueces	FM666	700	1,197,000	6/82	very few broken particles
5, 27	16	Nueces	IH37	—	—	7/84	severe surface deter. 40% agg. loss
14	13	DeWitt	SH72	1,225	1,212,750	6/84	good condition, some agg. breaks
14	13	DeWitt	US87	1,850	1,831,500	6/84	good condition, some agg. breaks
14	13	Gonzalez	US80	880	580,000	6/85	good condition, some breaks
14	15	Bexar	FM1303	770	—	—	good condition, some breaks
14	15	Bexar	FM2537	740	—	—	good condition, some breaks
26	7	Tom Green	US87	5,000	75,000	5/87	severe surface deter, crushing, dissolving agg.
26	7	Tom Green	US87	5,000	1,750,000	6/86	some agg. splitting and crushing
26	7	Tom Green	FM2288	1,900	570,000	7/86	asphalt bubbling, few breaks, good condition
1	7	Tom Green	US277	2,100	1,449,000	6/85	some agg. crushing and loss, good condition

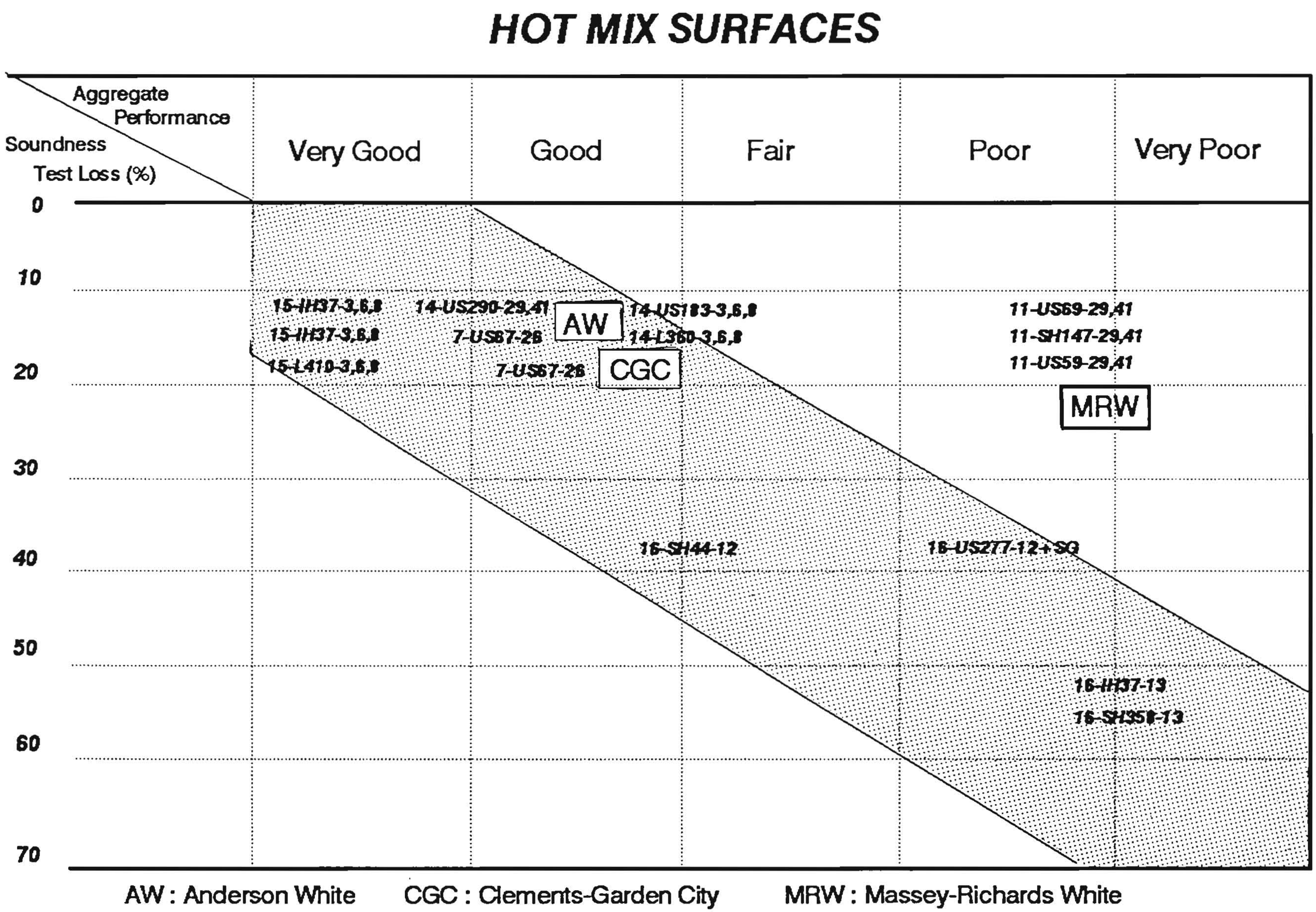


Figure 5.9 Correlation between Aggregate Soundness Loss and Field Performance of HMAC Surfaces

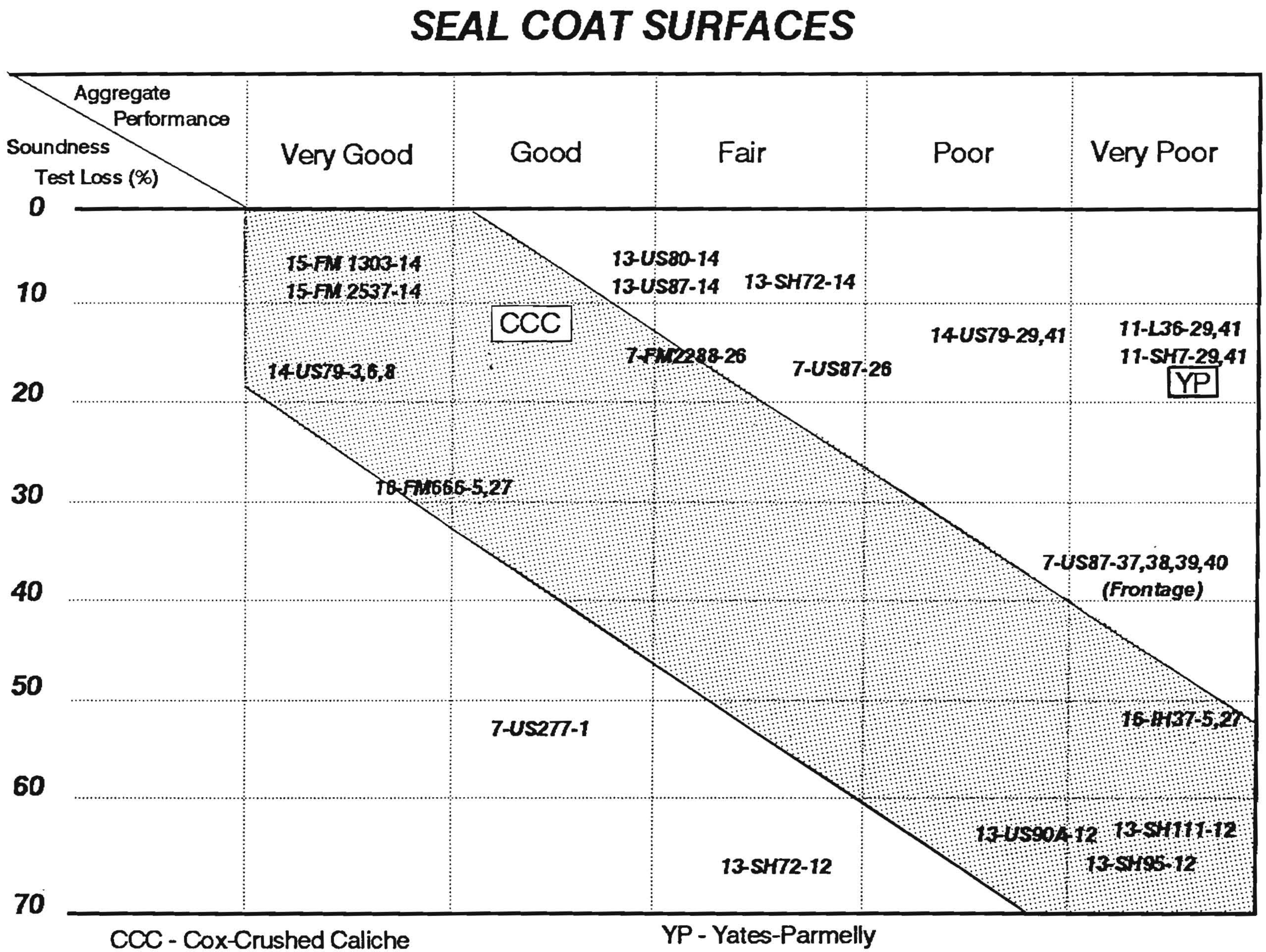


Figure 5.10 Correlation between between Aggregate Soundness Loss and Field Performance of Seal Coat Surfaces

directly from the source and also when the fines had been removed from that material to meet soundness loss requirements. Furthermore, wherever a soundness loss value for the aggregate that was used in a specific job was provided that value superseded the soundness value provided in Table 5.3 for that material.

Based on the results from study 3-9-85-438 it was concluded that among the various test parameters examined soundness test provided the best correlations with observed field performance. In the graphical form shown in Figures 5.9 and 5.10 the same data can be examined with regard to correlation between field performance and aggregate soundness loss. A good correlation would be indicated by a data spread that is confined within a narrow band that extends diagonally from the upper left hand corner to the lower right hand corner, such as the gray shaded area. Examination of these plots reveals that many of the test sections fall within such a band indicating that some correlation between soundness loss and field performance does exist. It may also be noted that this correlation is better in the case of HMAC surfaces than for the seal coat surfaces. However, at the same time it can be seen that certain pavement sections have shown very significant deviations from this general trend. For example, hot mix surfaces on US 69 in District 11 have shown poor to very poor performance in spite of the fact the aggregates used (nos. 29,41) had soundness loss values that ranged between 10.0 to 17.0%. On the other hand, seal coat surface on US 277 in District 7 showed good performance in spite of having used an aggregate(no.1) with soundness loss of 52%.

Subsequently, the aggregates types from Abilene District were plotted on the same charts. The evaluations provided by the district on some of the aggregates were not specific to selected projects but were based on their general performance in a number of projects in which they were used. Therefore the charts show where a given type of aggregate would fall based on its average soundness loss and in-service performance. The following aggregates have been used in the preparation of hot mix asphalt concrete: Anderson white limestone, Clements-Garden City yellow limestone and Massey-Richards white limestone. Based on Figure 5.9 it can be concluded that the first two types of aggregates from Anderson and Clements-Garden City sources follow the general trend shown by most other aggregates. Their soundness values were in the moderate range and they have demonstrated good in-service performance. However, the third aggregate type, namely Massey-Richards white limestone clearly deviates from the general trend. Its soundness loss has never been excessive. However, contrary to what may be expected from its moderate soundness loss the in-service performance has consistently been poor to very poor.

Similarly, the two types of aggregates that have been used by the district in seal coat preparation are shown in Figure 5.10. The first aggregate Cox crushed caliche has low soundness loss and has shown good in-service performance and therefore follows the general trend. The second aggregate, Yates Parmelly material, may be identified as the worst material in terms of its in-service performance among all materials that are being currently used in the district. However, the soundness loss value for this aggregate is well within acceptable limits. This particular material appear to be one of the aggregate types that show extreme deviation from the general performance-soundness loss relations.

Chapter 6
CONCLUSIONS AND RECOMMENDATIONS

The tasks completed in this study included: (a) review of pertinent literature on previous research work to document the suitability of magnesium sulfate soundness test as an aggregate evaluation method (b) characterization of selected aggregates from Abilene District through a series of laboratory tests (c) collection of data to establish field performance of these aggregates. Based on the findings of these tasks and subsequent data analyses the following conclusions were drawn.

Conclusions:

1. The problems experienced with the use of the aggregates Yates-Parmelly white limestone and Massey-Richards White limestone are clearly due to their high absorptivity. These two aggregates and Massey-Richards blue limestone had the three highest absorption values (ranging between 4.2%-5.8%) when they were compared with absorption data reported for 409 other aggregates examined in another research study. A second comparison between Abilene district aggregates and other Texas aggregates revealed that their absorption values were among the highest 7 out of a total of 42. The percent absorption for the reference material, Clements-Garden City aggregates was 2.9% which is significantly lower than the absorptivity measured for the three other Abilene aggregates.
2. The results of the sulfate soundness test of the above problem aggregates fail to identify them as absorptive materials. The average 5-cycle sulfate soundness loss for Yates-Parmelly, Massey-Richards white and Massey-Richards blue limestones are 17.0%, 20.0% and 13.3%, all of which are well below the current specifications. An examination of the relationship between sulfate soundness and absorption reveals that there is a general trend for the soundness loss to increase with absorptivity. At the same time, however, there are aggregates with

significant deviations from the above general trend. In other words, some aggregates have high absorption values but yield low soundness losses; others have low absorption but yield high soundness losses. The three problem aggregates from Abilene district belong to the former category.

3. The reproduceability of the soundness test results is poor. However, in comparison to the data reported in literature and based on the guidelines provided in the ASTM Procedures, the aggregates from Abilene District yielded consistent results. However, the variability observed in the soundness test results for the Yates-Parmelly aggregate is noticeably higher than those for the other three aggregates tested.

4. The technical literature available on the use of soundness test as a predictor of field performance primarily address aggregates used in concrete mixes rather than in asphalt concrete. Their findings can be summarized as follows. *The sulfate soundness test only provides a very rough indication of the ability of aggregates to produce durable concrete. If properly interpreted in the light of other tests and field service record, they assist engineering judgement in determining the permissibility of using a particular aggregate in a particular application. The use of a specific limit on soundness loss to distinguish between acceptable and unacceptable aggregates is not justified. If the limit is set low enough to reject all objectionable materials, it will also reject most acceptable ones. If it is high enough to accept all good aggregates, it will also accept many that should not be used. Therefore an aggregate should not be accepted or rejected based solely on soundness test results, especially if the previous service record of the aggregate proves otherwise. Service Record is the engineer's best criterion for predicting aggregate performance.*

5. The information available on aggregate soundness and their performance in asphalt concrete mixes is more limited. Three such research studies, all dealing with Texas aggregates were located and reviewed in detail. The findings of these research studies are somewhat contradictory. Two of the above studies were in favor of the use of soundness test and the third identified the test as a poor predictor of field performance. The results of the analyses performed in the third

research study indicated that out of seven(7) distress modes investigated two(2) distress modes were not affected at all by aggregate soundness. Aggregate soundness was listed as the least important test for four(4) other distress modes. In the analysis for the remaining distress mode aggregate soundness ranked seventh(7^{th}) out of nine test parameters. Among the studies that supported the use of soundness test, the first was a departmental research study dealing with aggregates in a local area. The second was more comprehensive and included a total of 41 aggregates used in pavement construction projects in different parts of Texas. Based on the findings of the latter study it was reported that *among all tests examined soundness test provided the best correlation with actual in-service performance.* The data reported in the above research study were further reviewed. This review confirmed that some correlation between aggregate soundness loss and field performance does exist. This correlation was better for hot mix asphalt concrete surfaces than for seal coat surfaces. However, it could also be noticed that certain aggregates have shown significant deviation and have resulted in very poor performance despite their low soundness loss and vice versa.

6. In the present study, information was collected on the in-service performance of each of the selected aggregates through a questionnaire sent to the Abilene district engineers who have had experience with these local aggregates. Based on these evaluations the following can be concluded regarding the field performance of each aggregate. The performance of the Yates-Parmelly aggregate has been very poor in spite of its low soundness loss. Massey-Richards white limestone also has demonstrated poor to very poor performance in spite of its low soundness loss. On the other hand, Anderson white limestone, Clements-Garden City limestone and Crushed Caliche from Cox source have good in-service records which are compatible with good performance in the soundness test.
7. Based on the observations made in 4, 5 and 6 above it is concluded that for many aggregates, sulfate soundness provides an indication of their absorptivity and in-service performance. However, significant deviations from this general behavior do occur for some aggregates. Therefore the use of a inflexible

soundness limit in aggregate selection is not justified. Especially when substantial data on previous performance of the aggregate is available, a decision regarding the suitability of the aggregate should be made based on this data even though such data is contradicted by aggregate soundness.

8. The percent loss in Los Angeles abrasion tests for all the aggregates were high compared with other Texas aggregates. However, these values were still below the specification limit (35%) currently used by the Abilene district with the exception of the Yates-Parmelly limestone. Based on the data available from the district 8 laboratory all the local materials, including Yates-Parmelly aggregate meet the L.A. wear specification. Therefore, it is evident that L.A. Abrasion test has not been particularly helpful in identifying problem aggregates. All three previous studies indicated that L.A. wear was a poor predictor of aggregate field performance.

9. The freeze-thaw test results obtained for the three of the four aggregate types (Massey-Richards white limestone, Clements-Garden City limestone and Yates-Parmelly limestone) were very low (range: 2.2-4.9%). The freeze-thaw loss for Massey-Richards blue limestone was much higher (22%). These results show no correlation with the field performance of the aggregates.

Recommendations:

Based on the findings of this study the following recommendations are made.

1. There is substantial evidence on the poor field performance of the two aggregates, Yates-Parmelly white limestone and Massey-Richards white limestone and therefore, their use in the preparation of hot mix asphalt concrete and seal coats may be discontinued even if they meet the current soundness loss requirement.

2. Direct measurement of percent absorption of many of the local limestones show that they are highly absorptive. The findings of this study has clearly demonstrated that the sulfate soundness has failed to identify the absorptive nature or the poor field performance of the Abilene district aggregates. Therefore, caution must be exercised in the use of soundness test as a aggregate

selection method.

3. The study does not, however, recommend to discontinue the use of soundness loss requirement altogether. The data available statewide, particularly the more recent data, show that the use of a specification limit on aggregate soundness has resulted in improved road performance. Communication with many TxDot engineers confirmed that the soundness loss requirement has improved the quality of the aggregates by helping to reduce the amount of fines and deleterious substances present in the aggregate.

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APPENDIX A

Test Method Tex-401-A

Rev: December 1989

State Department of Highways and Public Transportation

Materials and Tests Division

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATE

Scope

This test method, which is a modification of ASTM Designation: C 136, covers a procedure for the determination of the particle distribution of fine and coarse aggregate samples using sieves with square openings. The test is intended for use in the analysis of aggregates for portland cement concrete and surface treatments. It is also applicable to the sieve analysis of mineral fillers.

Definitions

The term "sieve" as used in this procedure is intended to denote wire mesh with square openings meeting the requirements of ASTM Designation: E 11 and used for the separation of aggregates into various specified sizes. The definitions of fine and coarse aggregate as used in this test method are in conformance with ASTM Designation: C 125.

Apparatus

1. Quartering machine, sample splitter or quartering cloth.

2. A set of Standard U.S. Sieves containing the following sizes: 3", 2-1/2", 2", 1-3/4", 1-1/2", 3/4", 1/2", 3/8", No's 4, 8, 16, 30, 50, 100, 200 and pan which meet the requirements of Test Method Tex-907-K.

3. Mechanical sieve shaker.

4. Balance

A. For fine aggregate, a balance or scale accurate within 0.1% of the test load at any point within the range of use, graduated to at least 0.1 grams.

B. For coarse aggregate, a balance or scale accurate within 0.1% of the test load at any point within the range of use, graduated to at least 0.5 grams.

5. Drying oven capable of attaining a temperature of 230°F or more.

6. Pans with diameter to fit sieves.

7. Small scoop, brushes, etc.

Test Record Form

Identify the material with laboratory number and record test data on work sheet and report on an acceptable Department form.

Sampling

Sample the aggregate in accordance with Test Method Tex-400-A.

Preparation of Sample

Obtain a test sample in accordance with Test Method Tex-400-A, Quartering a Sample. For materials consisting of a mixture of fine and coarse aggregate, use a No. 4 sieve and separate into two sizes before obtaining test sample.

Prepare the aggregate as follows:

A. Coarse Aggregate

1. The sample of aggregate to be tested for sieve analysis shall be thoroughly mixed and reduced by use of a quartering machine, sample splitter or quartering cloth to an amount that will be approximately 4000 grams when dried.

2. Place the approximate 4000-gram sample of aggregate in an oven and dry to substantially constant weight at approximately 230 F. Remove the sample from the oven and allow to cool to room temperature. Weigh and record weight to nearest gram. Coarse aggregate need not be dry for tests in the field.

B. Fine Aggregate, Laboratory Method

1. Select a representative sample of approximately 2000 grams from material that has been thoroughly mixed and that contains sufficient moisture (about SSD condition) to prevent segregation. Where the fine aggregate is a combination of sands, the sample shall contain these sands in the proportions by weight in which they will be used. Do not include mineral filler in the sieve analysis.

2. Determine the amount of material finer than the No. 200 sieve in accordance with Part I of Test Method Tex-406-A.

3. Reduce dry sample (from Step #5 of Part I of Tex-406-A) to approximately 1000 grams by means of a splitter or quartering cloth.

4. Weigh the sample and record to the nearest gram.

Note: For sieves with openings smaller than No. 4, the weight retained on any sieve at the completion of the sieving operation should not weigh more than 4 g/sq in. of sieving surface. (This is approximately 200 grams for 8-in. diameter sieves.)

C. Fine Aggregate, Field Method

1. Secure a representative sample of approximately 2000 grams of the sand to be tested. Where the fine aggregate is a combination of sands, the sample shall contain these sands in the proportions by weight in which they occur in the total weight of sand used in the mix. Do not include mineral filler in the sieve analysis.

2. Dry the sample to below saturated surface-dry in the sun or by artificial heat.

3. Select a representative sample of the sand of approximately 1000 grams.

D. Mineral Filler

Dry the mineral filler at approximately 230°F and then obtain a laboratory test size sample of approximately 500 grams by carefully quartering the material. Perform the sieve analysis immediately after removing from oven.

Procedure

1. Perform the sieve analysis on the aggregate sample by separating the material into a series of particle sizes by means of such sieves as are necessary to determine compliance with specifications for the material. Place the set of sieves, with largest openings on top, into a pan and pour the prepared aggregate onto the top screen. The hand sieving is done by means of a lateral and vertical motion of the sieves accompanied by a jarring action so as to keep the material moving continuously over the surface of the sieves. Limit the amount of material on each sieve to a single layer to prevent clogging the openings and continue sieving until not more than one percent of the residue passes any sieve in one minute of shaking. Do not turn or manipulate particles through the openings of the sieves by hand. If mechanical sieving is used, shake the material for approximately ten minutes and check the thoroughness of sieving by the hand method described above.

2. Determine the weight and record to the nearest gram of particles retained on each sieve using a scale with a capacity large enough to obtain the weight of the total sample. Weigh the portion of aggregate retained on the largest size sieve first, record this weight, then place the contents of the next largest size sieve on the scale and obtain the cumulative weight of the two sizes. Continue this operation of obtaining cumulative weights until the contents of the smallest sieve used have been emptied and weighed.

Calculations

Use the cumulative weights to calculate the percentages retained on the various sieves on the basis of the dry weight of the total sample which includes the weight of the material which passed the smallest size sieve used in the analysis as follows:

$$\text{Percent retained} = \frac{\text{Weight retained (grams)}}{\text{Weight of total sample}} \times 100$$

Note: When using Method B, Fine Aggregate, Laboratory Methods, add the percentage finer than No. 200 sieve determined by Tex-406-A to the percentage passing No. 200 sieve by dry sieving of the same sample. Total sample weight for calculating percentages retained will be the dry weight of the sample plus the proportionate weight loss by washing (Tex-406-A).

Reporting Test Results

Report the percentages to the nearest whole number for the total percentages retained on each sieve.

Notes

1. In performing this analysis use caution to lose none of the sample during the shaking or weighing operations. However, if there is an insignificant discrepancy between the original dry weight of the sample and the sum of the weights of the various parts, assume the small amount to pass the smallest size sieve and use the original weight.

2. Any pan of suitable size and texture will be satisfactory. Avoid the use of metal pans which react with aggregates.

APPENDIX B

Test Method Tex-201-F

Rev: December 1989

State Department of Highways and Public Transportation

Materials and Tests Division

BULK SPECIFIC GRAVITY AND WATER ABSORPTION OF AGGREGATE

Scope

This test method describes a procedure for determining the bulk specific gravity and water absorption of aggregate. The test is performed by obtaining the oven-dry weight of a quantity of aggregate and measuring the volume of the material in a saturated surface-dry condition by displacement of water. This bulk specific gravity may be used in calculating the theoretical gravity of a bituminous mixture. The water absorption may be used to determine the amount of free moisture in aggregate which is an indication of the porosity of the material. Figures la and lb demonstrate the theory of the bulk specific gravity determination.

Definitions

Bulk Volume: The bulk volume of an aggregate includes both the volume of the impermeable portion of the aggregate particles and the volume of the permeable voids in the particles. The bulk volume of the aggregate is equal to the volume of water displaced by the aggregate in a saturated, surface-dry condition.

Bulk Specific Gravity: This term is defined as the ratio of the oven-dry weight of the aggregate to the bulk volume of the aggregate particles.

Apparatus

1. A balance with a minimum capacity of 4000 g which meets the requirements of Test Method Tex-901-K, Class III-D.

2. Half-gallon glass fruit jar and pycnometer cap.

3. Drying oven capable of attaining a temperature of 200°F or more, hot plate, gas burner, or suitable microwave oven.

4. Wide-mouth funnel.

5. A set of Standard U.S. sieves which meet the requirements of Test Method Tex-907-K.

6. Round pans, 7-3/4 quart capacity.

7. Small masonry pointing trowel.

8. Small ear syringe.

9. Sample-splitter, quartering machine, or quartering cloth (unless shoveling method on clean surface is used.)

Materials

1. Lint-free cotton cloth.

2. Fine carborundum cloth.

3. Turpentine.

4. Clean tap water.

Test Record Form

Record test data on work card, Form No. D-9-F15 and report test values on Form No. 231.

Calibration of Pycnometer

It is necessary to prepare and calibrate the pycnometer to assure that it is of definite and constant volume. Select a half-gallon fruit jar with good threads on neck and with rim free from cracks or broken places. Clean the jar and fill with clean tap water. With the gasket seated smoothly in place, screw the metal pycnometer cap snugly on the jar. Fill the jar with water at 77 ± 1°F. Other water temperatures may be used when accurate control of the water temperature at 77 ± 1°F is not practical. However, the water temperatures used during the pycnometer calibration and the final weighing of the pycnometer containing the test sample should not differ by more than 2°F. Use ear syringe, Figure 3, to complete filling with water, leaving a rounded bead of water on top of the cap. If the pycnometer leaks water, place a piece of fine grain carborundum cloth on a smooth, solid, plane surface and pour a small amount of turpentine on the cloth. Hold the

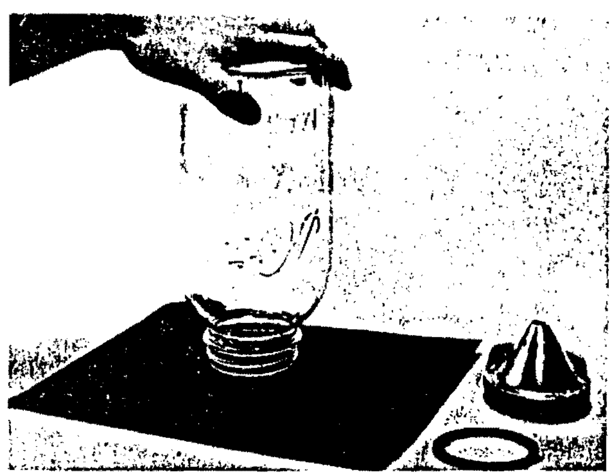


Figure 2

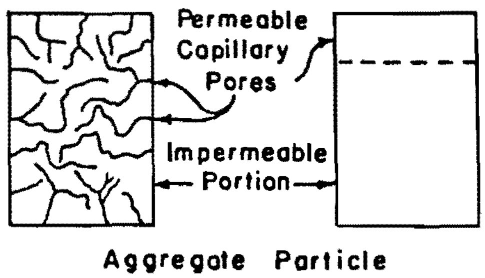
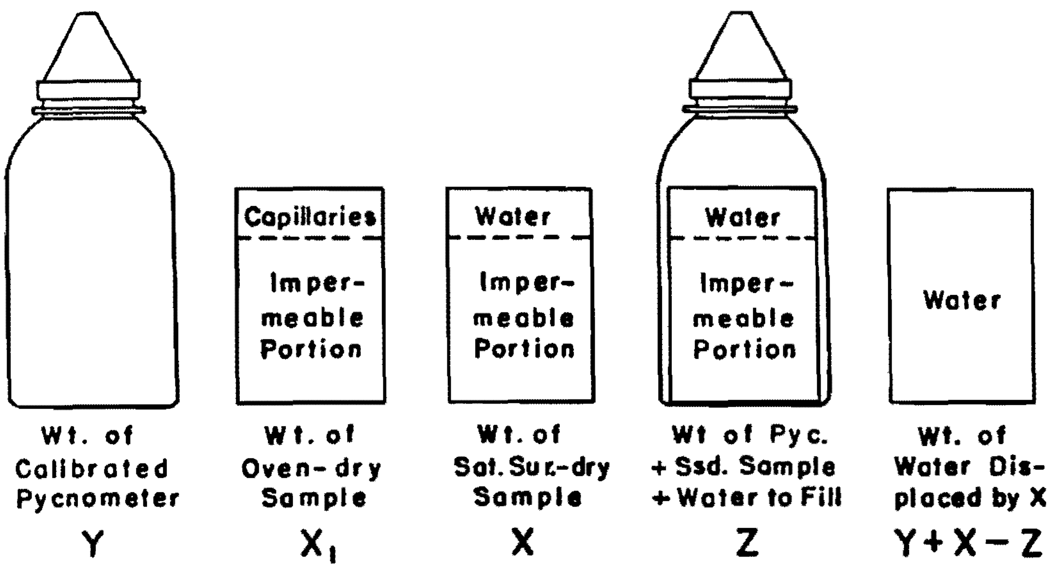


Figure 1a



$$\text{Vol. } X_1 = \text{Vol. } X = \text{Vol. } Y + X - Z; \quad \text{Bulk Sp. Gr.} = \frac{X_1}{Y+X-Z}$$

Figure 1b

Figure 3

jar as shown in Figure 2, smooth and true the rim by rotating the jar. Apply force and continue the grinding action until the rim of the jar appears to be perfectly smooth. Weigh the pycnometer filled with water to the nearest estimated 0.1 gram, Figure 3, and record weight as Y each time pycnometer is used.

Preparation of Sample

1. Secure a quantity of representative material proposed for use and reduce to laboratory test size by quartering.

2. Use the procedure outlined in Test Method Tex-200-F for sieve analysis and divide the material classified as coarse aggregate (material retained on the No. 10 sieve) into sizes to conform with the requirements of the specification. Sieve the fine aggregate (material passing the No. 10 sieve) over the No. 80 sieve. Save the material passing the No. 80 sieve and determine the specific gravity in accordance with Test Method Tex-202-F.

3. After the aggregates have been separated into the proper sizes, rinse or wash with clean water to remove any fine materials that might have existed as a coating on particles or in the form of lumps. The coarse aggregates are washed over a No. 10 sieve.

4. Place approximately 1500 - 2000 grams of each size aggregate, obtained from Step 2 above, in separate milk pans; cover with water and saturate for 24 hours, or boil the aggregate for four hours. Keep the aggregate inundated throughout the soaking period or while boiling to thoroughly saturate all of the material with water. (Synthetic aggregates should not be boiled for saturation. Soak for 24 hrs.) After this period of saturation, rewash the coarse aggregates over the No. 10 sieve to remove slaked material, if necessary.

BULK SPECIFIC GRAVITY

Procedure

1. Surface-dry each aggregate portion as follows:

a. Surface-dry all aggregate particles retained on the No. 10 sieve by means of the lint-free cloth. Drain the water from the sample, transfer a portion of the material to the cloth and roll in the cloth until all surface moisture has been removed. Do not dry past the surface-dry condition. Place the surface-dry aggregate in a small pan and cover with lid. Continue this operation until the total sample has been surface-dried and weigh immediately to prevent loss of moisture by evaporation.

b. Carefully drain the water from the aggregate passing the No. 10 sieve and retained on the No. 80 sieve. Then place the wet material on a smooth non-absorbent surface, such as a metal or tile topped work bench, and allow to air dry (Figure 4). An air circulating type fan may be used as an aid in decreasing time required for drying but do not apply artificial heat or sunlight. Use a small trowel to stir and mix the sample frequently so that the particles on top will not become drier than the surface-dry condition. Determine the saturated, surface-dry condition as follows:

Method (1): Place a small amount of aggregate of the same grading as that being tested, which is obviously drier than surface-dry, into a dry milk pan with smooth bottom. Tilt the pan to an approximately 45° angle with table and tap lightly on the bottom observing the manner in which the dry material slides down the bottom of the tilted pan. Place a portion of the sample which is near to surface-dry condition in another dry milk pan, tilt and tap while observing how the material flows or slides (Figure 5). When the aggregate being tested ceases to adhere to the bottom of the pan and flows freely, as the dry sample did, it is judged to be surface dry.

Method (2): Scoop up on a small masonry pointing trowel some of the same aggregate that is being tested that is obviously drier than surface-dry. Tilt the trowel slowly to one side, observing how the dry material flows freely from the trowel. Then scoop up the same amount of the nearly surface-dry sample being tested and tilt the trowel in the same manner watching it flow from the edge of the trowel. When the material being tested ceases to adhere to the trowel surface and flows off freely as individual particles, as the dry sample did, it is said to be in a saturated, surface-dry condition.

Note: Be certain that the trowel is completely dry before each check on the material.

2. Transfer the saturated, surface-dry material to the balance and weigh immediately to prevent the loss of moisture by evaporation. Weigh the sample to the nearest estimated 0.1 gram and record weight as X.

3. Place the saturated, surface-dry sample into the pycnometer jar approximately one-fourth full of water by means of the wide-mouth funnel, taking care to lose none of the sample. The water should be at approximately the temperature used for calibration. Rinse the funnel thoroughly so that any clinging particles will be washed into the jar.

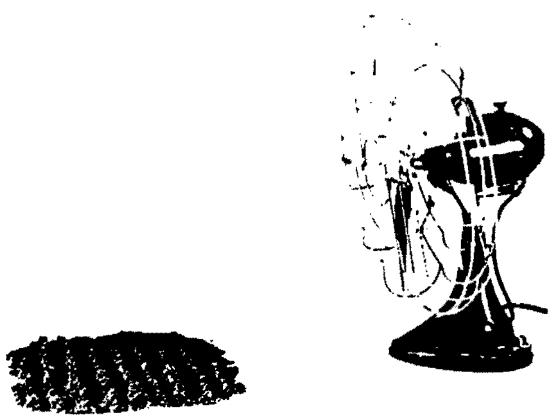


Figure 4

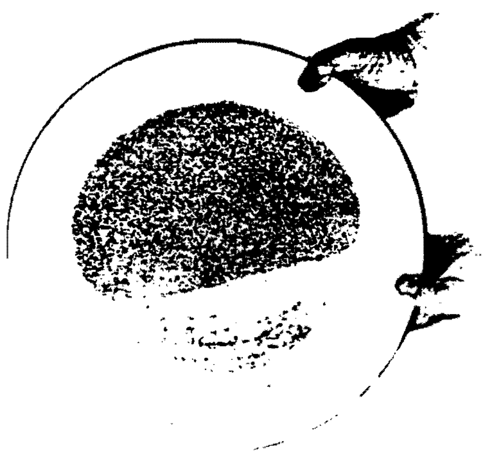


Figure 5

4. Fill the jar with water to within approximately one-half inch of the rim, screw the cap on the jar and fill completely with water. Insure that the water temperature is 77 ± 1°F or within 2°F of the other selected calibration water temperature. Place finger over hole in the cap and roll the pycnometer to free all entrapped air. When the sample contains large pieces of coarse aggregate (retained on 3/8" sieve), the pycnometer should be rolled gently to prevent breaking the glass jar. The material should be gently tossed from one end of the jar to the other with a swinging motion while rolling. When a quantity of air bubbles has accumulated, refill the pycnometer, washing out the air and roll again. Repeat this process until all of the entrapped air has been removed. To facilitate the removal of the air, a water-aspirator may be used, but care should be exercised to prevent siphoning out any of the finer particles.

5. Dry the outside of the pycnometer thoroughly, use ear syringe to carefully fill with water, leaving a rounded bead of water on top of pycnometer cap, and weigh to nearest estimated 0.1 gram (Figure 3). Record weight as Z.

6. Remove the cap from the pycnometer and pour the sample into a clean, tared milk pan. Use plenty of water to rinse jar, cap and hands thoroughly. Allow the material to remain undisturbed until the water becomes perfectly clear, then decant or siphon the water from the sample. Take care to lose none of the material while pouring or draining the water from sample.

7. Dry the aggregate to constant weight at a temperature of 220° to 400°F and cool to room temperature before weighing. Record the net oven-dry weight of sample to the nearest estimated 0.1 gram as X_1.

Calculations

1. Calculate the bulk specific gravity of the aggregate by the following formula:

$$G = \frac{X_1}{X + Y - Z}$$

Where:

G = Bulk (oven-dry) specific gravity of aggregate

X_1 = Weight (grams) of oven-dry sample

X = Weight (grams) of saturated, surface-dry sample

Y = Weight (grams) of calibrated pycnometer filled with water

Z = Weight (grams) of pycnometer containing saturated surface dry sample and water.

2. Using the data from No. 1 above, calculate the apparent specific gravity (G_A) of the aggregate as follows:

$$G_A = \frac{X_1}{X_1 + Y - Z}$$

3. Calculate the average bulk specific gravity of combined sizes of aggregate or combination of materials as follows:

$$G = \frac{100}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \text{etc.}}$$

Where:

G = Average bulk specific gravity of combination

G_1 = Bulk specific gravity of Material No. 1

G_2 = Bulk specific gravity of Material No. 2

W_1 = Percentage of Material No. 1 from screen analysis or based on total weight of combination.

W_2 = Percentage of Material No. 2 from screen analysis or based on total weight of combination.

$W_1 + W_2 + W_3$, etc., should total 100%

4. Using the test data secured in determining the bulk specific gravity, calculate the water absorption of the aggregate as follows:

$$A = 100\,\frac{X - X_1}{X_1}$$

Where:

A = Percent water absorption (24 hours) of aggregate based on the oven-dry weight of sample

X = Weight (grams) of saturated, surface-dry sample

X_1 = Weight (grams) of oven-dry aggregate

5. Calculate the average percent water absorption of combined materials as follows:

$$A = \frac{A_1W_1 + A_2W_2 + \text{etc.}}{100}$$

Where:

A = Average percent water absorption (24 hours) of combined materials based on the total weight of oven-dry combination

A_1 = Percent water absorption of Material No. 1

A_2 = Percent water absorption of Material No. 2

W_1 and W_2 are the same as defined under Step 2.

Notes:

1. When it is desired to determine the average bulk specific gravity of aggregate which contains aggregate sizes finer than the No. 80 sieve, the apparent specific gravities determined according to Test Method Tex-202-F may be used for those sizes in the formula shown in 3, above.

2. Repeated bulk specific gravity results should check within ± 0.02.

APPENDIX C

State Department of Highways and Public Transportation

Materials and Tests Division

SOUNDNESS OF AGGREGATE BY USE OF SODIUM SULFATE OR MAGNESIUM SULFATE

Scope

This test method covers the procedure to be followed in testing aggregates to determine their resistance to disintegration by saturated solutions of magnesium sulfate or sodium sulfate. Attention is called to the fact that test results by the use of the two salts differ considerably and care must be exercised in fixing proper limits in any specification which may include requirements for these tests. The test as performed is a modification of ASTM designation: C 88-83 or AASHTO T104.

Note 1 - When testing HMAC coarse aggregate or surface treatment aggregate, the smallest size of material to be tested will be retained on the No. 8 sieve.

Significance and Use

This test method provides a procedure for making a preliminary estimate of the soundness of aggregates for use in concrete and other purposes.

Values for the permitted-loss percentage by this test method are usually different for fine and coarse aggregates, and attention is called to the fact that test results by use of the two salts differ considerably and care must be exercised in fixing proper limits in any specifications that include requirements for these tests. The test is usually more severe when magnesium sulfate is used; accordingly, limits for percent loss allowed when magnesium sulfate is used are normally higher than limits when sodium sulfate is used.

Apparatus

Sieves - with square openings of the following sizes conforming to Test Method Tex-907-K for sieving the samples in accordance with sections titled Samples, Preparation of Test Samples, and Quantitative Examination:

150 um (No. 100)	8.0 mm (5/16 in.)
	9.5 mm (3/8 in.)
300 um (No. 50)	12.5 mm (1/2 in.)
	16.0 mm (5/8 in.)
600 um (No. 30)	19.0 mm (3/4 in.)
	25.0 mm (1 in.)
1.18 mm (No. 16)	31.5 mm (1-1/4 in.)
2.36 mm (No. 8)	37.5 mm (1-1/2 in.)
	50 mm (2 in.)
4.00 mm (No. 5)	63 mm (2-1/2 in.)
	larger sizes by
4.75 mm (No. 4)	12.5 mm (1/2 in.)
	spread

Containers - Containers for immersing the samples of aggregate in the solution, in accordance with the procedure described in this test method, shall be perforated in such a manner as to permit free access of the solution to the sample and drainage of the solution from the sample without loss of aggregate.

Note 2 - Baskets made of suitable wire mesh or sieves with suitable openings are satisfactory containers for the samples.

Temperature Regulation - Suitable means for regulating the temperature of the samples during immersion in the sodium sulfate or magnesium sulfate solution shall be provided.

Balances - For fine aggregate, a balance or scale accurate within 0.1 g over the range required for this test; for coarse aggregate, a balance or scale accurate within 0.1% or 1 g, whichever is greater, over the range required for this test.

Drying Oven - The oven shall be capable of being heated continuously at 230 ± 9°F (110 ± 5°F) and the rate of evaporation, at this range of temperature, shall be at least 25 g/h for 4 h, during which period the doors of the oven shall be kept closed. This rate shall be determined by the loss of water from 1-L Griffin low-form beakers, each initially containing 500 g of water and temperature of 70 ± 3°F (21 ± 2°C), placed in each corner and the center of each shelf of the oven. The evaporation requirement is to apply to all test locations when the oven is empty except for the beakers of water.

Specific Gravity Measurement - Hydrometers conforming to the requirements of Specification ASTM E 100, or a suitable combination of graduated glassware and balance, capable of measuring the solution specific gravity within ± 0.001.

Special Solutions Required

Prepare the solution for immersion of test samples from either sodium or magnesium sulfate in accordance with one of the procedures listed below (Note 3). The volume of the solution shall be at least five times the solid volume of all samples immersed at any one time.

Note 3 - Some aggregates containing carbonates of calcium or magnesium are attacked chemically by fresh sulfate solution, resulting in erroneously high measured losses. If this condition is encountered or is suspected, repeat the test using a solution that has been used previously to test the same type of carbonate rock provided that the solution meets the requirements for specific gravity.

Prepare a saturated solution of sodium sulfate by dissolving a USP or technical grade of the salt in water at a temperature of approximately 130°F. Add sufficient salt (Note 4), of either the anhydrous ($NaSO_4$) or the crystalline ($NaSO_4 \cdot 10H_2O$) form, to ensure not only saturation, but also the presence of excess crystals when the solution is ready for use in the tests. Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed. Allow the solution to cool to 68°F to 75°F. Again stir, and allow the solution to remain at the designated temperature for at least 48 hours before use. Prior to each use, break up the salt cake, if any, in the container and stir the solution thoroughly. Determine and document both the temperature and the specific gravity of the solution a minimum of once a week as test reproducibility will be affected if these factors are allowed to vary from the test requirements. When obtaining a specific gravity reading, obtain it prior to stirring the solution. When tested, the solution shall have a specific gravity not less than 1.151 nor more than 1.174. Discard a discolored solution, or filter it and check for specific gravity.

Note 4 - For the solution, 215 g of anhydrous salt or 700 g of the decahydrate per litre of water are sufficient for saturation at 71.6°F (22°C). However, since these salts are not completely stable and since it is desirable that an excess of crystals be present, the use of not less than 350 g of the anhydrous salt or 750 g of the decahydrate salt per litre of water is recommended.

Prepare a saturated solution of magnesium sulfate by dissolving a USP or technical grade of the salt in water at a temperature of approximately 130°F. Add sufficient salt (Note 5), of either the anhydrous ($MgSO_4$) or the crystalline ($MgSO_4 \cdot 7H_2O$) (Epson Salts) form, to ensure saturation and the presence of excess crystals when the solution is ready for use in the tests. Thoroughly stir the mixture during the addition of the salt and stir the solution at frequent intervals until used. To reduce evaporation and prevent contamination, keep the solution covered at all times when access is not needed. Allow the solution to cool to 68°F to 75°F. Again stir, and allow the solution to remain at the designated temperature for at least 48 hours before use. Prior to each use, break up the salt cake, if any, in the container, and stir the solution thoroughly. Determine and document both the temperature and the specific gravity of the solution a minimum of once a week as test reproducibility will be affected if these factors are allowed to vary from the test requirements. When obtaining a specific gravity reading, obtain it prior to stirring the solution. When used, the solution shall have a specific gravity not less than 1.295 nor more than 1.308. Discard a discolored solution, or filter it and check for specific gravity.

Note 5 - For the solution, 350 g of anhydrous salt or 1230 g of the heptahydrate per litre of water are sufficient for saturation at 73.4°F (23°C). However, since these salts are not completely stable, with the anhydrous salt being the more stable of the two, and since it is desirable that an excess of crystals be present, it is recommended that the heptahydrate salt be used and in an amount of not less than 1400 g/litre of water.

Samples

The sample shall be obtained and reduced to test portion size in accordance with Test Method Tex-400-A.

Fine Aggregate - Fine aggregate for the test shall be passed through a 9.5 mm (3/8 in.) sieve. The sample shall be of such size that it will yield not less than 100 g of each of the following sizes, which shall be available in amounts of 5% or more, expressed in terms of the following sieves:

Passing Sieve	Retained on Sieve
600 ug (No. 30)	300 um (No. 50)
1.18 mm (No. 16)	600 um (No. 30)
2.36 mm (No. 8)	1.18 mm (No. 16)
4.75 mm (No. 4)	2.36 mm (No. 8)
9.5 mm (3/8 in.)	4.75 mm (No. 4)

If 5% or more of the sample is retained on the 9.5 mm (3/8 in.) or larger sieve, that portion must be tested, with the amount of material listed under Coarse Aggregate below.

Coarse Aggregate - Coarse aggregate for the test shall consist of material from which the sizes finer than the No. 4 sieve have been removed. The sample shall be of such a size that it will yield the following amounts of the indicated sizes that are available in amounts of 5% or more:

Size (Square-Opening Sieves)	Weight, g
5 mm (3/8 in.) to 4.75 mm (No. 4)	300 ± 5
19.0 mm (3/4 in.) to 9.5 mm (3/8 in.)	1000 ± 10
Consisting of:	
12.5 mm (1/2 in.) to 9.5 mm (3/8 in.) material	330 ± 5
19.0 mm (3/4 in.) to 12.5 mm (1/2 in.) material	670 ± 10
37.5 mm (1-1/2 in.) to 19.0 mm (3/4 in.)	1500 ± 50
Consisting of:	
25.0 mm (1 in.) to 19.0 mm (3/4 in.) material	500 ± 30
37.5 mm (1-1/2 in.) to 25.0 mm (1 in.) material	1000 ± 50
63 mm (2-1/2 in.) to 37.5 mm (1-1/2 in.)	5000 ± 300
Consisting of:	
50 mm (2 in.) to 37.5 mm (1-1/2 in.) material	2000 ± 200
63 mm (2-1/2 in.) to 50 mm (2 in.) material	3000 ± 300
Larger sizes by 25 mm (1 in.) spread in sieve size, each fraction	7000 ± 1000

If 5% or more of the sample is retained on any sieve smaller than the No. 4, that portion shall be tested. The minimum amount tested shall conform to the Fine Aggregate above. (See Note 1.)

When an aggregate to be tested contains appreciable amounts of both fine and coarse material, having a grading with more than 10 weight % coarser than the 9.5 mm (3/8 in) sieve and, also, more than 10 weight % finer than the 4.75 mm (No. 4) sieve, test separate samples of the minus No. 4 fraction and the plus No. 4 fraction in accordance with the procedures for fine aggregate and coarse aggregate, respectively. For concrete aggregate, report the results separately for the fine aggregate fraction and the coarse aggregate fraction, giving the percentages of the coarse and fine size fractions in the initial grading. For bituminous aggregate, combine the weighted fine and coarse aggregate losses based on the percentages of plus No. 4 and minus No. 4 material in the original sample.

Preparation of Test Sample

Fine Aggregate - Thoroughly wash the sample of fine aggregate on a 300 um (No. 50) sieve, dry to constant weight at 230 ± 9°F (110 ± 5°C), and separate into the different sizes by sieving, as follows: Make a rough separation of the graded sample by means of a nest of the standard sieves specified in the Samples Section. From the fractions obtained in this manner, select samples of sufficient size to yield 100 g after sieving to refusal. (In general, a 110 g sample will be sufficient.) Do not use fine aggregate sticking in the meshes of the sieves in preparing the samples. Weight samples consisting of 100 ± 0.01 g out of each of the separated fractions after final sieving and place in separate containers for the test.

Coarse Aggregate - Thoroughly wash and dry the sample of coarse aggregate to constant weight at 230 ± 9°F (110 ± 5°C) and separate it into the different sizes shown in the Samples Section by sieving to refusal. Weigh out quantities of the different sizes within the tolerances of the Samples Section and, where the test portions consists of two sizes, combine them to the designated total weight. If only one size is available, test the designated total weight. Record the weights of the test samples and their fractional components. In the case of sizes larger than 19.0 mm (3/4 in.), record the number of particles in the test samples.

Procedure

Storage of Samples in Solution - Immerse the samples in the prepared solution of sodium sulfate or magnesium sulfate for not less than 16 h nor more than 18 h in such manner that the solution covers them to a depth of at least ½ in. (Note 6). Cover the containers to reduce evaporation and prevent the accidental addition of extraneous substances. Maintain the samples immersed in the solution at a temperature of 68°F to 75°F for the immersion period.

Note 6 - Suitably weighted wire grids placed over the sample in the containers will permit this coverage to be achieved with very lightweight aggregates.

Drying Samples After Immersion - After the immersion period, remove the aggregate sample from the solution, permit it to drain for 15 ± 5 min, or until sample stops dripping, and place in the drying oven. The temperature of the oven shall have been brought previously to 230 ± 9°F (110 ± 5°C). Dry the samples at the specified temperature until constant weight has been achieved. Establish the time required to attain constant weight as follows: with the oven containing the maximum sample load expected, check the weight losses of test samples by removing and weighing them, without cooling, at intervals of 2 to 4 h; make enough checks to establish required drying time for the least favorable oven location (see Apparatus Section) and sample condition (Note 7). Constant weight will be considered to have been achieved when weight loss is less than 0.1% of sample weight in 4 h of drying. After constant weight has been achieved allow the samples to cool to room temperature when they shall again be immersed in the prepared solution as described in Storage of Samples in Solution.

Note 7 - Drying time required to reach constant weight may vary considerably for several reasons. Efficiency of drying will be reduced as cycles accumulate because of salt adhering to particles and, in some cases because of increase in surface area due to breakdown. The different size fractions of aggregate will have different drying rates. The smaller sizes will tend to dry more slowly because of their larger surface area and restricted interparticle voids, but this tendency may be altered by the effects of container size and shape.

Number of Cycles - Repeat the process of alternate immersion and drying until the required number of cycles is obtained. Aggregates will be subjected to 5 cycles unless otherwise specified.

Quantitative Examination

Make the quantitative examination as follows:

After completion of the final cycle and after the sample has cooled, wash the sample free from the sodium sulfate or magnesium sulfate as determined by the reaction of the wash water with barium chloride ($BaCl_2$). Wash by circulating water at 110 ± 10°F (43 ± 6°C) through the samples in their containers. This may be done by placing them in a tank into which the hot water can be introduced near the bottom and allowed to overflow. In the washing operation, the samples shall not be subjected to impact or abrasion that may tend to break up particles. If barium chloride indicates the presence of salt in clear tap water, the following alternate procedure should be used.

Alternate: After the completion of the final cycle and after the sample has been cooled, immerse the sample in warm tap water (initial temperature 85 ± 15°F) overnight in a sink or other container. In the washing operation, the samples shall not be subjected to impact or abrasion that may tend to break up particles.

The next working day wet sieve the sample using the sieve to determine loss and clean the containers to remove any sulfate salt. Wet sieve the size of aggregate passing the No. 4 over the same sieve on which it was retained before the test, and wet sieve the size of aggregate retained on the No. 4 over the sieve shown below for the appropriate size of particle. For all sizes of aggregate, the sieving shall be by hand, with agitation sufficient only to assure that all undersize material passes the designated sieve. No extra manipulation shall be employed to break up particles or cause them to pass the sieves. After wet sieving, dry each fraction of the sample to constant weight at 230 ± 9°F (110 ± 5°C). Weigh the material retained in each sieve and record each amount. The difference between each of these amounts and the initial weight of the fraction of the sample tested is the loss in the test and is to be expressed as a percentage of the initial weight for use in Table 1.

Size of Aggregate	Sieve Used to Determine Loss
63 mm (2-1/2 in.) to 37.5 mm (1-1/2 in.)	31.5 mm (1-1/4 in.)
37.5 mm (1-1/2 in.) to 19.0 mm (3/4 in.)	16.0 mm (5/8 in.)
19 mm (3/4 in.) to 9.5 mm (3/8 in.)	8.0 mm (5/16 in.)
9.5 mm (3/8 in.) to 4.75 mm (No. 4)	4.0 mm (No. 5)

Report

Report test results to the nearest 0.1% loss.

Weight of each fraction of each sample before test.

Material from each fraction of the sample finer than the sieve designated in the Quantitative Examination Section for sieving after test, expressed as a percentage of the original weight of the fraction.

Weighted average calculated from the percentage of loss for each fraction, based on the grading of the sample as received for examination or, preferably, on the average grading of the material from that portion of the supply of which the sample is representative. See Example A.

For fine aggregates (with less than 10% coarser than the 9.5 mm (3/8 in.) sieve), assume sizes finer than the 300 um (No. 50) sieve to have 0% loss and sizes coarser than the 9.5 mm (3/8 in.) sieve to have the same loss as the next smaller size for which test data are available.

For coarse aggregate (with less than 10% finer than the 4.75 mm (No. 4) sieve), assume sizes finer than the 4.75 mm (No. 4) sieve to have the same loss as the next larger size for which test data are available.

For an aggregate containing appreciable amounts of both fine and coarse material tested as two separate samples as required in the Samples Section, compute the weighted average losses separately for the minus No. 4 and plus No. 4 fractions based on recomputed gradings considering the fine fraction as 100% and the coarse fraction as 100%. Report the results separately giving the percentage of the minus No. 4 and plus No. 4 material in the initial grading. See Example B.

For the purpose of calculating the weighted average, consider any sizes in the Samples Section that contain less than 5% of the sample to have the same loss as the average of the next smaller and the next larger size, or if one of these sizes is absent, to have the same loss as the next larger or next smaller size, whichever is present.

Kind of solution (Sodium or Magnesium sulfate).

Note 8 - Table 1, shown with test values inserted for purpose of illustration, is a suggested form for recording test data. The test values shown might be appropriate for either salt, depending on the quality of the aggregate.

APPENDIX D

State Department of Highways and Public Transportation

Materials and Tests Division

ABRASION OF COARSE AGGREGATE BY USE OF THE LOS ANGELES MACHINE

Scope

This Test Method covers the procedure for testing conventional and lightweight coarse aggregate for resistance to abrasion in the Los Angeles testing machine with an abrasive charge. The apparatus and procedure used in this test are identical with ASTM Designation: C 131.

Procedure

Use the apparatus specified to prepare and test the required gradings of aggregate in accordance with the procedure described in ASTM Designation: C 131.

Reporting Test Results

Record type grading and test data on Form No. 9.561 and report type grading and wear to the nearest whole percent on Form No. 272.

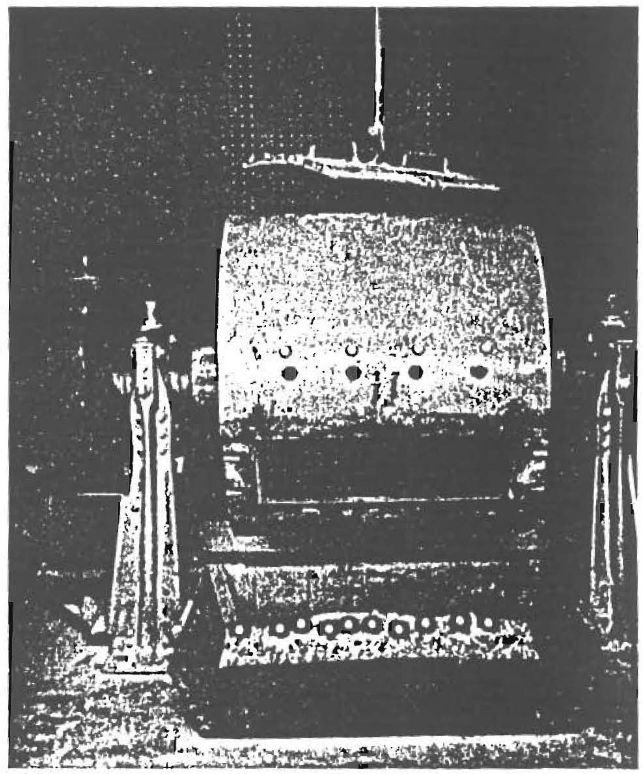


Figure 1

APPENDIX E

State Department of Highways and Public Transportation

Materials and Tests Division

COARSE AGGREGATE FREEZE-THAW TEST

Scope

This method of test describes a procedure to be followed in testing synthetic coarse aggregate to determine their resistance to disintegration by freezing and thawing. It furnishes information helpful in judging the soundness of aggregates subjected to weathering action.

Apparatus

The apparatus shall consist of the following:

1. The freezing chamber - the freezing chamber shall be any commercial type freezer of suitable dimensions and shall be capable of maintaining a constant temperature of 15°F or lower.

2. Trays and containers - shallow metal trays approximately one inch in depth and of suitable dimensions to contain the aggregate sample in a single layer.

3. A set of Standard U.S. Sieves of the following sizes: 3/4", 5/8", 1/2", 3/8", No. 4 and No. 10 which meets the requirements of Test Method Tex-907-K.

4. A balance with a minimum capacity of 800 grams which meets the requirements for Test Method Tex-901-K, Class II-C.

5. Drying oven - the drying oven shall provide a free circulation of air through the oven and shall be capable of maintaining a temperature of 230 ± 9°F.

Sample

The test sample shall be prepared from aggregate representative of that being furnished. The aggregate shall be washed and dried at 230 ± 9°F to constant weight and separated into individual size fractions as follows:

Size of Aggregate		Weight of Individual Sizes - grams			
			Test Grade		
Passing -	Ret'd	A	B	C	D
3/4 in.	5/8 in.	400 ± 10			
5/8 in.	1/2 in.	250 ± 10	250 ± 10		
1/2 in.	3/8 in.	200 ± 10	200 ± 10	200 ± 10	
3/8 in.	#4	100 ± 5	100 ± 5	.100 ± 5	100 ± 5
#4	#10	30 ± 5		30 ± 5	30 ± 5

Should the sample contain less than 5 percent of any of the sizes specified in grades above, that size shall not be tested, but for the purpose of calculating the test results, it shall be considered to have the same loss during the treatment as the next smaller size or the next adjacent size where 5 percent or more exists.

Procedure

1. The oven-dry weight of each fraction of the prepared sample shall be obtained to the nearest estimated 0.1 gram.

2. Each fraction of the sample shall then be placed in a separate tray, and enough demineralized or distilled water shall be added to each tray to adjust the water level to approximately three-fourths of the average stone depth.

3. The trays shall be immediately placed in the freezing chamber and allowed to remain there until the water is completely frozen (about two hours).

4. The trays containing the sample shall be removed from the freezing chamber and allowed to thaw at room temperature until no ice is evident in the water. Demineralized or distilled water shall be added to each tray when required to maintain the proper water level.

5. Steps 3 and 4 shall be repeated until 50 cycles have been obtained. One cycle shall be defined as one series of freezing and thawing.

6. After 50 cycles, the sample (remaining in the trays) shall be dried to a constant weight at 230°F.

7. The oven-dry fraction in each tray shall be shaken over the same sieve used in the original separation and the weight retained on each sieve obtained to the nearest estimated 0.1 gram.

Report the weighted average calculated from the percent loss for each fraction, based on the grading of the sample received for examination, to the nearest 0.1 percent.

Note:

The sieve used to separate the original fractions for test must be the identical sieve used to examine the same fractions after the test. This is necessary since sieve sizes include a tolerance in mesh openings. For example, all sieves of a given size, say 3/8 inch, do not have exactly the same size opening. The A.S.T.M. tolerance between different sieves of the same size cannot be accepted in this test.

Example:

Sieve Size	Grading of Original Sample	Actual Loss Percent	Weighted Loss Percent
5/8-1/2 in.	11.2	5.2	0.58
1/2-3/8 in.	37.0	9.3	3.44
3/8 in.-No. 4	51.8	2.2	1.14
	TOTAL WEIGHTED LOSS		5.16

Report as 5.2% weighted loss.

APPENDIX F

QUESTIONNAIRE

This questionnaire has been prepared to collect information on the field performance of aggregates used in Abilene District in the construction of Hot Mix Asphalt Concrete and Seal Coat Surfaces. THe information collected will be used in a research study on the "Use of Soundness Test as an Aggregate Evaluation Test Procedure."

Section I : General

I.1 Name of the Engineer: ______________________

I.2 Phone No: ( ) - -

Section II : Description of the Jobs Performed

II.1 Hot Mix Asphalt Surface ___ or Seal Coat ___

New Construction ___ or Overlay ___

II.2 Highway : ______________________

II.3 Month/Year of Construction : ______________

II.4 Average Daily Traffic** : ________________

Section III : Aggregate Information

III.1 Description of Aggregate : ______________________

(white limestone, siliceous gravel etc.)

III.2 Estimate of % Soundness Loss**: ________________

III.3 Estimate of % Absorption**: ________________

(** Please provide an estimate or a range for these variables to the best of your ability; This information will be verified using the records available at the design office whenever such data is available.)

Section IV : Performance Data

This section deals with the actual performance of the pavement surface constructed using the aggregate described in Sec.III above. The following distress types have been identified as the distress modes associated with poor aggregate quality. Therefore, please provide your evaluation of the pavement surface based on **only these particular distress modes.**

Distress Types Associated with Poor Aggregate Performance

(a) Cracking of the mat due to drying of the mix which results from high absorption of the aggregate.
(b) Aggregate splitting, cracking, and disintegration into small pieces.
(c) Dissolution of Aggregate.
(d) Shelling; Aggregate loss leaving the outer coat in the binder.
(e) Aggregate wear, abrasion, and tendency to polish.
(f) Cluster of small pits on the surface due to loss aggregate or "popouts."
(g) Problems due to aggregate seggregation.

IV.1 Evaluate the condition of the pavement surface soon after construction in terms of the distress modes above. Also mention any particular difficulties experienced during construction, such as rainfall, poor laying capability of the mix etc.

(Please make your evaluation as complete as possible. Use additional sheets if necessary.)

IV.2 Describe the condition of the pavement surface after the first six months of service.

IV.3 Describe the condition of the pavement surface after 1 year of service.

IV.4 Describe the condition of the pavement surface after 2 years of service.

IV.5 What is the current condition of the pavement, i.e. if the pavement is more than 2 years old?