A Cost-Benefit Analysis of the Use of Local Materials by the Texas Department of Transportation

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16. Abstract

This report was written in response to the Senate Bill 370 directive to TxDOT to develop "a cost-benefit analysis between the use of local materials previously incorporated into roadways versus use of materials blended or transported from other sources." Aggregates for use in hot-mixed asphaltic concrete and in flexible base were analyzed. The primary objective of this cost-benefit analysis was to determine if TxDOT's specifications and procedures for these materials were valid and cost-effective.

Forensic studies were used to evaluate the effect of aggregate quality on pavement performance and to provide a measure of the validity and overall effectiveness of current specifications and procedures in ensuring satisfactory pavement performance. Aggregate cost factors were also identified and analyzed.

Primary findings and recommendations include the following:

1. Inadequate aggregate quality has a strong detrimental effect on pavement performance. While aggregate quality is a key to desired pavement performance, cost of aggregates was found to be a small percentage of overall project costs.
2. Current specifications and procedures are appropriate and cost-effective for most pavement construction. Continued monitoring of pavement performance will be necessary to assure that current specification criteria remain adequate under ever-increasing traffic volumes and weights.
3. Base material acceptance should be established on engineering properties alone, eliminating the mineral type selection as soon as the technology can be developed and implemented.
4. To assure cost-effective use of aggregate materials and to assure maximum use of local materials, final decisions regarding aggregate requirements for individual project conditions must remain with the project engineer. Plan note and special provision avenues must remain available for this purpose.

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A COST-BENEFIT ANALYSIS OF THE USE OF LOCAL MATERIALS BY THE TEXAS DEPARTMENT OF TRANSPORTATION

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EXECUTIVE SUMMARY

Senate Bill 370 of the 1997 Texas Legislative Session directed the Texas Department of Transportation (TxDOT) to develop "a cost-benefit analysis between the use of local materials previously incorporated into roadways versus use of materials blended or transported from other sources." The roadway materials being analyzed are aggregates to be used in producing hot mix asphaltic concrete and flexible base. The primary objective of this cost-benefit analysis was to determine if the department's specifications and procedures for these materials are valid and cost-effective.

The task force began by reviewing the department's specifications for these aggregates. The group also reviewed the applicability of several key testing procedures being used in the specifications. Forensic pavement studies were evaluated to determine the effect of aggregate quality on pavement performance. The forensic studies also provided a measure of the validity and overall effectiveness of current specifications and procedures in ensuring satisfactory pavement performance. Aggregate cost factors were identified and analyzed.

Primary findings and recommendations of the task force include the following.

1. <u>Impact of Aggregate Quality on Pavement Performance and Cost.</u> Inadequate aggregate quality has a strong detrimental effect on pavement performance. This can include complete failure of a new pavement soon after opening to traffic. When using aggregates of marginal quality, early pavement failure of only an occasional project will usually more than offset "savings" from other projects using these materials. While aggregate quality is a key to desired pavement performance, cost of aggregates was found to be a small percentage of overall project costs.

2. <u>Aggregate for Use in Hot Mix Asphaltic Concrete.</u> Current standard specification criteria and test procedures are appropriate and cost-effective for most pavement construction. When project conditions are unique enough to raise doubt about the necessary quality standard to assure adequate pavement performance, a conservative quality standard for the aggregate is normally the most cost-effective. Continued monitoring of pavement performance will be necessary to assure that current specification criteria remain adequate under ever-increasing traffic volumes and weights.

3. <u>Aggregate for Use as Flexible Base.</u> Current standard specifications for flexible base require that the districts specify a mineral type for the aggregate. To ensure that the most cost effective materials are being utilized, each district must continue to review their specific project requirements and local source

options when deciding the mineral type to specify. It is recommended that base material acceptance be established on engineering properties alone, eliminating the mineral type selection, as soon as this technology can be developed and implemented. The department should continue to move toward a mechanistic pavement design procedure, to be coupled with a testing technique which can be specified and used in the laboratory during design and then also be used to verify quality of construction in the field.

4. Selection of Aggregate Quality Standards. To assure cost-effective use of aggregate materials, and to assure maximum use of local materials, final decisions regarding aggregate requirements for individual project conditions must remain with the project engineer. Plan note and special provision avenues must remain available for this purpose.

The philosophy of the department in establishing specification requirements for raw materials is embodied in a quote attributed to John Ruskin (1819 – 1900), a noted essayist and Oxford University professor.

> *"It's unwise to pay too much, but it is worse to pay too little. When you pay too much, you lose a little money — that is all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the thing it was bought to do. The common law of business balance prohibits paying a little and getting a lot — it can't be done. If you deal with the lowest bidder, it is well to add something for the risk you run. And if you do that, you will have enough to pay for something better."*

Since it is impossible for the quality and performance of a constructed item to exceed the quality and performance of the component materials, obtaining desired performance from department-constructed roadways necessitates that the aggregate materials are capable of performing to the desired level.

CHAPTER 1. INTRODUCTION

A task force was established by the Executive Director of the Texas Department of Transportation (TxDOT) in August 1997 to address the requirements of Senate Bill 370 pertaining to the cost-effectiveness of materials being used by the department. Specifically, TxDOT was directed to develop "a cost-benefit analysis between the use of local materials previously incorporated into roadways versus use of materials blended or transported from other sources." This report focuses on use and selection of aggregates by the department, as they are the primary roadway construction material. The legislative directive is met by this report.

This cost-benefit analysis addresses costs and benefits separately and in detail. Both the costs and the benefits associated with aggregate use in construction are complex issues. An attempt is made to include all factors involved with aggregate cost, and a limited amount of specific project cost information is provided. The benefit to be obtained from the use of the selected aggregate is, of course, proper pavement performance. Performance includes both how well the pavement serves and how long it serves. For this reason, the benefits analysis of this report relies in large measure on actual pavement performance case histories. As test requirements are the means used to assure proper quality in aggregates, explanations of several key test procedures used by the department are included.

Because benefits in terms of service quality and life are not transposed into dollar values without liberal use of assumptions, and because bid prices for aggregates are dependent on a number of factors, some not related to production and transportation costs, the determination of classic, numerical cost-benefit ratios was not deemed a reasonable or helpful manner of analyzing costs and benefits.

CHAPTER 2. BACKGROUND

2.1 IMPORTANCE OF AGGREGATES IN CONSTRUCTION

Aggregates are an important component of many structural elements in transportation construction. As such, they are used in large quantities on most projects, and their capabilities to meet the strength and durability requirements of the structure have a major impact on the performance level to be obtained. Therefore, they play a particularly important role in the cost-effectiveness of transportation construction.

2.2 AGGREGATE AVAILABILITY IN TEXAS

Texas is blessed with a wide variety of aggregates suitable for use in construction. Unlike many other states, which may have only one or two aggregate types and a half dozen sources, Texas has a broad spectrum of mineralogies and numerous pits serving the needs of the transportation construction industry. The approximate locations of sources of aggregates for asphalt pavement construction are shown in Figure 1. While the sources are numerous, there are areas of the state with no geological formations suitable

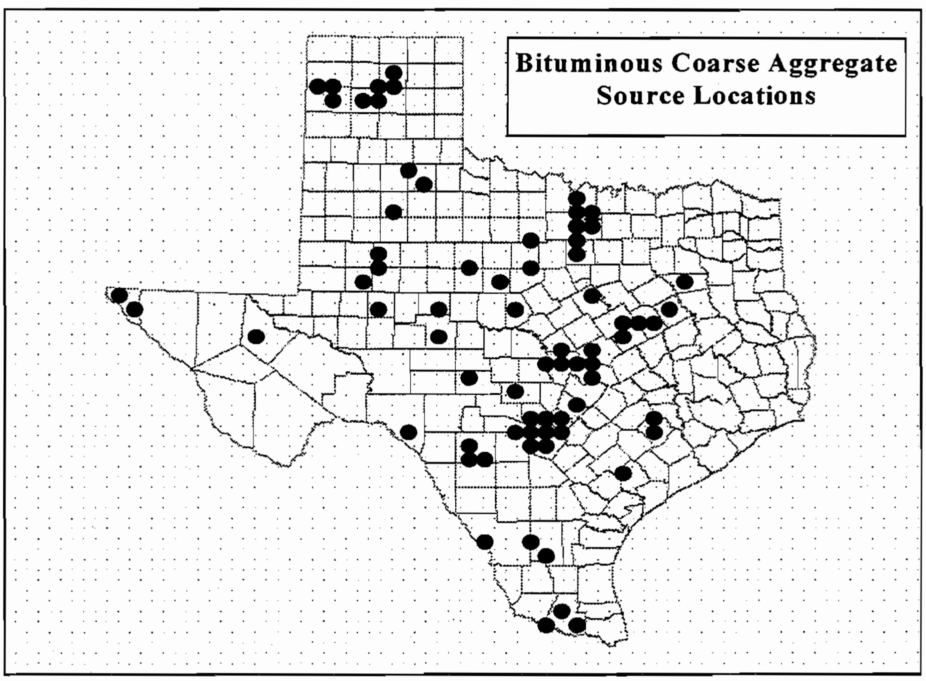


FIGURE 1

for use as construction aggregate. The coastal and the northeast Texas counties have very few local sources. In addition to the sources shown, there are over a dozen out-of-state sources which at least occasionally supply asphalt paving aggregates to projects in Texas.

2.3 NATURAL VARIABILITY IN AGGREGATE QUALITY

Each aggregate mineralogy has a somewhat different group of properties. One mineralogy may generally have good inter-particle friction, but it may be only adequate in strength and durability as a general rule. Another mineralogy may have excellent strength, but tend to be marginal in the area of adhesion with cements.

A wide range in quality can also be found between sources of the same mineralogy. For instance, some limestone sources provide aggregates which are many times stronger and more durable than limestone aggregates from other sources. Some siliceous aggregates are chemically reactive with elements in portland cement, potentially causing severe damage to the involved structure, while other siliceous aggregates do not react in this manner.

The quality of aggregate from an individual pit will also differ on a day-to-day basis. These differences occur, in large part, because of natural variations in aggregate composition in the pit. Figure 2 shows magnesium sulfate soundness test results from a source with low variability in aggregate composition and quality. While natural variations are not particularly large in many cases, they can be extreme in others.
Figure 3 shows the large variability in magnesium sodium soundness test results for an aggregate source located less than ten miles from the source shown in Figure 2. In some of the worst cases of variability within a source, two mineralogies exist in the same pit. An example would be a quality limestone material being naturally blended with a soft caliche material.

While all aggregate sources have some variability in quality, sources of lower quality aggregate are often more variable. This is also demonstrated in Figures 2 and 3.

A most important point to understand is that sources with higher variability are more likely to occasionally produce stockpiles or shipments of materials which are outside the specification limits. This is true whether or not the average value of all test results easily meets the specification requirement. Since department sampling and testing capability is limited, the likelihood of substandard material being used on projects increases from sources with high variability.

FIGURE 2

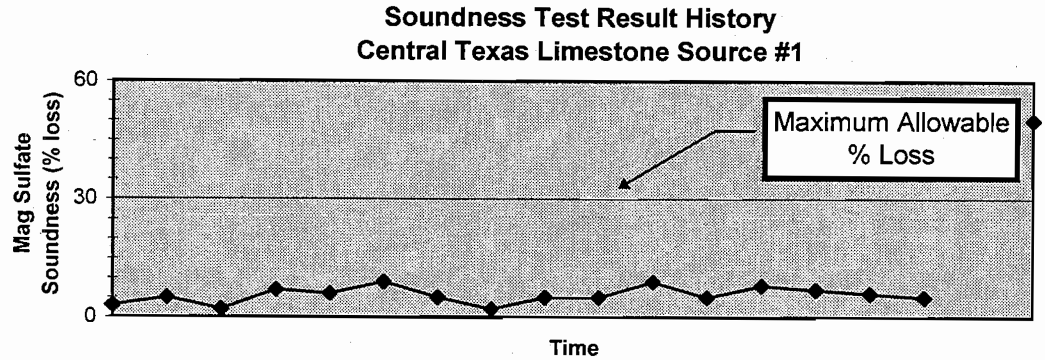
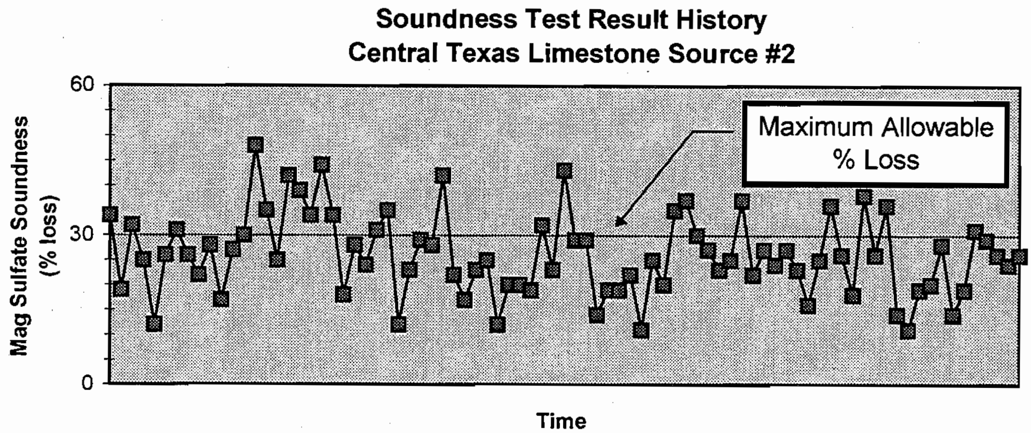


FIGURE 3



2.4 EFFECT OF PRODUCTION FACTORS ON AGGREGATE QUALITY

The method of production of the aggregate can also affect the quality and uniformity of the final product. Some of the factors that affect the quality of the final product are the types of crushers, how the crushers and other equipment are adjusted, how much material is scalped to make other products, how much material is scalped and wasted because of poor quality, and the speed of the operation. At times of high demand for aggregate, product quality from marginal quality sources usually declines because of equipment inefficiencies and the decreased likelihood that the lower quality ends of production will be removed and wasted. The variability in quality shown in Figure 3 is an example. Many of the spikes in the chart indicating out-of-specification production occurred during periods of high demand.

2.5 DEPARTMENT PHILOSOPHY ON SELECTING AGGREGATE QUALITY STANDARDS

The philosophy of the department is to specify materials quality in a manner to maximize cost-effectiveness in transportation operation and service to the public. Basic to cost-effectiveness, aggregate quality standards are required which protect initial construction investment from premature performance deterioration and even structural failure. Determining appropriate quality standards is, therefore, a very important department function.

Test procedures and specification requirements used by the department have been developed and revised over the years. Many of the procedures and requirements are the same or similar to those published on the national level and are also used by other agencies across the country. Some of our procedures and requirements have been developed by the districts, the Materials and Tests Division, and by university researchers under department contract to address specific conditions or needs in Texas. The objective of these aggregate quality standards is to allow competition between all sources of aggregate which can produce aggregates capable of providing the design level of performance in the structure. An alternative to use of specifications in this manner, which appears to be a current trend in industry, is the use of warranty specifications to assure performance.

While matching quality standards to desired performance seems a straightforward concept, there are several complicating factors to be considered in the process of establishing specification requirements capable of preventing premature pavement failure or deterioration. Several key factors follow.

1. Most laboratory tests only simulate stresses and other conditions in the pavement. Therefore, test results are only strong indicators of anticipated performance. They don't guarantee performance. This is the current state of technology in aggregate quality testing.

2. The department must rely on occasional samples and tests to measure quality, and since the quality level from each source is variable between those samples, the department receives and uses materials with both better and worse quality than that indicated by department tests. Because it is necessary to provide reasonable assurance that the lower ends of quality being provided on the project will not cause early pavement failure, a somewhat higher specification value is necessitated than would be if the aggregates were completely uniform in quality.

3. Premature pavement failures are quite often the result of several contributing factors. When marginal or poor quality materials are used, the project becomes more susceptible to problems resulting from less-than-ideal weather conditions during construction, marginal quality in construction technique, and other less than optimal circumstances on the job. It is for this reason that sometimes it is possible to obtain adequate performance from an aggregate source on one or a number of projects before an embarrassing and costly pavement failure occurs during or immediately after construction. A comparison of monetary loss from a single pavement failure to the potential savings obtained from using lesser quality aggregate is provided in Chapter 3.

Consistent with the necessity to prevent early pavement failures, and because of the other considerations discussed above, specifications are generally selected conservatively whenever the necessary quality level cannot be precisely determined. Further, since pavement performance is the ultimate goal, the judgment of the local engineer designing the pavement must be relied upon to properly modify standard requirements when this is necessary. That engineer is in the best position to understand desired performance of the pavement and to be familiar with prior experiences using local aggregate sources.

A statement attributed to John Ruskin (1819 - 1900) captures the dilemma of specification writers, particularly those operating in a low bid system of contractor selection.

> *"It's unwise to pay too much, but it is worse to pay too little. When you pay too much, you lose a little money — that is all. When you pay too little, you sometimes lose everything, because the thing you bought was incapable of doing the thing it was bought to do. The common law of business balance prohibits paying a little and getting a lot — it can't be done. If you deal with the lowest bidder, it is well to add something for the risk you run. And if you do that, you will have enough to pay for something better."*

These words are as true today as they were a hundred years ago. It is the desire of the department to "pay for something better" under the trust given by the taxpayers of Texas.

2.6 PAVEMENT DESIGN CONSIDERATIONS

While it is common knowledge that bridges and multi-story buildings are structurally designed to carry anticipated loads, most are probably unaware that pavement structures are similarly designed by professional engineers. Pavement structures must resist environmental conditions, fatigue failure, and dynamic overloads just as any other load-carrying structure.

Just as in the design of a bridge or building, the engineer must always keep economic factors in mind when selecting the type of structure and materials to be required. The design of new pavement structures are, therefore, both engineering and economic processes. The importance of considering economics is borne out by an estimate by the Federal Highway Administration that sixty percent of their highway reimbursement expenditures are for pavement-related items.

The design of a pavement, then, must consider the availability of materials, the engineering properties of materials, and their costs. Addressing each of these issues is critical to building a pavement that serves the interests of both the traveling public and the economy of state government. All aggregate types that could satisfactorily serve the design purpose should be considered. The consideration of cost and engineering properties must be performed together so that a cost-effective design solution results. The current pavement design procedure used by the department for flexible pavements, i.e. pavements using asphalt cements, allows consideration of all of these factors. Alternate designs using various pavement layer types and thicknesses can be compared, based on their anticipated performances and life cycle costs. The final design decisions are based on a combination of all of these considerations, plus the consideration that it is necessary to assure competition in bidding to supply the materials.

Evolution of TxDOT Pavement Design

TxDOT has long recognized the importance of structural pavement design. Over the years, the department has continually reviewed pavement design procedures used by others, refined and adapted some of these procedures for our conditions, and in some cases have developed our own design procedures. Participation in the joint development of design procedures with the American Association of State Highway and Transportation Officials (AASHTO) assures that the department is aware of the latest technologies across the country.

The earliest pavement design procedures for flexible pavements were based on supporting the mission "to get the farmer out of the mud". An example is the Texas Triaxial design procedure. This was a simple design procedure based on building a pavement structure that the expected truck wheel loads would not "punch through". Roadways at that time had very little traffic, and a long-term fatigue analysis was not considered. The Texas Triaxial procedure is still used as a support tool for designing roadways with little anticipated truck traffic, or for temporary construction detours.

A design procedure known as the Texas Flexible Pavement Design Procedure, version 11 (FPS-11) largely superseded the Texas Triaxial procedure in the early 1970s. Very importantly, FPS-11considered fatigue aspects of pavement deterioration. It used "stiffness coefficients" determined from roadway tests as its basis. Also, being the first automated system, it was the first design procedure to allow easy consideration of alternate materials with different costs and engineering properties. It would analyze a variety of different pavement structures and the rehabilitation strategies that would be needed for each of them for the pavements to serve for the design life (typically twenty years). Estimated costs of the various designs would be calculated and included in the design report for the further analysis of the design engineer. Major limitations of this procedure included that stiffness coefficient is not a standard engineering property, there is no laboratory test for stiffness coefficient, nor could stiffness coefficient be used for acceptance of the constructed pavement.

The currently used flexible pavement design procedure, implemented in 1995, is the Texas Flexible Pavement Design Procedure —version 19 (FPS-19). This design procedure uses elastic modulus as the major material property. The FPS-19 is viewed as a stepping stone to the future goal of a true mechanistic flexible pavement design procedure. Although an improvement, FPS-19 is still empirically based, and so does not predict pavement performance based purely on measurable engineering properties of materials. A comparison of various pavement design alternatives is still possible, as was the case in FPS-11.

TxDOT is participating with AASHTO in the development of a true mechanistic pavement design procedure. The five-year AASHTO research project is expected to produce the initial product in the year 2002. The development of a mechanistic pavement design procedure will enable the department to move away from specifying types of materials and will focus instead on actual engineering properties that relate to pavement performance. One of the goals of a mechanistic pavement design procedure would be development of a laboratory test to be used on the pavement materials to calculate elastic moduli and any other pertinent engineering property that could be used to design pavements. This would enable the engineer to better evaluate new sources of local materials for use on projects.

Pavement Design and Overall Project Development

The results of the pavement design are shown on the plans as the typical pavement section. The types of pavement materials and the thicknesses of each pavement layer to be constructed are identified. The pavement design and typical section information must be developed early in the project design process because this information affects other engineering aspects of the project. This information defines, in large measure, the direction for the development of the complete set of construction plans. Thickness changes can cause changes to the gradeline, the earthwork quantity calculations, and the hydraulics of the project. Because of this inter-relationship, significant changes to the thickness of the typical section after the project has been designed may cause considerable complexity in revising the plans and estimated quantities. Generally, this is more of a problem with plans for urban projects than it is for rural projects.

Use of Alternate Pavement Designs

The inter-relationship between the pavement design and other engineering aspects of the project also affects the viability of producing plans with alternate pavement designs. The cost of developing a set of plans is often in the range of six to ten percent of the total project cost. Developing alternate pavement designs for potential use of competitive material types undoubtedly increases the cost of developing the set of plans and may also increase the time required to prepare the plans. An increase of up to twenty to thirty percent in design costs and two to six months in design time may occur. Within these ranges, the higher cost increases and more lengthy delays would be associated with projects in urban areas or areas of relatively flat terrain where the hydraulics of the overall project must be changed. Changing the drainage may require changing the gradeline, driveways, intersections, bridge structures, and other design elements. Any savings realized by designing for alternate materials may be more than offset by increased design costs and delays. Therefore, use of alternate pavement designs should be limited to circumstances likely to result in significant savings.

Pavement Design and Material Properties

Part of the pavement design process is the decision of the engineer on minimum properties for the component and composite pavement materials. For instance, while it is possible to construct a pavement out of most aggregates, as long as they are sufficiently durable to withstand construction-related stresses, how long they will perform satisfactorily under anticipated traffic and in the local climatic conditions is another matter. Standard specification minimum properties are established in an effort to cover most conditions. The project design engineer must determine if the standard criteria are proper for the conditions on the specific project being developed. All factors must be considered in making that decision. These factors include the engineering properties of the materials, economic factors, and the number of producers that appear to be in position to competitively bid on the project. Unnecessarily establishing a higher standard may limit the competition, driving up material costs for the project. Setting a lower value to allow local materials may, however, result in considerably reduced performance and not be the most cost-effective solution. Because of the complexity of these decisions, and because it is often not possible to accurately predict the impact on pavement performance when requirements on one component material are changed, the engineer designing the pavement must rely on experience and use good judgment.

Life Cycle Cost in Pavement Design

Life cycle cost analysis methods are important for comparing alternative pavement designs. TxDOT has included life cycle cost analysis techniques in the automated flexible pavement design procedures for approximately twenty-five years. TxDOT also has a research project currently underway developing life cycle cost analysis methods for rigid pavements. The department has also participated as one of the pilot states in the evaluation of the life cycle cost analysis systems currently being developed by the Federal Highway Administration. Life cycle cost analysis has been recognized by TxDOT as a key measure of the cost effectiveness of our pavement design operations.

It is hoped that the accuracy of life cycle cost analysis will continually improve, and that factors such as component material criteria can one day be included. Development in these areas is hindered by lack of long-term performance information and limitations in currently available technology. These limitations have restricted our ability to get feedback from the construction processes. It is necessary to know the as-constructed properties of the pavement, not just those specified by the pavement designer, and to compare those to long-term pavement performances if a meaningful evaluation and refinement of the life cycle cost analysis method is to be accomplished.

Pavement Design Summary

Pavement design is a most important aspect of assuring cost effectiveness on projects. It is interrelated with decisions made regarding component material quality, and it dictates the direction of a number of other engineering design aspects. TxDOT has made significant improvements in pavement design procedures over the past several decades. An active research program has improved ability to study pavement performance and to improve design decisions. The department's participation in the development of a mechanistic pavement design procedure will establish the framework to improve future decisions on the use of materials from all potential sources, including materials from new sources and materials that have been salvaged from our roadways to be recycled.

2.7 AGGREGATE TESTING PROCEDURES USED BY THE DEPARTMENT

There are several test procedures and requirements which are central in determining which aggregate materials are used by the department. These test procedures and specification requirements are generally described below, along with the basis for each specification requirement.

Magnesium Sulfate Soundness Test

Purpose and History. The soundness test is used to measure the internal strength of an aggregate, and therefore its ability to withstand weather, construction and traffic-related stresses. The requirements in department specifications are designed to eliminate the use of aggregates that are too soft and/or absorptive to properly perform in pavements. Besides disintegrating during the construction compaction process and under traffic loadings, aggregates which are too soft absorb asphalt during construction and while in service, thereby causing early aging and cracking of the pavement. The test was originally developed for qualifying aggregates for use in portland cement concrete. In the late 1970s, the test also proved to be of value to determine quality of aggregates for hot mix asphaltic concrete and seal coat use. It became a standard specification requirement of the department for hot mix asphaltic concrete and seal coat in the late 1980s.

Test Description. The soundness test exposes the aggregates to five cycles of saltwater solution and oven-drying. The wetting and drying cycles cause the salts to recrystallize and expand. This expansion creates internal pressures within the aggregate, and weaker particles fracture and disintegrate. Magnesium sulfate is the salt used for testing aggregates for use in hot mix asphaltic concrete, seal coats and flexible base.

Basis for TxDOT Acceptance Criteria. The specification requirement has been selected to assure that aggregates being used will perform satisfactorily under current traffic loads. The numbers and weights of trucks on our highways continue to increase. To handle these increased loads, the department is using innovative asphalt-aggregate mixtures which contain more coarse aggregate. These mixtures are designed so that the coarse aggregates are in contact and bear directly on each other to carry the imposed loads. Therefore, tougher aggregates are required than used in the past. The department changed the number of cycles in the standard test from four to five in 1993 while maintaining the same specification requirement. This change raised the required aggregate quality level, which tended to compensate for the greater in-service demands on aggregate. This change also brought the test procedure into agreement with the nationally-accepted number of cycles for this test.

Another change to the test procedure made in recent years eliminated the effect of sample gradation on test results. The gradations of test samples are now "normalized" to a standard gradation when determining the final test results. As the purpose of the test is to assure adequate toughness and durability qualities of the minerals composing the aggregate, the size of the aggregate should not be allowed to affect the test results.

Department specification requirements are designed to allow as much competition as possible. Among other departments of transportation and agencies which specify soundness quality for hot mix aggregate, the most common requirement is 18 percent maximum loss after five cycles (ASTM C-88). Based on Texas experience using local aggregates, however, the department has set our standard specification maximum loss at 30 percent (Test Method Tex-411-A). Additionally, our standard specifications allow the local district to increase or decrease this standard soundness requirement based on their experience using aggregates in their local area. *Therefore, while current department specifications are more lax than those used by other agencies, and are also very flexible, their basis is performance on the roadway.*

This performance basis was documented by a research study completed by the University of Texas in 1987. The study was done during the time when there was growing interest in the test and districts were beginning to write the requirement into their project plans. One of the conclusions of the field and laboratory study was that the soundness test was the most successful among the material tests evaluated to predict disintegration of aggregates in pavements. This conclusion was based, in part, on district survey responses that the test was successfully eliminating sources which had performed poorly on earlier projects.

The most recent and significant national research study pertaining to aggregate testing, "Aggregate Tests Related to Asphalt Concrete Performance in Pavements," was funded by the National Cooperative Highway Research Program. In their report of May 1997, the soundness test is reported to be an indicator of pavement performance in the areas of raveling, popouts and potholing. The report suggests that field evaluations be used to establish maximum allowable loss values for specifications in the various climatic zones in the United States. As districts are allowed to modify soundness requirements in their plan notes, our specifications already allow requirements to vary with climatic and other differences.

Sand Equivalent Test

<u>Purpose and History.</u> The sand equivalent test is used to determine if an aggregate contains enough clay or clay-sized particles to detrimentally affect the pavement performance of an asphalt and aggregate mixture. It was developed in 1950 by Francis Hveem, an engineer working for the California Division of Highways. As reported by Mr. Hveem, the test was developed to prevent the re-occurrence of pavement failures they were experiencing. From the pictures in his report, the failures were complete pavement disintegrations in the form of raveling and asphalt stripping. The test was evaluated between 1958 and 1960 by Robert Kriegel of the department's Materials and Tests Division. His findings confirmed the ability of the sand equivalent test to indicate the presence of detrimental fines that were not revealed by other tests in our specifications.

Test Description. The sand equivalent test involves the agitation of an aggregate sample while submerged in a liquid solution. The liquid chosen for this test has the qualities required to cause clay-sized particles to remain in suspension in the fluid for a period of time adequate to obtain a measurement of the amount of the detrimental material. Measurements made after the prescribed settling time are calculated as a ratio of the amount of larger, sand-like particles to the size of the column of suspended clay in the test beaker.

Basis for TxDOT Acceptance Criteria. The first statewide specification including sand equivalent testing was the 1962 Standard Specifications. A minimum value of 45 was required for aggregates to be used in hot mix asphaltic concrete. This requirement was based on the California determination that a minimum value of 45 was desirable for plant-mixed bituminous surface mixes in general and a value of 55 was desirable for Class A plant mix. A later study in New Mexico concluded that the California recommended minimum values were somewhat conservative, ruling out a number of New Mexico aggregates which they believed performed satisfactorily. An Arizona study generally supported the work of the above states, concluding that a value of 55 or higher always resulted in satisfactory performance, and values in the range of 35 to 54 almost always provided satisfactory performance.

A case history supporting the value of the sand equivalent test in our specifications was reported by the Materials and Tests Division in 1980. A new pavement on IH-30 raveled extensively immediately after receiving a heavy rain. The report included the following description.

> In the heavy raveling sections, there was a considerable amount of the coarse aggregate on the shoulders and most of the asphalt was gone from this aggregate. The guardrail and grass adjacent to the shoulder in the raveling areas were coated with asphalt and fines.

Samples of the various combinations of aggregates being used on the project were taken from plant stockpiles and tested for sand equivalent. Two of the combinations tested were found to have sand equivalent values of 36 and 38. The newest materials delivered to the project tested at 73. Although not verified in the report, it is likely that actual quality of the aggregates used earlier on the project included qualities both better and worse than those of the tested samples. From the above descriptions and other information in the report, it appears that severe stripping to the point of emulsification of the asphalt occurred. As clay coatings can cause the asphalt to lose bond with the aggregate, as they can take on water, and as they can act as an emulsifying agent, it is likely that the presence of this clay was a primary cause of the loss of this pavement.

Polish Value Test

Purpose and History. The polish value test is used to determine if coarse aggregates will retain enough microtexture after being worn by years of traffic to allow adequate friction for safe vehicle braking on a wet pavement. The Federal Highway Administration (FHWA) has for many years required that each transportation department have a program and procedures in place designed to assure adequate skid resistance on wet pavements. The polish value test has been the cornerstone of the Texas skid accident reduction program.

The polish value test originated in England. It was evaluated by the Materials and Tests Division, beginning in the early 1960s, and it was adopted into pavement design policy and our specifications in 1974. A number of changes to specification requirements and several test method changes have occurred over its period of use.

A highly desirable aspect of this test is that it is performed on coarse aggregate samples as opposed to the testing of the aggregates in-place on a roadway. This allows a source of aggregate to be evaluated and approved prior to any use of the aggregate in highway construction. This is quite advantageous to contractors as it reduces their risks when preparing bids for department projects. All frequently used sources of aggregate have been evaluated and rated in Texas, with the results updated twice each year in a catalog published by the department.

A disadvantage of this test method is that it does not take into account macrotexture of the pavement, which also contributes to skid resistance of a roadway. For this and probably other factors, this test has been shown to underestimate the skid resistance actually provided by some aggregates, particularly many crushed siliceous aggregates, when the pavements are tested using a locked-wheel skid trailer.

Test Description. The polish value test requires the embedding of coarse aggregate particles on the top surface of a series of curved polyester resin specimens. These specimens are mounted in an accelerated polishing machine where a rubber tire and silicon carbide grit provide a polishing action for a period of nine hours. After removal from the polishing machine and cleaning, the specimens are tested with the British portable tester, which is a pendulum with a rubber slider on the end to contact the test specimen. After sliding across the specimen, aggregates with more microtexture absorb more energy and the pendulum swing past the specimen is less than when the aggregates have become very smooth under the polishing action. A highly textured specimen results in a higher polish value number.

Basis for TxDOT Acceptance Criteria. Criteria were established in 1974 based heavily on the results of a research study reported by the Texas Transportation Institute in report 126-2. In that study a rough correlation was developed between a polish value of 28 and a locked-wheel skid trailer test number of 30, which is regarded to be about the minimum desirable level of skid resistance. When first instituted, a polish value of 35 was required for interstate highways and all highways with 5,000 ADT and above. Polish values of 33 and 30 were required for lesser traffic categories. These higher values were selected to provide higher levels of confidence that the materials delivered to the project would serve adequately. Because of later research and further analysis of earlier data, the currently required minimum values are 32 for pavements in the highest traffic categories in Texas and 30 and 28 for lower traffic categories.

Because of the inadequacy of the polish value test to accurately predict the skid performance of all aggregate types, Texas specifications and policies allow for documented pavement skid performance to be used in lieu of polish value. The difficulty with this approach to approval has been that it takes considerable numbers of test projects and time under traffic to adequately determine anticipated skid performance.

The department is currently engaged in research to further improve the methods of assuring that adequate wet weather skid resistance is provided in Texas pavements.

Moisture Susceptibility Tests

Purpose and History. The detrimental effect of moisture on asphalt pavements has been recognized for decades. However, in the 1970s and 1980s, changes in asphalt refining techniques, construction equipment and methodologies, and heavier traffic loads and traffic volumes caused an increase in moisture related pavement failures across the country. Moisture damage occurs when water breaks the adhesive bond between the aggregates and the asphalt cement. The result is stripping, or the separation of asphalt and aggregates in the pavement, which in turn leads to the formation of wheel path ruts, shoving and washboard type roughness, excessive asphalt coming to the surface (bleeding), and the formation of potholes.

In the fall of 1979, an asphalt concrete overlay on IH-10 near Columbus, Texas began to rut, shove and bleed before the project was even completed. A forensic investigation concluded that the primary cause of this pavement failure was aggregate susceptibility to moisture damage coupled with the lack of effectiveness of the anti-stripping agent being used to prevent damage from moisture. At that time, there was no definitive test to predict pavement moisture susceptibility. A major research effort was initiated by the department to have the Center for Transportation Research at the University of Texas to develop a suitable test for use in Texas. During the same time period, the National Cooperative Research Program (NCHRP) was sponsoring a major study to investigate this problem. As a result, the Texas State Department of Highways and Public Transportation (now TxDOT) adopted two tests to predict moisture susceptibility: Test Method Tex-530-C "Effect of Water on Bituminous Paving Mixtures" and Test Method Tex-531-C "Prediction of Moisture Induced Damage to Bituminous Paving Mixtures Using Molded Specimens". These tests are also used to evaluate the effectiveness of anti-stripping additives used in paving mixtures.

Moisture damage in asphalt pavements continues to be a concern in Texas and nationwide. The Strategic Highway Research Program (SHRP) recognized the need for even better prediction capabilities, but no method has been developed to suitably replace the current methods. Within TxDOT, research is ongoing using scaled accelerated pavement testers, the Hamburg Wheel Track Tester and the Asphalt Pavement Analyzer, but a final production test of high and verifiable reliability has yet to be established.

Test Description: Test Method Tex-530-C, "Effect of Water on Bituminous Paving Mixtures". This is a boiling-type test, where 200 grams of the asphalt-aggregate mixture is placed in boiling water for ten minutes. The mixture is then spread onto a white paper towel and visually examined. A second examination occurs 24 hours later. The test results are reported as the estimated percent of stripping, that is, the tester makes a visual judgment as to what percentage of the aggregate have lost their asphalt coating as a result of the boiling process.

The boiling test is a simple and straightforward test procedure. This test can be completed in just over 24 hours, and preliminary answers can be obtained immediately after boiling, within 20 minutes of the actual production of the plant mix material. However, interpretation of test results is dependent on operator judgment, so the accuracy and precision of this test method are not ideal.

Test Method Tex-530-C is primarily a field test to ensure that bituminous mixtures being produced have adequate moisture damage resistance (that is, anti-stripping additives are effectively being added to the mixture). Some districts have used Test Method Tex-530-C as a mixture design test in place of Test Method Tex-531-C. Since August 1997, this test has been precluded from use in mixture design approval.

<u>Basis for TxDOT Acceptance Criteria —Test Method Tex-530-C</u>. The acceptable percent of stripping varies depending upon material type and application. That is, in some cases of hot-mix asphalt and maintenance material, no stripping (0 percent stripping) is allowed. In general, a tolerance of 0-10 percent stripping is allowed for most asphalt-aggregate paving mixtures.

<u>Test Description: Test Method Tex-531-C "Prediction of Moisture Induced Damage to Bituminous Paving Mixtures Using Molded Specimens"</u>. This test method requires the molding of eight asphalt-aggregate mixture specimens using the Texas gyratory compactor. Four of these specimens are kept dry while the remaining four specimens are saturated with water in a vacuum chamber, placed in a freezer at 0°F for a minimum of fifteen hours, and finally they are submerged in a 140°F water bath for 24 hours. All eight specimens are then brought to a constant temperature of 77°F for four hours and tested by indirect tensile loading until failure. The average strength of the moisture conditioned specimens is divided by the average strength of the unconditioned specimens. The resulting value is known as the Tensile Strength Ratio (TSR).

This procedure was modified in April 1997. Work coordinated by the Materials and Tests Division showed limited relationship between saturation level and TSR for some aggregates, while some aggregates with a history of stripping showed a higher probability of failing the test when the specimens were subjected to higher saturation percentages. Thus, a higher saturation was adopted to increase the likelihood that poor performing mixtures would be identified. This change also eliminated a time-consuming step from the test method, which is already very lengthy, around 3-4 days in duration.
The time required to complete this test makes it unsuitable as a production control test. Test Method Tex-531-C is used for mixture design approval.

<u>Basis for TxDOT Acceptance Criteria —Test Method Tex-531-C</u>. Prior to August 1997, the specification limit for TSR was 0.70, meaning that the conditioned specimens had to retain at least 70 percent of the tensile strength of the unconditioned specimens. Continuing problems across the eastern and coastal areas of the state with moisture susceptible pavements prompted a large field assessment of stripping in the winter and spring of 1997. Results from this field study confirmed that specifying a TSR of 0.70, determined by the current test procedure, was

insufficient to ensure that materials susceptible to stripping would be eliminated at the mixture design phase. In addition, SHRP has recommended that the TSR should be 0.80 to ensure effective protection against moisture damage. Since August 1997, the TSR specification limit has been established at 0.80, with an additional requirement that the conditioned specimens have a minimum tensile strength of 70 psi (480 kPa). Contractors have been noted to be using higher grades of anti-stripping additives since this specification was revised. Also, results of testing in the Houston and Pharr district laboratories show that the new requirements are more stringent than the old requirements (Appendices A and B). However, the final measure of success with the new test procedure and specification requirements cannot be determined until field performance data can be collected from pavement constructed under these new requirements.

2.8 REVISIONS TO AGGREGATE QUALITY STANDARDS

Procedures and specification requirements have been revised over the years. In the early years of the department, traffic levels were very low. Correspondingly, there were fewer aggregate testing procedures. As demands on pavements increased, and as premature pavement failures indicated needs to prevent use of aggregates with certain characteristics, additional tests were developed and placed into specifications. Increased demands on pavements have included higher traffic levels, increased tire pressures, heavier allowable truck weights, and higher traffic speeds. Another significant event which affected aggregate quality requirements was the 1975 change in the department to design pavement structures for a 30-year design life instead of 20 years. More durable aggregates are now needed. Currently, our tests and specifications must be adequate to assure performance of our pavements under not only current traffic volumes, but also under sharply increased traffic loadings expected in the near future. The North American Free Trade Agreement (NAFTA) and the generally strong economy in Texas are factors which will continue to cause increased demands on our pavements. Future revisions to procedures and specification criteria may be necessary as the department continues to monitor pavement performances statewide under the changing traffic levels and structural needs.

CHAPTER 3. ECONOMIC FACTORS (COSTS)

3.1 ECONOMIC FACTORS INFLUENCING BID PRICES

State law requires that the department award projects based on competitive bids with the award going to the lowest cumulative bidder. A contractor must look for every cost reduction advantage in preparing his or her bid in order to be successful. Therefore, basic business practice drives contractors to provide the least expensive materials. In some cases this means the materials closest to the minimum specification requirements.

The cost associated with the use of an individual aggregate source is dependent upon several factors. The most obvious factors are quarrying, crushing and processing costs. These can differ considerably between sources and types of aggregates. Some aggregates are harder and more difficult to crush, while some others may have greater quantities of undesirable elements to be removed from the final product. Costs to remove aggregate from the quarry can also vary widely. There are several important factors which are not as obvious. These include the fact that some aggregates may by their nature require the contractor to use expensive additives in the mixture being prepared. Also, some aggregates make the resulting construction material more difficult and labor-intensive to use at the job site. A final and considerable factor in aggregate cost is the distance that the aggregate must be transported from the quarry to the plant or job site. Therefore, it is the total cost of production and transportation, potential effect on constructability, and the impact on the use of other materials which determine if a contractor elects to use a given source of aggregate.

The bid price, however, considers other factors as well. One important factor is competition for the project. In cases where transportation costs for all other competitors are high compared to those of a single, conveniently located source, the bidder with the considerably shorter haul distance may well attempt to take advantage of increased profit potential. In those cases, savings to the department are minimal, in actuality, compared to potential savings.

There are other potential factors affecting bid prices which are not readily apparent. Some of these are the contractor's current workload and the need to keep crews busy, cash flow pressures, and protecting the contractor's market share (i.e., desire to keep other contractors from moving operations into a geographic area). These issues can impact a contractor's price but are not quantifiable by someone other than the estimator. On a specific project level there are additional internal and external factors that come into play. Specifically, raw and processed material availability, subcontractor availability, interaction between materials in the mixture design, project supervisor availability, project location, and transportation options all can enter into consideration.

A unit bid price for Hot Mix Asphalt Concrete Pavement (HMACP) includes the costs of raw materials (production, royalties, processing, personnel, transporting, overhead and profit), plant production (testing, design, personnel, handling, fuel, hauling, waste, down time, equipment, overhead, etc.), and placement (equipment, personnel, hauling, laying, rolling, coring, profiling, waste, re-work, etc.). Of all these variables, the specific issues of transportation costs and aggregate costs are to be explored in more detail.

Transportation of raw and processed materials is usually by either truck or rail. The relative locations of the pit, plant, and project site are key factors in the choice of transportation. Rail is certainly more economical for large volumes over longer hauls, but drawbacks include limited delivery points, and, more recently, scheduling of car availability. Trucking, on the other hand, can deliver to whatever point needed and is generally available from multiple sources, assuring availability when needed. With the recent deregulation of the trucking industry, contractors and truckers are more frequently entering long-term relationships over multiple projects and with negotiated rates.

Remote aggregate sources using rail transportation compete with local sources relying on trucking in numerous areas of the state. The Yoakum District is one of these areas. In some districts, such as Houston, there are no truly local aggregate sources. Because of the considerable distances involved to even the closest sources, transportation economics is different for their projects than for projects in the Yoakum District.

It is easy to see that there are many complex and highly fluid variables that impact unit bid prices. The most important factor of all is to assure competition. In the absence of a competitive market, one contractor can dictate the price of a material in a market. Any decision that gives a single contractor control of a market, or even the perception of control, will result in decreased competition by other contractors and higher prices for the department.

3.2 AGGREGATE COSTS VERSUS TOTAL PROJECT COSTS

The following tables show reported project cost data for coarse aggregate and hot mix asphaltic concrete. These are compared to the total project costs from these successful bidders. Coarse aggregate is the focus because it is most frequently the aggregate size transported considerable distances to projects. Table 1 compares these costs on overlay projects, where paving is the only major construction activity involved. Table 2 indicates costs on rehabilitation projects, where other work is more substantial. The four projects in each category are from different districts and are of varying size so that a feeling for the amount of variability around the state might be given. As shown, the costs of coarse aggregates composed only about 13 percent, on the average, of the total project costs on overlay projects. On rehabilitation projects, the costs of these aggregates averaged less than 3 percent of total project costs.

It is interesting to note in Table 1 the differences between the costs of the hot mix pavements and the total project costs. Even on simple hot mix overlay projects, costs to mobilize, handle traffic, traffic markers and striping, and other various items amount to considerable percentages of total project costs. In the four projects shown in Table 1, the percentages of costs for other than the paving material and placement ranged from 26.9 to 40.8 percent of the total project costs.

TABLE 1 —Analysis of Coarse Aggregate Costs on Overlay Projects

Project	Tons of Hot Mix	Bid Price for Hot Mix ($/Ton)	Total Cost of Hot Mix ($)	Tons of Coarse Aggregate in Hot Mix	Coarse Aggregate Unit Cost ($/ton)	Total Cost of Coarse Aggregate ($)	Total Project Cost ($)	% Coarse Aggregate Cost of Total Project Cost
A	72,786	28.35	2,063,483	42,216	15.80	667,012	3,486,292	19.1
B	93,443	32.00	2,990,176	53,263	7.20	383,494	4,520,309	8.5
C	49,694	30.20	1,500,759	30,313	8.00	242,504	2,052,766	11.8
D	22,244	33.64	748,288	13,346	8.50	113,441	1,109,573	10.2
							Weighted Average	12.6

TABLE 2 —Analysis of Coarse Aggregate Costs on Rehabilitation Projects

Project	Tons of Hot Mix	Bid Price for Hot Mix ($/Ton)	Total Cost of Hot Mix ($)	Tons of Coarse Aggregate in Hot Mix	Coarse Aggregate Unit Cost ($/ton)	Total Cost of Coarse Aggregate ($)	Total Project Cost ($)	% Coarse Aggregate Cost of Total Project Cost
A	45,982	34.85	1,602,473	28,049	15.80	443,174	10,245,989	4.3
B	13,522	32.00	432,704	7,708	7.20	55,498	7,779,570	0.7
C	16,245	36.00	584,820	9,747	8.00	77,976	4,931,531	1.6
D	29,897	30.00	896,910	17,340	8.50	147,390	3,472,419	4.2
							Weighted Average	2.7

It is apparent that the costs of coarse aggregates are a rather small percentage of total project costs. *Because of this fact, there is no potential for substantially lowering total project costs on a statewide basis by lowering coarse aggregate quality standards to increase competition.* As an example, based on the above average values, the use of an aggregate that costs as much as ten percent less than another aggregate would decrease the total project costs less than one percent in most cases and less than a half percent on the larger, higher cost projects.

3.3 EFFECT OF AGGREGATE COSTS ON CONTRACT AWARDS

The task force evaluated bidding and aggregate costs in a district which has suppliers of crushed gravel and limestone bidding competitively on hot mix asphaltic concrete projects. Tables 3 through 6 show competing bids and aggregate cost information on four recent projects. The unit and total costs of aggregates shown in the tables do not include transportation costs to deliver them to the projects. The transportation distances for the aggregates are approximate. The limestone aggregate costs were obtained from the aggregate suppliers. A gravel aggregate supplier was not comfortable providing that information, so cost information was obtained from one of the supplier's customers.

TABLES 3 through 6 — Analysis of Bids on Four Projects

TABLE 3

Project 1 ----- 18,062 Tons of Type C Hot Mix Asphaltic Concrete							
Bidder and Aggregate Type	Bid Price for Hot Mix ($ /ton)	Coarse Aggregate Unit Cost ($/ton)	Fine Aggregate Unit Cost ($ /ton)	Aggregate Shipping Distance (miles)	Total Cost of Aggregate ($)	Total Bid for Hot Mix ($)	Total Bid for Project ($)
1 - Limestone	29.00	7.00	3.00	70	92,657	523,798	8,518,533
2 - Limestone	32.00	6.75	3.75	70	95,232	577,984	9,068,808
3 - Gravel	32.00	10.00	9.50	2	168,157	577,984	9,362,111
4 - Limestone	32.65	5.17	3.75	70	78,965	589,724	9,463,765

TABLE 4

Project 2 ----- 102,992 Tons of Type C Hot Mix Asphaltic Concrete							
Bidder and Aggregate Type	Bid Price for Hot Mix ($ /ton)	Coarse Aggregate Unit Cost ($/ton)	Fine Aggregate Unit Cost ($ /ton)	Aggregate Shipping Distance (miles)	Total Cost of Aggregate ($)	Total Bid for Hot Mix ($)	Total Bid for Project ($)
1 - Limestone	29.02	6.60	3.00	70	528,719	2,990,176	4,520,309
2 - Limestone	30.94	6.60	3.00	70	528,719	3,186,406	4,702,323
3 - Gravel	31.15	10.01	9.51	30	959,612	3,205,095	4,768,350

TABLE 5

Project 3 ----- 13,522 Tons of Type C Hot Mix Asphaltic Concrete							
Bidder and Aggregate Type	Bid Price for Hot Mix ($ /ton)	Coarse Aggregate Unit Cost ($/ton)	Fine Aggregate Unit Cost ($ /ton)	Aggregate Shipping Distance (miles)	Total Cost of Aggregate ($)	Total Bid for Hot Mix ($)	Total Bid for Project ($)
1 - Gravel	32.00	10.00	9.50	On Project	125,889	432,704	7,779,570
2 - Limestone	35.00	7.00	3.00	70	69,368	473,270	8,124,228
3 - Limestone	31.40	5.17	3.75	70	59,117	424,590	8,462,662
4 - Limestone	28.85	6.75	3.75	70	71,295	390,110	8,731,816

TABLE 6

Project 4 ----- 59,745 Tons of Type C Hot Mix Asphaltic Concrete							
Bidder and Aggregate Type	Bid Price for Hot Mix ($ /ton)	Coarse Aggregate Unit Cost ($/ton)	Fine Aggregate Unit Cost ($ /ton)	Aggregate Shipping Distance (miles)	Total Cost of Aggregate ($)	Total Bid for Hot Mix ($)	Total Bid for Project ($)
1 - Gravel	27.67	10.01	9.51	20	556,607	1,653,100	2,664,546
2 - Limestone	28.12	5.17	3.76	90	261,363	1,680,200	2,766,340
3 - Limestone	29.19	6.60	3.00	90	306,675	1,744,156	2,840,428
4 - Limestone	32.59	6.76	3.76	90	315,427	1,946,864	3,106,619

A first observation is that the contractor with the lowest hot mix bid price was usually the successful low bidder on the project. However, in only one case does it appear that the lower cost of the hot mix actually made the difference in winning the contract.

Another observation is that the price of crushed gravel at the gate of the aggregate source is considerable higher than that of limestone. The reported prices for crushed gravel were sometimes double that for limestone. This could be due to higher production costs and/or other economic factors mentioned earlier.

The higher gravel aggregate costs appear to be a primary reason that shipping distances must be considerably shorter for the gravel to successfully compete with the limestone sources. The local gravel aggregate was successful on two of the three projects where the difference in aggregate transportation distance was approximately 70 miles. This indicates that this is the approximate point where savings in transportation costs offset the higher cost of the aggregate in hot mix asphaltic concrete in this area of the state.

3.4 ECONOMY BASED ON A LONG-TERM ANALYSIS

Certainly there are areas in the state where lower total project costs would result if aggregate quality requirements are lowered enough. This savings in initial project cost must be balanced, however, against the potential for the substandard or at least marginal quality material to either cause or contribute to an early loss of pavement performance. The cost to replace a pavement is many times greater than the difference in cost between two aggregates on a given project.

For purposes of an example, information was gathered from a project in central Texas requiring 99,492 mgr of Type C hot mix asphaltic concrete:

> Aggregate 1 — The aggregate cost was $562,947, and the hauling cost was estimated at $767,697 (70 miles at $0.10/ton/mile). The bid price for the hot mix was $32.00/mgr.
>
> Aggregate 2 — The aggregate cost was $1,020,784, and the hauling cost was estimated at $198,984 (20 miles at $0.10/ton/mile). The bid price for the hot mix was $34.30/mgr.

In this case, the local aggregate (Aggregate 2) was not the low bid material even though enjoying a considerable haul distance advantage. Additional costs to produce Aggregate 2 and other contractor costs may have been significant factors.

For the sake of an example to show that initial savings can easily be offset by rehabilitation costs, the below calculation assumes that the aggregate costs are the same for both aggregates. Only the haul distance differs. In that case, the savings in using the local material would be $568,713.

Should that project rut, strip, or ravel to the point of requiring the hot mix to be removed and replaced, costs to the department are estimated at $948,000 for milling and $3,184,000 for the hot mix. There would be other expenses as well, including user costs when lanes had to be closed again to do the work. But just considering the milling and hot mix costs, if Aggregate 2 was borderline in quality, and if only one project in seven failed because of the borderline quality in the aggregate, the initial savings on the seven projects would be more than offset by the one which failed and required replacement.

Based on the actual bid prices on this project, and the fact that contractors do consider competition and many other factors when bidding, one pavement failure would probably more than offset savings from closer to twice that many successful projects using these materials.

CHAPTER 4. PERFORMANCE FACTORS (BENEFITS)

Differences in aggregate properties can and do significantly affect the performance of the aggregate and, consequently, the structural performance of the pavement. For example, the surface texture and angularity of an aggregate have a major affect on strength, compactability, and skid resistance of an asphalt-aggregate paving mixture. The toughness of an aggregate affects its ability to carry traffic loads without fracturing. Therefore, specification criteria which set acceptability limits for aggregate properties are extremely important in assuring desired performance in constructed pavements.

Comparing the benefits to be obtained from the use of different aggregates is a difficult proposition. Since benefits are in terms of pavement performance, one approach would be to place comparison test sections and observe differences in performance. This approach, however, would only compare several of the hundreds of aggregate sources and combinations of sources used in Texas. It would also require many years to complete an evaluation of relative benefits in this manner.

An alternative approach, more expedient and more global in nature, is to study the performance of pavements which have been placed in service in the past. These pavements hold the answer to a very central question. That question is if the department's quality standards for aggregates are proper, or, as suggested by an occasional aggregate producer, do they require higher quality than necessary for the aggregate to perform their functions in the pavement structure.

For this reason, the benefits analysis of this report relies in large measure on actual pavement performance case histories. Case histories where marginal quality materials were used and desired performance was not obtained are the focus because they offer the best insight into where specification requirements should be established. These histories also offer a stern reminder of the importance of maintaining proper aggregate quality standards in department specifications

4.1 PAVEMENT PERFORMANCE HISTORIES — AGGREGATE SOUNDNESS

As discussed in some detail in Chapter 2, the magnesium sulfate soundness test is used to measure an aggregate's resistance to disintegration.

Through years of experience, TxDOT has learned that soundness specification requirements of 30 percent will usually eliminate aggregates which have a tendency to crush during production or during the pavement compaction process. Aggregates which crush or disintegrate allow a reduction in the amount of coarser aggregate to carry traffic loads, and they also generate excessive amounts of fine particles in the paving mixture. Excessive amounts of fine particles can cause various performance problems in the new paving surface. Forensic pavement investigations performed by the department to determine causes of premature failures have found that poor or marginally sound aggregates have caused or contributed to early pavement failures. Summaries of several forensic studies follow. The forensic reports are included in the appendices.

1. In 1996, a section of a project on US 83 in west Texas suffered excessive cracking caused by de-bonding of the surface layer from the level-up course. As stated in the forensic report, the cracking appeared to be caused by a lack of free asphalt film due to an extremely high percentage of very fine dust in the aggregates. The increased surface area resulting from this condition "robbed" free asphalt from the mixture, resulting in a mixture with inadequate bonding characteristics. Magnesium soundness test results ranged from 22.0 to 30.5 percent on this project, making the aggregate marginal according to commonly specified requirements. (See Appendix C.)
2. In 1994, a project on IH 10 had a problem with flushing and rutting. These were caused by high laboratory densities, which in turn were attributed to excessive amounts of very fine dust in the mixture. The excessive amount of dust was apparently generated by degradation of coarse aggregate during the plant mixing process. Magnesium sulfate soundness test results on the most common coarse aggregate size ranged from 27.0 to 28.0 percent. Stockpiles of smaller coarse aggregates tested in the low to mid 40s. (See Appendix D.)

In addition to these forensic reports, the Center for Transportation Research at The University of Texas in Austin performed research on the soundness test and reported its finding in a report entitled "Evaluation of the 4-Cycle Magnesium Sulfate Soundness Test" (Research Report 438-1F). The Abstract, Summary, Introduction, and the Summary and Conclusions portions of the report, found in the appendices, include strong support for the use of soundness testing for hot mix paving aggregates. (See Appendix E.) The highlights of this report are as follows:

1. The soundness test was the best among seven evaluated tests in predicting performance of aggregate. It was recommended that specifications include this test for evaluating aggregate quality.
2. The soundness test is successful in indicating soft, absorptive aggregates that wear readily during construction or under traffic.
3. Most districts, after implementing soundness testing, have experienced improved performance in pavements.
4. A 30 percent soundness limit on aggregates for hot mixes and a 25 percent limit on aggregates for seal coats are likely to improve performance of roadways. Also, roads constructed with a soundness limit greater than 30 percent showed extensive signs of surface disintegration.
5. When blends of aggregate are used, the soundness test should be performed on each individual aggregate.

Finally, the Center for Transportation Research performed research entitled "Compaction of Asphalt Mixtures and the Use of Vibratory Rollers" (Research Report 317-1). Pages 6 and 7 of this report address soundness as an aggregate property which affects the resistance of the mixture to compaction. The report further states that unsound aggregate may fracture under the dynamic loading of vibratory rollers which will effectively change the gradation of the mixture, may reduce actual density, or may increase the susceptibility of the mixture to moisture damage from stripping. (See Appendix F.)

4.2 PAVEMENT PERFORMANCE HISTORIES — MOISTURE DAMAGE (STRIPPING)

Asphalt pavement mixtures can suffer extreme damage due to the adverse effects of moisture. Several forms of such damage occur, but stripping is the major cause of distress of asphalt mixtures due to moisture. Stripping describes the loss of adhesion between aggregates and binder due to the presence of moisture in the asphalt matrix (i.e., the physical separation of the asphalt cement and the aggregate).

Stripping, a distress mechanism, can manifest itself by three types of failure: fracture (longitudinal or "alligator" cracking); distortion (rutting, shoving or wash-boarding); or, disintegration (raveling, shelling or potholes).

Several factors affect the moisture susceptibility of asphalt mixtures: environment, aggregate type, and asphalt cement and mixture properties. High traffic also contributes to stripping in asphalt pavements.

In Texas, siliceous aggregates and rhyolite have shown a greater propensity for stripping than other aggregate types. These are evidenced by the following forensic investigations.

1. In 1995, an evaluation of 1.5 miles of IH 35 in south Texas was performed. The distress was evidenced by surface flushing and deep wheel ruts. The distress was confined to the outside northbound lane, and represented approximately one typical day's production. It is believed to be due to the use of gravel combined with, perhaps, a problem with the addition of the lime admixture used as an anti-strip agent. (See Appendix G.)
2. In 1996, a forensic study on IH 30 in northeast Texas was conducted. The findings concluded that the surface cracking and potholes are stripping due to strip-susceptible aggregates and the presence of excessive moisture in the pavements. (See Appendix H and the Sand Equivalent section in Chapter 2.)
3. In 1995, IH 27 in the Texas panhandle was investigated due to the presence of regular transverse cracking at 30- to 50-foot intervals with longitudinal cracking in the wheel paths. Pumping from the cracks and potholes have appeared, primarily in the left wheel path of the outside lane. The causes are believed to be an existing weak subgrade, an existing gravel base which has a history of moisture damage, and the new asphalt mixture made from a gravel which has historically shown a susceptibility to stripping. (See Appendix I.)
4. During the summer of 1996, a section of IH 20 between Abilene and Fort Worth showed rutting and shoving in various locations. Based on field and laboratory investigations, the problems were found to be caused by stripping of the bottom three inches of the asphaltic concrete surface. (See Appendix J.)

In addition to the above case studies, a joint industry-TxDOT team was formed in 1995 to evaluate and make recommendations for improving the performance of crushed gravel hot mix in northeast Texas. The Executive Summary of the report is in Appendix K. The team identified two foremost pavement performance concerns, loss of asphalt-aggregate bond (stripping) and raveling. Their recommendations center on the stripping issue.

Finally, Materials and Tests Division representatives were in a coastal district in the spring of 1997 gathering data on polish values. As a part of this effort, cores were taken from numerous asphalt pavements at randomly selected sites. These cores (see pictures in Appendix L) are very informative. Limestone roadways up to 8+ years old showed little or no stripping. Gravel pavements as little as four years old were completely stripped (one gravel road, only slightly more than ½ year old, was still in very good condition). Several roadways had both limestone or sandstone layers and gravel layers. The gravel layers were anywhere from moderately stripped to completely stripped; the limestone/sandstone layers were not. It is important to note that the gravel roadways which stripped were treated with anti-strip agent, usually at 1 percent by weight of the asphalt (a standard dosage rate), and were tested using Test Method 531-C.

CHAPTER 5. AGGREGATE USE IN BASE MATERIALS

5.1 BACKGROUND

The vast number of aggregate sources in Texas also meet the needs of transportation contractors for aggregate base materials. The current standard specification for aggregate base, Item 247, is written such that the project design engineer is responsible for selecting the type of base to be utilized. The current specifications are also written such that aggregate base materials are specified primarily according to aggregate mineralogy. As examples, the designer may specify Type A, which requires that a crushed stone be used, or the designer may select Type B, which requires use of crushed or uncrushed gravel. The designer's selection is based upon availability of materials in the project area (costs) and the designer's prior experience with performance of those materials (benefits). This procedure has been in place since the 1951 specifications were published.

Although not the most desirable manner of specifying aggregate base, as discussed in more detail later, this procedure functioned rather well for several reasons. In the early days of the department, the shipping of aggregate materials over distances more than about twenty miles was quite difficult and costly. Since the different mineralogy types tend to be regionally located in Texas, in many cases the designer simply specified the only mineral type of aggregate available in the market area of the project. This often resulted in the use of a local material due to initial cost restraints as opposed to being based on engineering design considerations. Also, it should be noted that these roadways were not subjected to the traffic volumes and vehicle loads of today, and less-advanced pavement design methodology allowed more conservative design thicknesses to be built.

This approach to specifying aggregate base is less desirable today than in earlier years because a number of factors have changed. With the modern advances in transportation and the development of a state and nationwide infrastructure, the task of shipping materials has become significantly less cumbersome over time. In today's construction arena, it is not uncommon for materials to be shipped one hundred miles or more for use in construction. Therefore, there is more overlap of market areas for the various mineralogical aggregate types. Also, because the roadways of today are required to withstand heavier loads and much greater volumes of traffic, it has become more critical that pavement designs and their base layer thicknesses be based on engineering properties. The department must take advantage of newer technology as it becomes available.

5.2 COST COMPARISON OF ALTERNATE MATERIALS

As discussed in Chapter 2, there are some areas of the state that do not have quality local materials to use in construction. There are also areas that have numerous sources of several mineralogical types available to compete on projects. A district in one area of the state that has two mineral types close enough to compete has utilized an alternate bidding item to allow this competition. The primary bid items provide for Type B gravel with 1.5 percent by weight lime to be added. The alternate bid item allows for the use of Type D limestone. The 1.5 percent of lime required with the gravel base was determined through laboratory tests to be necessary for the gravels in that area to meet the desired Class 1 triaxial classification. Regardless of the material selected, the quantity of material required on each project remains the same, and either material must meet a Class 1 triaxial classification.

The following table outlines the bidding data associated with several of these projects. The bid prices for the base in these tables include the costs to deliver the materials. It was noted that the closer gravel materials appeared to be cost competitive when the distance of the haul was less than about twenty miles. When the gravel materials were located farther from the project than that, then the advantage of its use appeared to diminish to the point that limestone producers could successfully compete while transporting their materials a hundred miles or more.

TABLES 7 through 9 Bidding Data On Projects With Allowable Base Alternates

TABLE 7

Project 1 ----- Grading, Structures, Surfacing ----- Base Quantity: 120,000 CY			
Bidder	Base Selected By Bidder	Unit Bid Price For Base	Total Project Bid Price
1	Item 247 (TY B)(Gravel with Lime)	$ 18.90/CY	$ 8,518,533
2	Item 247 (TY B)(Gravel with Lime)	$ 12.00/CY	$ 9,068,808
3	Item 247 (TY B)(Gravel with Lime)	$ 13.14/CY	$ 9,372,111
4	Item 247 (TY B)(Gravel with Lime)	$ 12.50/CY	$ 9,463,765

The TY D (Limestone) alternate bid item was not bid on Project 1 by any of the bidders. There were numerous gravel sources available within a twenty mile radius of this project.

The bid price for base from the low bidder on Project 1 is much higher than those from the competition. The low bidder is purchasing base while the competitors were going to supply their own base material. The higher bid price for the base by the successful bidder was more than made up by the bidder's lower bid price for embankment materials.

TABLE 8

Project 2 ----- Shoulder and ACP Overlay ----- Base Quantity: 40,089 CY			
Bidder	Base Selected By Bidder	Unit Bid Price For Base	Total Project Bid Price
1	Item 247 (TY D)(Limestone)	$ 19.19/CY	$ 2,282,305
2	Item 247 (TY B)(Gravel with Lime)	$ 19.26/CY	$ 2,310,242
3	Item 247 (TY D)(Limestone)	$ 24.66/CY	$ 2,525,343
4	Item 247 (TY B)(Gravel with Lime)	$ 21.41/CY	$ 2,555,708
5	Item 247 (TY D)(Limestone)	$ 26.76/CY	$ 2,734,267
6	Item 247 (TY D)(Limestone)	$ 31.12/CY	$ 3,061,474

The nearest gravel source to Project 2 was approximately twenty miles. This resulted in competitive bids using both types of aggregate.

TABLE 9

Project 3 ----- Grading, Structures, Surfacing ----- Base Quantity: 30,606 CY			
Bidder	Base Selected By Bidder	Unit Bid Price For Base	Total Project Bid Price
1	Item 247 (TY D)(Limestone)	$ 22.24/CY	$ 2,570,380
2	Item 247 (TY D)(Limestone)	$ 22.93/CY	$ 2,585,167
3	Item 247 (TY D)(Limestone)	$ 22.55/CY	$ 2,615,596
4	Item 247 (TY D)(Limestone)	$ 19.11/CY	$ 2,742,982
5	Item 247 (TY D)(Limestone)	$ 26.76/CY	$ 2,809,545

The TY B (Gravel with 1.5% lime) prime bid item was not bid on Project 3 by any of the bidders even though one gravel source was located within approximately fifteen miles of the project. The limestone material was shipped by rail to one end of the project from a source approximately one hundred miles away.

From these projects, it would appear that shipping costs associated with base materials may have a greater effect on the source selected for use than do the costs of the materials themselves. As shown in Project 3, there are factors other than distance. Efficiency in transportation can be as critical to the selection process for base as is the distance to be transported.

It should be noted in this discussion that the requirement for the addition of lime to meet Class 1 requirements is undoubtedly a factor in the distance that gravel base can be transported and still compete favorably in this market area.

5.3 PAVEMENT DESIGN AND TESTING CONSIDERATIONS

Current aggregate base testing technology does not adequately address all department needs. The Texas triaxial test method is currently used to accept aggregate materials in the stockpile. While this test measures some engineering properties, these properties are not adequate in themselves for use in the current pavement design method. Instead, the department uses generally established values for each type of material layer in the design process. The triaxial test is also inadequate for verifying as-constructed properties of new base layers. The department currently relies primarily on density testing to determine adequacy of construction. Density is an indirect measure, based on assumptions, that the layer possesses the designed engineering properties. Research needs to be done to obtain improved testing technology. It is highly desirable that a test be developed that can be specified and used in the laboratory, that can provide needed engineering input for the pavement design, and that can be subsequently used to verify as-constructed layer properties in the field. A three-year study at the University of Texas at El Paso, Project 1735, "Development of Structural Field Testing of Flexible Pavement Layers", has begun work in this effort.

As discussed in Chapter 2, the department is moving toward a more mechanistic pavement design procedure. Improvements in pavement design technology also require advancement in testing procedures if the full benefits are to be obtained.

Until further advances can be made in these testing areas, it is recommended that the individual districts continue to review their specific project requirements and local source options to ensure that competition is maximized while ensuring that an acceptable pavement performance is obtained. Also, it is recommended that a Special Provision to Item 247 be approved for statewide use which includes a Type E designation. Type E would allow use of either Type A or Type C. (See Appendix M for draft Special Provision.)

CHAPTER 6. BLENDING AGGREGATES FOR DEPARTMENT APPLICATIONS

Blending of materials to meet specification quality requirements is currently allowed in specific cases. In other cases, it is not allowed. The decision on whether or not to allow blending is generally based on the reliability of the blended sample test result to indicate the performance to be expected. Other factors can also be involved, such as the ability of the department to properly inspect the blending operation to assure that the approved blend percentages are being used in the production of materials.

Examples where blending is allowed are for polish value and sand equivalent value requirements. In the case of polish value, a blend percentage is approved, and monitoring of production blending is relatively easy as it is done using calibrated cold feeds at the hot mix plant. For sand equivalent, which measures clay-sized impurities in the blended aggregate, it is the total amount of impurities which is of consequence. Therefore, the testing of a blended sample is actually the optimum method of testing.

However, blending is not allowed for many other quality requirements, including the soundness test. Since soundness testing measures the internal strength of aggregates, and since these aggregates are stacked on top of each other to carry traffic loads from the surface to the subgrade, a pavement layer cannot be much stronger than its weakest aggregate component. Therefore, blending some durable aggregates with softer aggregates has the affect of improving test results without significantly improving the pavement performance. This conclusion was also reached by University of Texas researchers studying the soundness test in 1987. They concluded from their project visits that the practice of specifying a 40 percent limit on blended aggregates was not effective in obtaining desired aggregate performance. They reported that problems occurred when rather soft aggregates (up to a soundness loss of 60 to 70 percent) were blended with hard aggregates. The soft aggregates still broke down under traffic or resulted in pavement cracking.

CONCLUSIONS

1. Quality of the aggregate has a considerable effect on pavement performance.

2. The cost to rehabilitate or reconstruct an occasional pavement normally exceeds the potential cumulative savings from use of marginal quality materials.

3. The magnesium sulfate soundness test provides a valuable indicator of the toughness of an aggregate. It is a measure of the probability of the aggregate to fracture or to be pulverized during the construction process and under traffic.

4. The department standard minimum specification requirement for magnesium sulfate soundness is more lenient than those specified by many other agencies. However, this requirement has been validated based on pavement performance experience in Texas. Forensic studies indicate that there is little, if any, safety factor built in to current soundness specification requirements.

5. The department standard specification allows the experience of local project designers to specify an alternative value for magnesium sulfate soundness loss. This flexibility provides maximum opportunity for the use of local materials that have proven an ability to perform adequately on a consistent basis.

6. The decision on whether or not to allow blending should be based on the reliability of the blended sample test result to indicate the performance to be expected. Blending aggregate sources to meet magnesium sulfate soundness test requirements can allow combinations of aggregate which will perform only to the level of the lowest quality material in the blend. Therefore, allowing blending to meet this requirement is not recommended.

7. The loss of bond between aggregates and asphalt (stripping) is a continuing problem in Texas pavements. Test procedures and corresponding specification requirements used through 1996 have been found inadequate to preclude stripping prone materials from being used in several areas of Texas. Revised test procedures and specification requirements are more stringent, but it is yet to be determined if they adequately address the stripping problem on a statewide basis.

8. Currently available testing procedures for flexible base aggregate are inadequate to allow basing acceptance on the engineering properties pertinent to the pavement design.

9. While it is clear that over-specifying quality is not in the best interest of the department and taxpayers, the findings strongly support a conservative approach in selecting quality standards for aggregates used in the construction of transportation facilities.

RECOMMENDATIONS

1. Quality requirements for aggregates should be based on the cost-effectiveness of the pavement performance to be provided. All costs associated with the occasional replacement of failed pavements, including inconvenience to the traveling public, must be included in these considerations.

2. Standard specifications regarding magnesium sulfate soundness testing should remain as currently required.

3. Future changes in aggregate quality requirements, including blending, should be based on engineering judgment and pavement performance.

4. Performance of the revised test procedure and specification requirements for moisture susceptibility should be evaluated for adequacy in precluding moisture susceptible mixtures from being used in Texas.

5. Continued emphasis on research is recommended to develop aggregate base testing procedures that are in concert with pavement design methods and which are suitable for field and laboratory use. These methods should replace current specification practice of selecting aggregate base type by mineralogy as soon as technological advances allow.

6. Districts should continue to review local material options during the project development phase so that local materials which will perform adequately on a consistent basis in those applications are allowed by the specifications and special provisions.

7. To assure cost-effectiveness in aggregate material selection, and to assure maximum use of local materials, final decisions regarding aggregate requirements for individual project conditions must remain with the project engineer. Plan note and special provision avenues must remain available for this purpose.

APPENDIX A

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Texas
Department
of Transportation

IN-HOUSE STUDY ON REVISED 531-C TEST METHOD

Prepared for
Mr. Dennis W. Warren, P.E.

by

Stanley F. Yin, P.E.

Texas Department of Transportation
Houston District Laboratory
Houston, Texas 77007

September 29, 1997

Purpose of Studies

The Materials and Tests Division has recently come up with a new specification requirement and a revised 531-C test procedures for the prediction of moisture-induced damage to bituminous paving materials using molded specimens. This is a preliminary study to access if there exists any effect to the existing job mix for Houston projects.

Scope

The scope of this laboratory study included the following items:

1. Materials selection and sampling
2. Test evaluation on the old and revised test methods
3. Analyzing test results from the two methods
4. Comparison of the old and new specification requirements

Materials selection and sampling

Hot Mix Asphaltic Concrete Type-D Surface Materials were carefully selected within Houston District Projects. These materials were confirmed to comply with our old project specification when tested using the old 531-C test method. 14 separate groups of samples were taken from several hot mix plant during construction and reduced to test sample portion for tests.

Test evaluation on the old and revised test methods

Individual materials were molded into sets of twelve (4 inches diameter) specimens at the Houston District Laboratory at 121°C to a compacted density of 93±1% using the Texas Gyratory Press. Samples were allowed to stand at room temperature for 24 hours, divided into three groups and tested using the following procedures:

Group one - Unconditioned Specimens

- Specimens were tested for indirect tensile strength at dry condition at 25±0.5°C

Group two - Moisture Conditioned using old method

- Samples were submerged in water and vacuumed to 60 to 80% saturation
- Saturated samples were conditioned: in a freezer at -18±3°C for a minimum of 15 hours; in a water bath at 60±3°C for 24±2 hours
- Conditioned specimens were tested for indirect tensile strength at 25±0.5°C

Group three - Moisture Conditioned using revised method

- Samples were submerged in water and vacuumed for 30 minutes at 711mm Hg
- Saturated samples were conditioned: in a freezer at -18±3°C for a minimum of 15 hours; in a water bath at 60±3°C for 24±2 hours
- Conditioned specimens were tested for indirect tensile strength at 25±0.5°C

Analyzing test results from the two methods

Laboratory results were computed and summarized from all three groups of samples. Table 1 revealed the test results on Average Tensile Strength and their appropriate Average Tensile Strength Ratios. Figure 1 and figure 2 illustrated the data in a bar chart with results from both the old and revised test methods.

Comparison of the old and new specification requirements

Test results were further evaluated to check for specification compliance. Table 2 tabulated the data to show the possible effects due to the changes of specification criteria.

Conclusion

From the above studies, the following conclusion are made:

1. The revised test method shows a lower Tensile Strength when process through the new specimen saturation procedures. Test data showed a decrease in Tensile Strength Ratio ranging from 5 to 20% dropped. In my opinion, the lower in strength is a direct effect from the severe sample saturation introduced by this revised 531-C test method.

2. From table 2, it can be concluded that, among the fourteen samples that passes the old TSR specification requirement of "0.7", nine out of fourteen samples will pass the new TSR specification criteria of "0.8" when using the old 531-C test method. When adopting the revised test procedures, only two out of fourteen samples passes the TSR requirements.

3. Test results also reveals that half of the fourteen samples failed to comply with the new Tensile Strength requirements of 70psi.

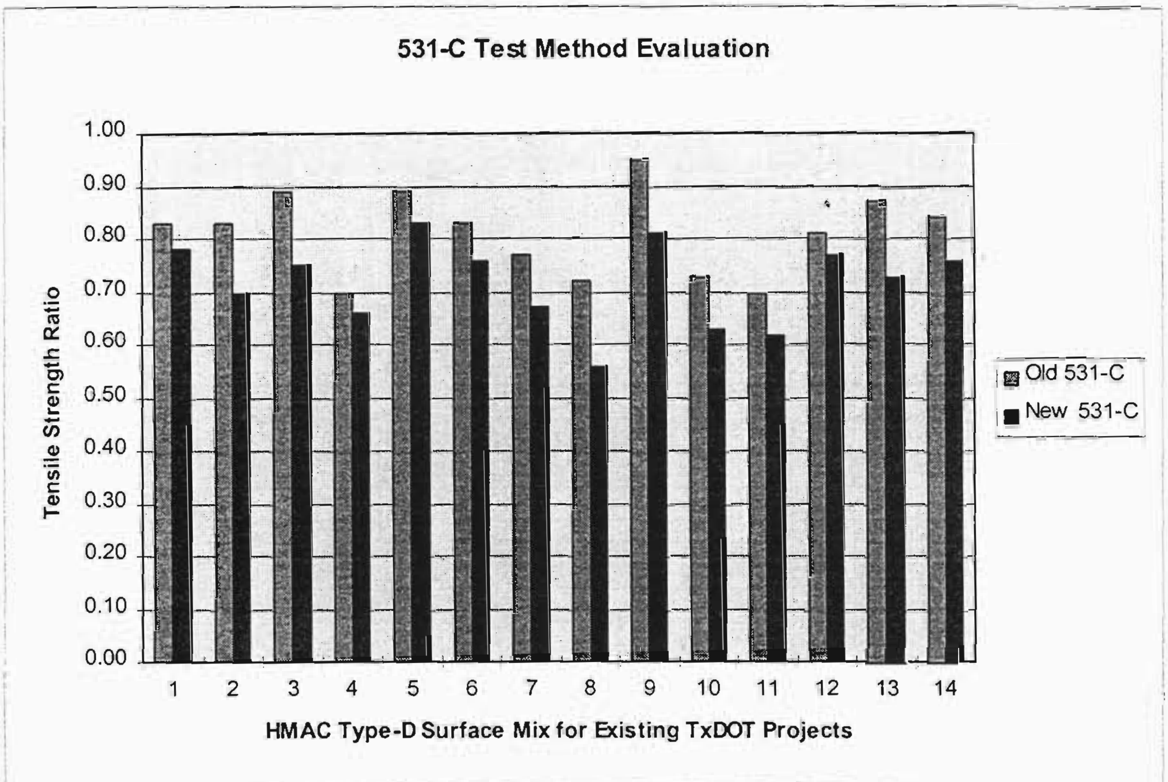
4. Based on this preliminary study, most of the existing hot mix materials using in Houston District will fail to comply with the new specification requirements. Individual contractors will have to make their own adjustments in their mixes to cope with the new changes. Further studies will be required to conclude the exact impact to our projects when acquiring these changes.

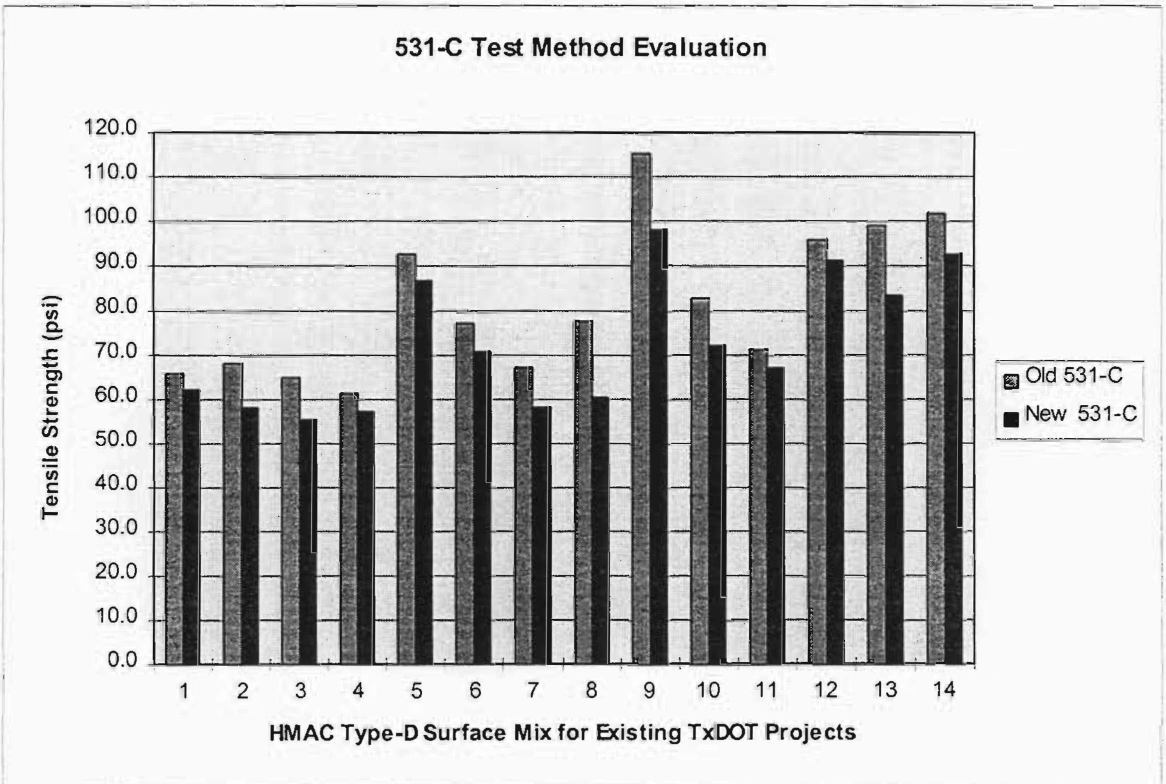
Table 1. Summaries of test results

Sample Number	Anti-Strip	Unconditioned Tensile Strength	Old 531-C Method		Revised 531-C Method	
			Tensile Strength	TSR Ratio	Tensile Strength	TSR Ratio
1	0.5%	79.7	65.8	0.83	62.3	0.78
2	0.5%	82.4	68.1	0.83	58.0	0.70
3	0.8%	73.4	65.2	0.89	55.3	0.75
4	0%	87.3	61.3	0.70	57.4	0.66
5	0.5%	104.3	92.6	0.89	86.9	0.83
6	1.0%	93.5	77.3	0.83	70.9	0.76
7	0%	87.4	67.2	0.77	58.1	0.67
8	0%	108.4	77.9	0.72	60.4	0.56
9	0.6%	121.4	115.3	0.95	98.2	0.81
10	0.8%	113.9	82.6	0.73	72.3	0.63
11	0%	109.0	71.3	0.70	67.1	0.62
12	1.2%	119.0	96.0	0.81	91.4	0.77
13	1.0%	114.4	99.0	0.87	83.7	0.73
14	1.0%	121.7	101.9	0.84	92.8	0.76

Table 2. New and Old Specification Comparison

Sample Number	Old 531-C Method		Revised 531-C Method			
	Tensile Strength	TSR Ratio	Tensile Strength		TSR Ratio	
	Specification: TSR 0.7 min.		Specification: Strength 70psi min. TSR 0.8 min.			
1	65.8	0.83	62.3	Failed	0.78	Failed
2	68.1	0.83	58.0	Failed	0.70	Failed
3	65.2	0.89	55.3	Failed	0.75	Failed
4	61.3	0.70	57.4	Failed	0.66	Failed
5	92.6	0.89	86.9	Passed	0.83	Passed
6	77.3	0.83	70.9	Failed	0.76	Failed
7	67.2	0.77	58.1	Failed	0.67	Failed
8	77.9	0.72	60.4	Failed	0.56	Failed
9	115.3	0.95	98.2	Passed	0.81	Passed
10	82.6	0.73	72.3	Passed	0.63	Failed
11	71.3	0.65	67.1	Failed	0.62	Failed
12	96.0	0.81	91.4	Passed	0.77	Failed
13	99.0	0.87	83.7	Passed	0.73	Failed
14	101.9	0.84	92.8	Passed	0.76	Failed


531-C Test Method Evaluation
Tensile Strength Ratio
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14
HMAC Type-D Surface Mix for Existing TxDOT Projects
Old 531-C
New 531-C


531-C Test Method Evaluation
Tensile Strength (psi)
120.0
110.0
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
HMAC Type-D Surface Mix for Existing TxDOT Projects
Old 531-C
New 531-C

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APPENDIX B

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Pharr Tex-531-C
Data Comparison

Tex Method 531-C (April 1997)
(100% Saturation)

Results with new procedure

LAB #	MIX TYPE	% AC	ANTI-STRIP	% LIME	LIME	GR 4	GR 6	SCREENS	SAND	StC	StU	TSR	BOIL TEST STRIP %
8	D	4.5	MORTON			FORDYCE	FORDYCE	B.P.	FORDYCE	58.0	65.3	0.89	5
9	D	6.0	MORTON			FORDYCE	FORDYCE	FORDYCE	FORDYCE	59.8	52.2	1.15	5
11	D	5.0	ARR-MAZ			FORDYCE	FORDYCE	B.P	FORDYCE	87.5	84.9	1.03	5
12	D	5.7	ARR-MAZ			FORDYCE	FORDYCE	FORDYCE	FORDYCE	78.6	81.4	0.97	5
17	D	4.1		1.0	WET	FORDYCE	FORDYCE	B.P	FORDYCE	120.4	82.8	1.45	5
18	D	5.4		1.0	WET	FORDYCE	FORDYCE	FORDYCE	FORDYCE	93.9	60.7	1.55	5

Tex Method 531-C (Sept. 1995)
(55 - 80% Saturation)

LAB #	MIX TYPE	% AC	Mix Method	% LIME	LIME	GR 4	GR 6	SCREENS	SAND	StC	StU	TSR	BOIL TEST STRIP %
13	D	4.8	HAND	1.0	DRY	UVM	UVM	UVM	FORDYCE	71.1	82.6	86	5-10
13	D	4.8	MECHANICAL	.0	DRY	UVM	UVM	UVM	FORDYCE	138.5	102.9	1.35	0-5

NOTES:
- B.P. - BORDER PACIFIC
- UVM - UPPER VALLEY MATERIALS
- StC - INDIRECT TENSILE STRENGTH CONDITIONED
- StU - INDIRECT TENSILE STRENGTH UNCONDITIONED

Mix designs selected for testing also with new procedure are circled

Tex Method 531-C (Sept. 1995)
(55 - 80% Saturation)

Results with old procedure

LAB #	MIX TYPE	% AC	ANTI-STRIP	LIME %	LIME	GR 4	GR 6	SCREENS	SAND	OTHER	StC	StU	TSR	BOIL TEST STRIP %
1	D	5.1				UVM	UVM	UVM	FORDYCE		96.9	110.1	0.88	10
4	D	4.5	AKZO NOBEL			UVM	UVM	UVM	FORDYCE		88.3	103.5	0.85	10
7	D	4.5	MORTON			UVM	UVM	UVM	FORDYCE		74.1	80.4	0.92	5
10	D	4.5	ARR-MAZ			UVM	UVM	UVM	FORDYCE		74.4	72.7	1.02	5
13	D	4.8		1.0	DRY	UVM	UVM	UVM	FORDYCE		80.4	89.5	0.90	10
16	D	5.0		1.0	WET	UVM	UVM	UVM	FORDYCE		93.2	83.5	1.12	15
2	D	4.6				FORDYCE	FORDYCE	B.P	FORDYCE		75.4	85.7	0.88	5
5	D	4.8	AKZO NOBEL			FORDYCE	FORDYCE	B.P	FORDYCE		86.4	76.9	1.12	5
8	D	4.5	MORTON			FORDYCE	FORDYCE	B.P	FORDYCE		83.8	77.0	1.09	10
11	D	5.0	ARR-MAZ			FORDYCE	FORDYCE	B.P	FORDYCE		83.1	66.1	1.26	5
14	D	4.5		1.0	DRY	FORDYCE	FORDYCE	B.P	FORDYCE		108.0	87.2	1.24	10
17	D	4.1		1.0	WET	FORDYCE	FORDYCE	B.P	FORDYCE		91.1	87.5	1.04	5
3	D	5.8				FORDYCE	FORDYCE	FORDYCE	FORDYCE		87.3	83.0	1.05	20
6	D	5.9	AKZO NOBEL			FORDYCE	FORDYCE	FORDYCE	FORDYCE		80.8	67.9	1.19	5
9	D	6.0	MORTON			FORDYCE	FORDYCE	FORDYCE	FORDYCE		91.6	63.4	1.44	5
12	D	5.7	ARR-MAZ			FORDYCE	FORDYCE	FORDYCE	FORDYCE		95.6	71.8	1.33	10
15	D	5.4		1.0	DRY	FORDYCE	FORDYCE	FORDYCE	FORDYCE		81.5	88.6	0.92	10
18	D	5.4		1.0	WET	FORDYCE	FORDYCE	FORDYCE	FORDYCE		98.6	82.7	1.19	5
19	D	5.1	AKSO NOBEL	1.0		FORDYCE	FORDYCE	FORDYCE	FORDYCE		99.6	78.4	1.27	10
20	D	5.8				FORDYCE	FORDYCE	FORDYCE	FORDYCE	SAT.TIME=3MIN. @ 28 IN Hg	53.5	63.6	0.84	30
21	D	5.8				FORDYCE	FORDYCE	FORDYCE	FORDYCE	2 X CYCLE (FREEZE-THAW)	48.3	63.6	0.76	30

NOTES:
- B.P. - BORDER PACIFIC
- UVM - UPPER VALLEY MATERIALS
- StC - INDIRECT TENSILE STRENGTH CONDITIONED
- StU - INDIRECT TENSILE STRENGTH UNCONDITIONED

APPENDIX C

Texas Department of Transportation

MEMORANDUM

To:	Mr. Blair Haynie, P.E.	June 28, 1996
From:	Maghsoud Tahmoressi, P.E. MT	Originating Section M&T/Bituminous
Subject:	Test Results on Cracked AC-45P portions of US 83	

We have completed our testing of samples you had sent us from the above referenced project. Test results are summarized in the attached table.

The nature of failure indicates that cracking is caused by debonding of the surface layer from the level-up course. The debonding appears to have been caused by lack of free asphalt film in the surface course. Examination of the attached test results indicate that extremely high percentage of minus 200 material could be the source of the problem.

To either prove or disprove this theory, it would be helpful to test some of the cores from the "good" portions of the SBS test section.

Please let me know if we can be of any assistance.

MT:jjl
Attachment

cc: Mr. Thomas Bohuslav, P.E.
Ms. Jeraldene Anderson

SUMMARY OF FORENSIC TEST RESULTS
CSJ 0034-02-027
US 83, TAYLOR COUNTY

Sieve	Percent Passing Sample No. 1	Percent Passing Sample No. 2	Specification Limits
5/8	100	99.7	95 - 100
3/8	66.0	71.2	50 - 70
4	38.5	41.8	30 - 45
10	26.7	28.9	15 - 25
40	19.7	20.5	6 - 20
80	16.3	17.2	6 - 18
200	11.9	12.9	6 - 10
AC Content	5.7	6.0	N/A
Penetration, 77°F	33	32	Min 50 Max 74
Viscosity, 140°F	28,369	32,591	Min 4,500
SBS Content	2	1.5	Min 3.0
Avg Lab Density	96.3	96.5	96 - 98
Avg Creep Stiffness	12,208	11,485	Min 6,000
Avg Creep Slope	5.3	3.7	Max 4.0
Avg Permanent Strain	0.37	0.33	Max 0.6

Table 1. Summary of Core Test Results

Part A. Core Densities

Core Location	Station	Direction	Rut Depth, Inches	Density Wheel Path	Density Between W.P.	Remarks
1	701+00	West Bound	1/8 "	97.7	95.0	Bottom of Bachelor Hill, Minor rutting
1	701+00	West Bound	1/8 "	97.3	95.1	
			Average	97.5	95.1	
2	542+00	West Bound	1/4 "	97.8	96.6	Rutting in this location is typical for the majority of the project
2	542+00	West Bound	1/4 "	97.8	95.8	
			Average	97.8	96.2	
3	504+00	East Bound	3/4 "	97.6	96.6	Top of Bachelor Hill, Severe rutting
3	504+00	East Bound	3/4 "	97.2	96.8	
			Average	97.4	96.7	

Part B. Mixture Information

Location	1	2	3
Sieve			
1/2 "	100	100	100
3/8 "	97.9	97.6	98.4
# 4	63.2	61.5	63.4
# 10	35.3	35.1	38.7
# 40	19.1	18.2	20.2
# 80	11.3	11.2	11.9
# 200	7.3	7.8	7.6
AC Content	5.1	5.4	4.8
Viscosity	4682	3273	2978
Penetration	40	47	41

APPENDIX D

Texas Department of Transportation

Memorandu

To:	Mr. William G. Burnett, P.E.	**Date:**	August 22, 1994
From:	Maghsoud Tahmoressi, P.E.	**Originating Section**	M&T/Bituminous
Subject:	Investigation of Flushing and Rutting on IH-10, Crockett County, San Angelo District		

Pursuant to our telephone conversation on August 18, 1994 regarding above referenced project, I travelled to San Angelo District to survey the project and gather information. I met with Messrs. Walter McCullough, Dennis Wilde, Victor Pinon, Paul Chevalier and Jerry Fields and discussed the project. The Area Engineer provided me a complete and well-organized copy of all pertinent construction data.

We travelled to the site and performed a visual inspection and obtained cores and rut depth measurements. Rutting and flushing is evident in the outside lane in both directions. Typical rut depth throughout the project is 1/4 inch. The most severe rutting is evident in the east bound outside lane of Bachelor Hill. Rut depth in this area is approximately 3/4 inch.

I performed an analysis of the construction data and summary of results are shown in Figures 1 through 3.

High Lab Density is the cause of distress in this project (Figure 1). The high lab density is attributed to excessive amounts of passing No. 200 aggregate (-#200) in the mix (Figure 2). The excessive amount of -#200 is generated by degradation of coarse aggregate in the plant (Figure 3).

Results of core testing are shown in Table 1. The in-place density between wheel path is more than 95.0% and the wheel path density is approaching 98%. This indicates that slightly more densification in the wheel path is expected to occur. It is anticipated that plastic deformation will continue to take place throughout the job. Sieve analysis of cores indicate that excessive amount of material passing No. 200 sieve is the primary cause of the distress.

Tests on recovered asphalt indicate that the asphalt is significantly more aged than expected for an AC-10.

Based on the analysis of the available data, it is evident that similar situations can be avoided by either not using excessively soft aggregate or wasting the fines which are collected in the baghouse instead of feeding them back into the mix. This project was constructed under Special Specification 3834 (non-QC/QA) and the aggregate met specification requirements.

I appreciate the cooperation and assistance which I received from the Area office and the District office in conducting this investigation. Please contact me at 465-7603 if you wish to discuss this further.

MT:jjl
Attachments

M. Tahmoressi

cc: Mr. Bobby Templeton, P.E.
Mr. Walter McCullough, P.E.
Ms. Katherine H. Hargett, P.E.

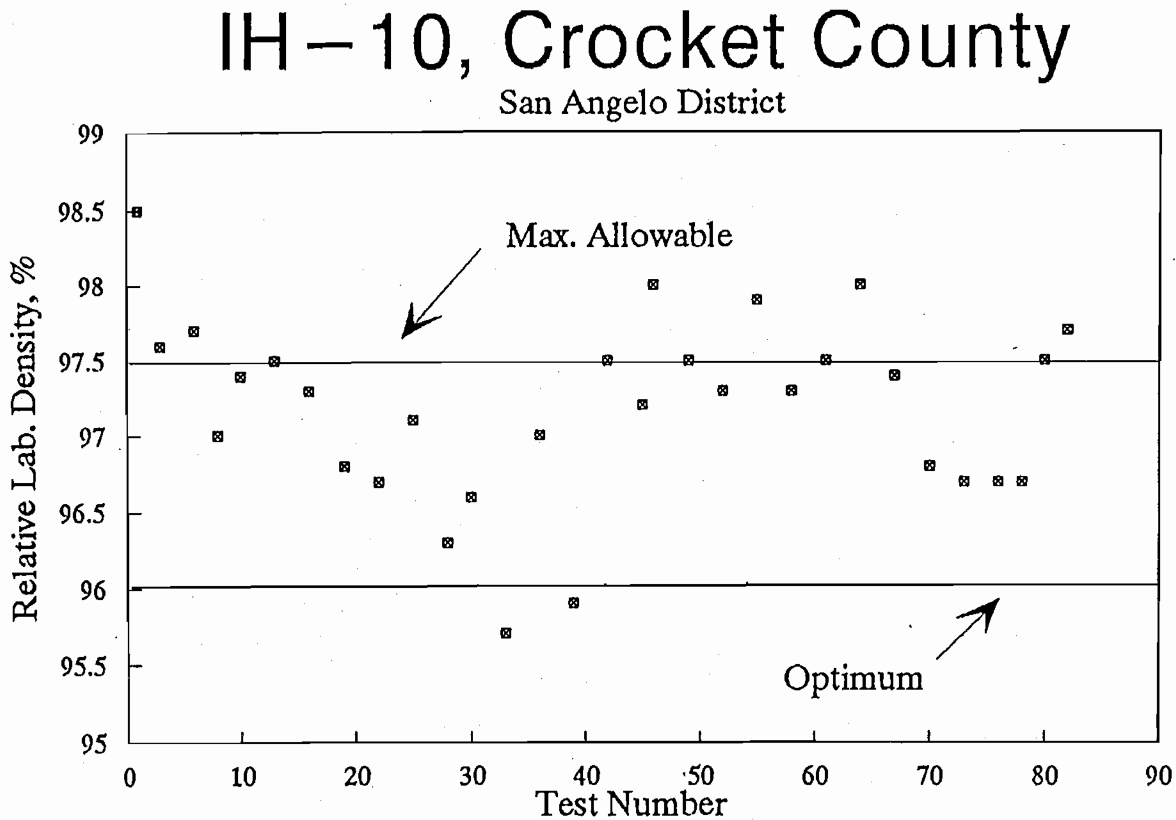

Figure 1. Variations in Relative Lab. Density

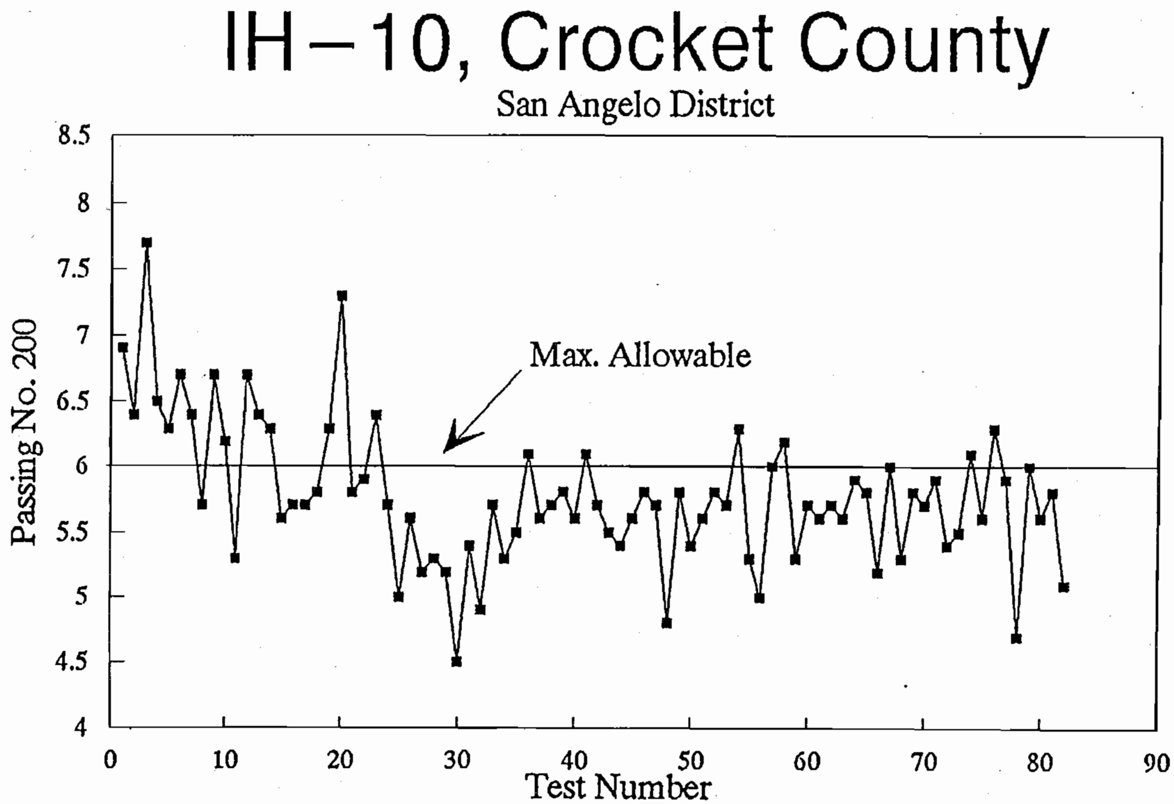

Figure 2. Variations in Percent Passing No. 200 Sieve

Table 1. Summary of Core Test Results

Part A. Core Densities

Core Location	Station	Direction	Rut Depth, Inches	Density		Remarks
				Wheel Path	Between W.P.	
1	701+00	West Bound	1/8 "	97.7	95.0	Bottom of Bachelor Hill, Minor rutting
1	701+00	West Bound	1/8 "	97.3	95.1	
			Average	97.5	95.1	
2	542+00	West Bound	1/4 "	97.8	96.6	Rutting in this location is typical for the majority of the project
2	542+00	West Bound	1/4 "	97.8	95.8	
			Average	97.8	96.2	
3	504+00	East Bound	3/4 "	97.6	96.6	Top of Bachelor Hill, Severe rutting
3	504+00	East Bound	3/4 "	97.2	96.8	
			Average	97.4	96.7	

Part B. Mixture Information

Location	1	2	3
Sieve			
1/2 "	100	100	100
3/8 "	97.9	97.6	98.4
# 4	63.2	61.5	63.4
# 10	35.3	35.1	38.7
# 40	19.1	18.2	20.2
# 80	11.3	11.2	11.9
# 200	7.3	7.8	7.6
AC Content	5.1	5.4	4.8
Viscosity	4682	3273	2978
Penetration	40	47	41

APPENDIX E

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CTR 3-9-85-438-1

EVALUATION OF THE 4-CYCLE MAGNESIUM SULFATE SOUNDNESS TEST

C.G. Papaleontiou, A.H. Meyer,
and D.W. Fowler

RESEARCH REPORT 438-1F

PROJECT 3-9-85-438

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN
NOVEMBER 1987

ABSTRACT

This report presents an evaluation of the 4-cycle magnesium sulfate soundness test to control quality of coarse aggregates for use in hot mix asphaltic concrete and seal coats. A total of 41 aggregates were tested for the purpose of this study in the laboratory and the behavior of eight of the aggregates was evaluated in the field by examining roadway performance. The soundness test was found to be the best method for predicting performance among specific gravity, absorption, aggregate durability index, freeze-thaw, Los Angeles abrasion, and a modified Texas wet ball mill (called Texas degradation) tests. Specific recommendations have been suggested to improve the soundness procedure. Also specification limits for hot mix and seal coat projects have been included.

The repeatability of the soundness test was approximately equal to that of durability index and lower than the repeatability of Texas degradation. Statistical analysis showed high correlation between soundness and other tests at soundness losses less than 20 percent, and low correlation at higher values. Texas degradation showed the best correlation with the soundness test. The model that describes their relationship has $R^2 = 0.72$.

SUMMARY

The 4-cycle magnesium sulfate soundness test is a laboratory method to control quality of coarse aggregates for hot mix asphaltic concrete (HMAC) and seal coats. The test which appears to measure an aggregate's ability to withstand degradation from traffic and climate effects, is specified by several Texas districts. However, acceptable values vary between districts and while this may be appropriate, there are no hard data to justify the differences.

The objectives of this study were to investigate if the soundness test is a valid measure of durability, and determine the most appropriate parameters for the test considering aggregate and pavement type, region, and traffic. Additionally, the objective was to determine the relationship of the soundness test to other material tests for the purpose of identifying a more appropriate or nondiscriminating test, or a simpler test to perform with less variability that provides equal information on performance. A total of 41 aggregates representing the most common or problem aggregates used by districts were tested in the laboratory. Tests included specific gravity, absorption, freeze-thaw, Los Angeles abrasion, aggregate durability index, a modified Texas wet ball mill (called Texas degradation), and 4-cycle magnesium sulfate soundness.

The performance of eight aggregates similar to those tested in the laboratory was evaluated in the field by examining surface disintegration of HMAC and seal coats constructed with the materials. The selected aggregates exhibited all the ranges of soundness values or were predicted with varying quality under the different tests. Results indicated that the soundness test is the best among the methods considered for predicting performance. The other tests have discriminated in favor of using two or more unacceptable aggregates. Specific recommendations have been made for the most appropriate specification soundness limits and for improving the soundness procedure.

A state wide survey has revealed that specification limits in districts are governed by material availability or prices. Districts that specify the soundness test have experienced increased performance with its use.

Extensive statistical analysis has been performed on the laboratory results. This included scatter plots, transformations, correlation, regression, and covariance. Freeze-thaw and Los Angeles had the lowest correlation with soundness, while absorption and Texas degradation the highest. Freeze-thaw, aggregate durability index, and Texas degradation showed high correlation among each other. Bivariate and multivariate models describing the relationship of tests with soundness have been developed. The best one variable model describing soundness variation was obtained with Texas degradation ($R^2 = 0.72$). The best two variable model was obtained with Texas degradation and specific gravity.

CHAPTER 1. INTRODUCTION

RELATIONSHIP BETWEEN LABORATORY EVALUATION AND FIELD PERFORMANCE

The question of predicting in the laboratory the service life of aggregates when used in hot mix asphaltic concrete (HMAC) or seal coat road surface applications has been a subject of investigation for over 150 years. Hundreds of reports have been published pertinent to this issue, each contributing its merit to the complex problem.

When road aggregates are tested for their suitability as road construction materials the intention is to obtain material with performance adequate to last the design life of the road. The word "performance" as applied to aggregates, is rather a vague term which reflects factors such as degradation, splitting, abrasion, wear, polishing, skid resistance, ravelling, stripping or resistance to deformation. It is also affected by many variables which can be either controlled or uncontrolled, e.g., aggregate mineralogy, pavement type, pavement design, subgrade conditions, maintenance practices, traffic characteristics, or weather conditions. Aggregate performance has, in addition, a synergistic effect on the overall performance of the road. Undesirable aggregate quality may lead to pavement disintegration, ravelling, cracking, bleeding, instability, rutting, or deformation.

The broad definition of aggregate performance, the wide range of variables affecting service life of aggregates, and the effect of aggregate quality on the overall performance of roadways connote the difficulty of developing a material test to assess performance. Various studies have developed several tests or proposed modifications to tests for better predictions and precision, but up to this date no single test has been completely successful. The controversy behind the results and recommendations of these studies and the many tests, demonstrate the level of influence of variable conditions in road design, construction, weather, and traffic on the relationship between laboratory and field.

One material test that has been somewhat successful in predicting performance is the 4–cycle magnesium sulfate soundness test. The test takes seven days to perform and as reported has low repeatability. The purpose of this study is to examine the test in the laboratory and assess it in the field.

THE 4–CYCLE TEST

The magnesium sulfate soundness test is a laboratory method for evaluating aggregates in HMAC and seal coats. It originated more than 150 years ago and through the years it has undergone several changes. Texas is among 26 states that utilize the test for quality control of aggregates.

The test which has been developed to determine the weather resisting properties of aggregates, has also shown indications that it reflects an aggregate's ability to withstand degradation from traffic. Several research studies have indicated that test results correlate with field performance, while others, have reported that the test discriminates against certain aggregate types like carbonates, cherts, shales and rhyolites. The repeatability of the test as stated in the ASTM standard specification is very low, and an outright rejection of an aggregate without confirmation from other tests more closely related to the specific service intended, is not recommended by the specification.

Sixteen Texas districts specify the test either for hot mixes and/or seal coats. The majority use a limit of 30 percent loss for aggregate rejection, while others specify lower or higher limits. While these numbers may be appropriate, there are no hard data to justify the differences.

PROBLEMS INVESTIGATED, OBJECTIVES, AND SIGNIFICANCE

The study will focus on examining the relationship of the soundness test to aggregate performance. If such a relationship exists, an investigation will be made as to what values are acceptable, if values should be statewide or regional, or whether different values for hot mixes and seal coats are more appropriate. Other aggregate tests will be evaluated in the lab and their relationship to the soundness test and field performance will be examined.

The objective of the study is to develop the most appropriate parameters for the 4–cycle magnesium sulfate soundness test on a statewide or regional basis, or identify a better test method for evaluating the durability of aggregates. This would be implemented through a recommended specification.

When a material test can predict performance in service it has significant benefits. It precludes inferior materials from use in certain applications, and permits better pavement management in terms of predicting when remedial treatment will most likely be required.

WORK PLAN

The work necessary to accomplish the objectives of this study was divided into four tasks. Each task is presented in the following paragraphs.

Task 1 - Literature Search

A search of the published literature related to the development, mechanisms, and use of the 4–cycle magnesium sulfate soundness was carried out. Additionally, the current practice and experience of Texas districts with the test was gathered through interviews with district maintenance and laboratory engineers. A search of literature related to the use and development of other material tests was also carried out to facilitate the laboratory task.

Task 2 - Laboratory Evaluation

A total of 41 aggregates that represent the most widely used or problem sources from all regions of the state were gathered and their physical properties determined in the laboratory. Tests included specific gravity, absorption, freeze-thaw, aggregate durability index and 4-cycle soundness. A modified procedure of the Texas wet ball mill test was also used. A thorough statistical analysis was performed to determine the relationship of the soundness test with other tests.

Task 3 - Field Evaluation

Hot mix and seal coat projects that were constructed with eight of the aggregate sources tested in the laboratory were examined in five districts and their performance evaluated.

Task 4 - Specification

Laboratory and field evaluations were compared and analyzed together with the experience of districts, and specific recommendations were made for the evaluation of aggregate durability.

CHAPTER 9. SUMMARY AND CONCLUSIONS

SUMMARY

The objectives of the study were to

(1) investigate the 4-cycle magnesium sulfate soundness test in the laboratory,

(2) evaluate the 4-cycle soundness as a laboratory method to predict performance of aggregates when used in HMAC and seal coat surface applications,

(3) determine the most appropriate parameters for the soundness test considering aggregate type, pavement type, region, and traffic,

(4) investigate the relationship between the soundness test and other material tests in an effort to identify a better method for evaluating durability of aggregates, and

(5) develop a specification addressing the 4-cycle soundness or a better method for evaluating aggregate behavior in the field.

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 tested in the laboratory. Tests included 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. Statistical analysis was used to determine repeatability of methods and develop models describing the relationship between soundness and the other tests.

The behavior of 8 aggregate sources evaluated in the lab, was assessed in several Texas districts by examining their performance in selected HMAC and seal coat projects. District experience in using the 4-cycle soundness test to qualify aggregates was gathered by visits to district offices, mail correspondence, and telephone interviews.

Based on the relationship between laboratory and field results and the experience of districts, specific recommendations are suggested for quality control of hot mix and seal coat aggregates.

CONCLUSIONS

1. The 4-cycle soundness test was the best among seven laboratory methods in predicting performance of aggregates in HMAC and surface treatments.
2. The soundness test is successful in eliminating soft, absorptive, weakly cemented limestone and sandstone aggregates. These materials crack, crumble, split, shell, and wear readily during construction from rolling, or in service due to traffic and the environment.
3. All siliceous gravels, because of low absorption and high durability, exhibited very small soundness losses.
4. Aggregates used in seal coats are more prone to disintegration than aggregates used in hot mixes because they are subjected to higher wheel stresses, are more exposed to weathering, and are more influenced by design and construction variables.
5. There was some evidence that aggregate breakdown is more affected by the magnitude of load rather than repetition of load. Repetition affects primarily wear of aggregates.
6. Most districts after implementing the soundness test have experienced improved road performance.
7. Districts have reported that Los Angeles abrasion, wet ball mill, and decantation tests do not eliminate problem aggregates.
8. There has been evidence that a soundness test should be specified in conjunction with a polish value test for satisfactory performance in terms of aggregate resistance to both breakdown and wear. Also frictional evaluation of several hot mix projects has revealed that high durability as determined by the 4-cycle soundness test does not guarantee a high frictional performance if an aggregate has a low PV.
9. Specifying only the PV test does not prevent the use of unsound materials.
10. Economics (material, availability, haul, and prices) govern the level of specification limits for soundness in some districts.
11. A 30 percent soundness limit on hot mixes and 25 percent on seal coats are likely to improve performance of roadways. Most districts will not be affected by these limits.
12. Four districts in central-west Texas stated that a 25 percent soundness limit on seal coats would create material shortage and/or raise prices.
13. Three districts stated that a 30 percent soundness limit on hot mixes would create a material shortage and/or raise prices; two other districts state that it would allow the use of unacceptable material.
14. Roads constructed with a soundness limit greater than 30 showed extensive signs of surface disintegration.
15. Laboratory tests on aggregate blends or on aggregates consisting of particles of varying quality are misleading if aggregates contain significant amounts of very soft particles.
16. Repeatability of the soundness test was better than that of procedure A of aggregate durability index and approximately equal to procedure C of the same test. Texas degradation had the highest repeatability.
17. All aggregate tests showed a good correlation with the soundness test at soundness losses less than 20. At

higher losses tests were insensitive to changes in soundness.

18. The minus No. 10 loss in the Texas degradation test had the best correlation with the soundness test. The model describing the relationship of the two tests is given in Table 5.11. The R^2 for the model is 0.718.
19. The combination of Texas degradation sediment and specific gravity tests gave the best two variable relationship with the soundness test. The model describing this relationship has $R^2 = 0.776$ and is given in Table 5.11.
20. There was strong evidence that the Los Angeles abrasion test permits the use of unacceptable aggregate.
21. Freeze-thaw, aggregate durability index, and Texas degradation had a very high correlation.
22. Texas degradation furnishes information helpful in determining the resistance of aggregates in HMAC and seal coats to producing clay-like fines.

RECOMMENDATIONS

1. The 4-cycle magnesium sulfate soundness test should be used to evaluate quality of aggregates for use in HMAC and surface treatments.
2. Specific observations and recommendations to improve the soundness test are included in Chapter 3 under "Recommendations."
3. A 30 percent soundness limit should be applied to HMAC and a 25 limit to seal coats.
4. Siliceous gravels should not be tested for soundness.
5. Research should be focused toward reducing run time and simplifying the 4-cycle soundness procedure.
6. When blends of aggregates are used, the soundness test should be performed on each individual aggregate.
7. District laboratories with tap water that does not contain enough salt to mask the effect of barium chloride when performing the soundness test, should use the barium chloride as a means of detecting presence of salt, as it may reduce the run time of the test.
8. Specification of the Los Angeles abrasion test should be discontinued.
9. The Texas degradation test (Appendices A and B) should be used as a replacement to Los Angeles abrasion. A testing program is required to determine which loss and/or sediment should be evaluated during the test.
10. Appendix B contains the test procedure that correlated best with the 4-cycle magnesium sulfate soundness test. A tentative allowable weight loss limit of 9 percent passing the No. 16 sieve is recommended for use if the Texas degradation test is used as a replacement for the soundness test. Adjustment to this limit is probable as more laboratory and field data are generated.

APPENDIX F

CTR 3-9-82

COMPACTION OF ASPHALT MIXTURES AND THE USE OF VIBRATORY ROLLERS

Thomas W. Kennedy, Freddy L. Roberts,
Robert B. McGennis, and James N. Anagnos

RESEARCH REPORT 317-1

PROJECT 3-9-82-317

CENTER FOR TRANSPORTATION RESEARCH
BUREAU OF ENGINEERING RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN
MARCH 1984

FACTORS AFFECTING THE COMPACTIBILITY OF ASPHALT MIXTURES

The resistance to compaction (Ref 6) is composed of

(1) interparticle frictional resistance,

(2) initial resistance (cohesion), and

(3) viscous resistance (time-temperature).

Immediately following laydown hot bituminous mixtures are in a highly plastic state. While in this plastic state the void content of the mixture is reduced through compaction by reorienting the solid particles into a denser arrangement. The mixture resistance to compaction while in this plastic state is basically a function of asphalt and aggregate properties and their interactions. Most compaction problems encountered in the field can be explained in terms of these factors.

Aggregate Properties

The five aggregate properties which affect the resistance of the mixture are

(1) particle shape and texture,

(2) concentration of coarse aggregate,

(3) gradation,

(4) absorption, and

(5) soundness.

Particle shape and texture influence the overall resistance of the mixture in that angular, rough surface textured aggregates are more difficult to compact than are rounded, smooth aggregates.

Gradations with high concentrations of coarse aggregates produce mixtures that are difficult to compact. For the production of dense graded hot asphalt concrete mixtures, Goode and Lufsey (Ref 7) proposed that the aggregates be graded according to the equation

$$P = 100 \times \left(\frac{S}{M}\right)^{0.45}$$

where P = Percent passing the particular sieve;

S = Size of opening for a particular sieve in microns; and

M = Maximum size of aggregate in microns.

Gradation curves that cross back and forth over the maximum density line (Fig 3), especially in the region of the No. 30 to No. 80 sieve, tend to produce tender mixtures that displace excessively during compaction.

Adequate filler content (minus 200) is necessary for a mixture to develop enough cohesion, i.e., initial resistance, to be compacted effectively. Filler material acting with the asphalt tends to hold the larger sized material in place (Ref 8). If the filler content is too high, "gummy" mixtures are produced. Such mixtures are difficult to compact because of a tendency to be picked up by the roller. In addition, these mixtures tend to exhibit excessive lateral displacement. Insufficient filler may require additional asphalt to fill the voids. This results in thicker asphalt films and possible instability in the unconfined mixture during compaction.

Absorptive aggregates tend to increase the resistance of the mixture by reducing the thickness of the asphalt film on the surface of the aggregate. The net effect is a reduction of the lubricating effect of the asphalt making compaction more difficult (Ref 8).

Although soundness does not directly affect the resistance of the mixture to compaction, it does tend to affect the density achievable by a certain compaction procedure (Ref 8). Unsound aggregate may fracture under the dynamic loading of vibratory rollers. Any such fracturing will effectively change the gradation of the mixture, may reduce actual density, or may increase the susceptibility of the mixture to moisture damage.

Asphalt

Asphalt viscosity and its relationship to temperature are shown in Fig 4. The rate of change of viscosity with temperature, i.e., the slopes of the lines relate to the temperature susceptibility of the asphalt. It is important to note that for grading purposes two asphalts which have the same viscosity or penetration grade (Fig 4) may have significantly different viscosities at normal temperatures for compaction.

Since the viscosity of the asphalt affects the overall resistance of the mixture, knowledge of this behavior characteristic is vital for effective compaction of asphalt mixtures. As the mixture temperature decreases during compaction, the viscosity of the asphalt increases at a

APPENDIX G

MEMORANDUM

Texas Department of Transportation

TO:	Mr. Salvador Mercado, P.E. Director of Operations, Laredo District	**Date:** August 4, 1995
FROM:	Design Division	**Originating Office** Pavements Section
SUBJECT:	Pavement Distress - IH35	

Mr. Charlie Smoot, Magshoud Tamoressi and I inspected the section of IH35 just north of SH83 with the Area Engineer and Laboratory Supervisor on Wednesday, August 2, 1995.

The distressed pavement was confined to the outside northbound lane and extended for approximately 1.5 miles. Although the distress is evidenced by surfacing flushing and deep wheel ruts or channelization, we agreed that the proximate cause of the distress is most likely related to moisture damage either in the underlying base course or very possible the recently placed 2 inch overlay.

A quick visual inspection revealed free moisture escaping through the center longitudinal joint and also at the shoulder edge where it abuts the soil front slope.

A "quick and dirty" evaluation and analysis of the problem on my part is as follows:

It is evident that soon after the overlay was placed, the shoulders were "pulled up" from the ditch to eliminate the 2 inch pavement drop off. This shoulder material is a highly plastic (high P.I.) soil that is highly impermeable . Also, immediately after this operation there was a very heavy rain as evidenced by the runnels cut into this shoulder material at regular intervals allowing free standing water to escape into the side ditch. I believe that this heavy rain immediately after placement allowed the overlay mixture to become saturated and the high P.I. soil pulled up to the side effectively created a moisture barrier that prevented the water from draining out of the mix. When these conditions are later coupled with high temperatures and heavy truck traffic we have created an ideal situation for asphalt stripping. Since the coarse aggregate used in the overlay mixture is a gravel this crates an even greater potential for stripping. Once the asphalt starts to strip it begins to migrate to the surface and becomes evident as surface flushing. Also as the asphalt is stripped from the aggregate, the cohesive bond binding the mixture is lost and the mix losses its stability which is evidenced by the deep rutting and shoving.

It should be noted (as was pointed out by Charlie and Magshoud) that the distress is confined to one lane and represents about one typical day's production. The obvious questions then is why just this section? There are several responses but no answer. First, the mixture was being treated with a lime admixture as an antistrip agent. Perhaps the lime feed line or bin clogged up (or ran out of lime) and this day's run had no antistrip. Our conventional tests would not pick up this problem. (If you feel this could be a problem, I recommend use of Tex -530-C (boil test) as a good indication of whether antistrip has or has not been added.). Another possibility could be relatively low in-place air voids for the section. Air voids in excess of 8-10 percent allow significant water intrusion. The kneading action of normal traffic can provide surface sealing and ultimate (6 mo to 2yrs) densification of approximately 2 percent.

In any case, at this point some type of corrective action to the pavement is needed. However we do need to determine the extent and severity of the damage, which can only be ascertained through a forensic type of study. Magshoud has volunteered to work with your District Laboratory Supervisor to obtain coring and subsurface samples for analysis.

If the damage is limited to the top 2 inch overlay there are two obvious solutions. The first as proposed by the Area Engineer would be to mill and replace (inlay) the existing lane. However, I proposed an alternate solution that you may want to investigate further and that is hot in-place recycling using the Wirtgen process. This would be a less costly but effective solution depending on the depth of pavement damage.

Once the cores and subsurface samples have been evaluated, we will be in a better position to proceed with viable options.

We appreciate the invitation and opportunity to be of assistance and will await your further decisions regarding our continued services and/or assistance. If you have any additional questions or concerns, please contact me at 512/465-7741.

Ken Fults

Ken Fults, P.E.
Director of Pavements

KWF/ajg

bcc:	Magshoud Tamoressi, P.E.	
	Gary Graham, P.E.	DES-PAV
	Fitzgerald Sanchez, P.E.	Laredo
	Charlie Smoot,	THMAPA
	John Nichols, P.E.	FHWA

APPENDIX H

Texas Department of Transportation

MEMORANDUM

TO: Tom Ellis, P.E.
District Engineer
Paris District

DATE: September 10, 1996

FROM: Design Division

Originating Office
Pavements Section

SUBJECT: **Forensic Study on I-30 in Franklin County**

Mr. Mohan Yeggoni and Mr. Mark McDaniel were requested to visit the Paris District in response to a forensic study request from Mr. John A. Yant, P.E.. Mr. Andrew Wimsatt, P.E., Ft. Worth Pavement District Engineer also assisted with the request of the distressed section of I-30 in Franklin county.

The following summary report is presented by the forensic team leader Mohan Yeggoni. This report consists of the Problem statement, Findings and Recommendations. Mohan will continue to work with your district personnel as needed on this project. If you need any assistance or further information, please call Mr. Mohan Yeggoni at (512) 465 3059. Thank you for the opportunity to participate in this project.

Ken Fults

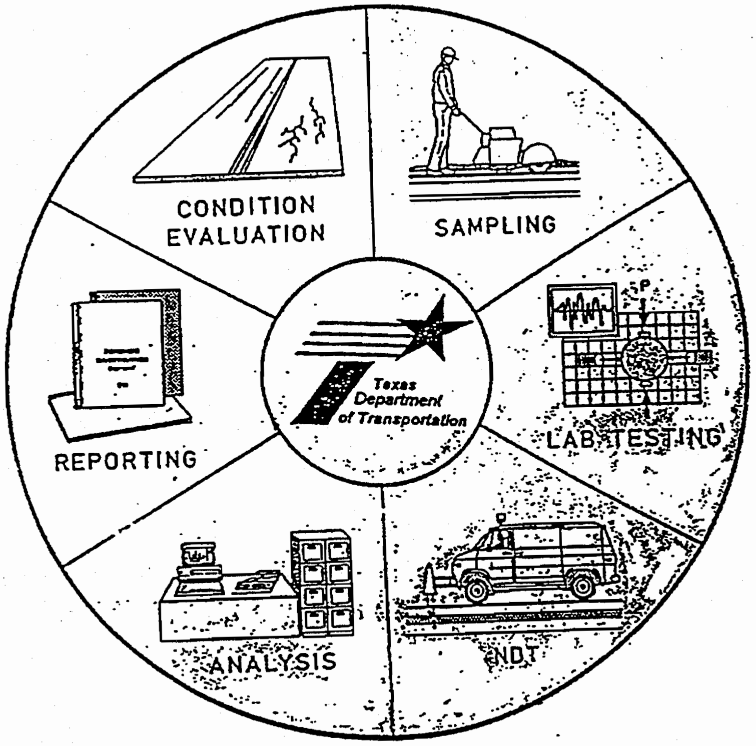
Ken Fults, P.E.
Director of Pavements

Attachment
KF/MY/ajg

cc:	Robert L. Wilson, P.E.	DES
	Katherine Holtz, P.E.	MAT
	John A. Yant, P.E.	Paris District, w/attachment
	Clifford Clottey, P.E.	Paris District, w/attachment
	Ernest Teague, P.E.	Area Engineer-Paris and Sulpher Springs w/attachment
bcc:	Andrew Wimsatt, P.E.	Ft. Worth District
	Mohan Yeggoni,	DES-PAV
	Mark McDaniel,	DES-PAV

PAVEMENT SECTION - DESIGN DIVISION

Texas Department Of Transportation



FORENSIC INVESTIGATION REPORT ______

DISTRICT Paris

COUNTY Franklin

HIGHWAY IH-30

MILEPOST ____________ To ____________

CONTROL - SECTION 0610-02-035

PROBLEM STATEMENT

Location

IH-30 in Franklin County, from Hopkins County line to the Titus County line.

Back Ground

The 8-inch CRCP was overlayed with 2.5 inches of black base and 1.5 inches of hot mix in 1985. A micro surfacing was done in 1994.

Allegator cracking, potholes and pumping of fines were observed a year ago and problems have been worsening ever since. A moderate to severe case of allegator cracking is present in the wheel paths. Several sections have been bladed and patched due to severe potholes and failures in the wheel paths. The highway carries a substantial amount of heavy truck traffic.

The district is considering a major rehabilitation of this highway and needed to determine how extensive the problem was and how soon the pavement needed to be rehabilitated before its serviceability drops below acceptable level.

Purpose of Study

1. Determine the cause and extent of the pavement failure, and
2. Identify potential rehabilitation Strategies

FINDINGS

1. The cause of the surface cracking and pothole is the stripping in asphalt concrete. Cores taken by the district lab showed moderate to severe stripping throughout the section. Occurrence of stripping is due to strip susceptible aggregates and presence of excessive moisture in the pavement. Cores taken in the shoulder showed that the soil cement underneath the asphalt concrete is in very good condition; however, this layer needs to be tested for structural adequacy if the traffic needs to be shifted onto the shoulder for construction traffic control. Sulfur Springs area office is already working on obtaining Falling Weight Deflectometer data on the shoulder to evaluate structural strength.

2. Ground Penetrating Radar test confirmed the core observations. There is moderate to severe stripping present in the entire section.

3. Rehabilitation is urgently required in the main lanes, preferably before the coming winter. Considering the time crunch to do any kind of rehabilitation before winter an alternate measure is given in the following section of Recommendations. The surface is essentially open and most of the rainfall will penetrate the surface down to the CRCP augmenting the problem. A hard freeze after a rainstorm can cause major pot holding problems, loss of serviceability and potential safety concerns.

RECOMMENDATIONS **

1. The existing surface must be removed. The CRCP should be overlayed with adequate thickness of asphalt concrete as soon as possible.

2. Since it may not be possible to do the entire rehabilitation before next winter, if possible through an emergency contract, it is strongly advisable to remove the hot mix surface and fix any failures in CRCP to get through the winter.

3. Proper drainage measures may be considered to improve the pavement performance; however, it was concluded from the discussions with district personnel that other pavement sections with similar terrain and drainage conditions are performing satisfactorily.

** Supporting documentation from the GPR testing is available if needed.

APPENDIX I

MEMORANDUM

Texas Department of Transportation

TO: Mr. Billy Parks, P.E.
Amarillo District Engineer

Date: June 8, 1995

FROM : Design Division

Originating Office
Pavements Section

SUBJECT: Forensic Investigation of IH 27

Please accept my apology for the delay in providing a forensic report on the above referenced project. I could offer the excuse that of the three investigators we had on this project, two accepted positions in various Districts. As you know Mr. Elias Rmeili, our lead investigator accepted a position in the Bryan District and Ms. Jackie Cato accepted a position in one of our North Texas Districts (Amarillo, I believe). Anyway I won't mention these obvious set backs.

I have reviewed the Forensic file with Ms. Caroline Herrera, Materials and Tests Division, (last of the original three) and offer the following observations and recommendations for your consideration.

A. **Pavement Distress Mode**
The existing pavement distress mode is evidenced by regular transverse cracking at 30 to 50 foot intervals with associated longitudinal cracking in the wheel paths. Some of the longitudinal cracks are pumping and disintegrations of the surface mix (potholes) has appeared primarily in the left wheel path of the outside (truck) lane.

B. **Significant Pavement History**
It appears that the original alignment was laid out in the late 1930's. The alignment crosses the outskirts of some 5 to 6 playa lakes (buffalo wallows). The existing subgrade is a very weak clay with a Triaxial Class of 5.7, Plasticity Index (PI) of 32, and Liquid Limit (LL) of 49. There is no evidence of chemical stabilization of the weak subgrade.

The original Northbound lanes were constructed of jointed concrete pavement and later symmetrically widened with concrete pavement. The Southbound lanes were constructed using flexible base. It appears from coring information that a 4 to 5 inch layer of caliche subbase was placed over the weak subgrade with about 7 inches of gravel base over the subbase and then topped with 5 inches of Asphalt Stabilized Base and 4 inches of Hot Mix Asphalt Surfacing.

One last but important note about the existing Section is poor to inadequate drainage.

C. **Possible (Probable?) Contributing Factors for Existing Pavement Distress (Failure)**

The existing subgrade is extremely weak (Triaxial Class 5.7), potential reactive (PI=32) and susceptible to moisture damage (LL=49).

The existing base (gravel) is extremely temperature susceptible (high thermal coefficient) and historically susceptible to moisture damage over time.

The Asphalt Stabilized Base and Hot Mix Asphalt is temperature susceptible (Aggregate - J. Lee Milligan Gravel; Asphalt - Diamond Shamrock) and historically susceptible to moisture damage (stripping).

My prediction of the progression of the distress mode is as follows:

Within 6 months or two years (maximum) transverse thermal cracks originating in the gravel base propagated through the HMA surfacing. The crack spacing is dependent on the quality of the gravel binder. A base material gains its strength from the binding (cementing) action of the binder (minus NO. 40 sieve). This creates a relatively weak but flexible slab that transfers stresses to the underlying subbase and/or subgrade. A properly performing flexible base will dissipate these stresses over a sufficiently wide area to prevent subgrade shear failure.

Once the transverse cracks reach an opening width of from 1/16 to 1/8 inch, moisture intrusion and resulting moisture damage begins its slow but steadily increasing rate of deterioration. As the deterioration progresses, associated distresses such as load induced stress cracking (longitudinal wheel path cracking), pumping of fines through the cracks, stripping of the asphalt binder, potholes and alligator cracking can appear almost overnight. This self perpetuating phenomena (as the cracks get wider, the distress increases; as the distress increases, the cracks get wider; etc.; etc.) can occur so rapidly that we think the pavement failed "all at once", when in fact the failure has been occurring over several years or even decades.

D. Recommended Solutions, Options and Future Considerations

I have tried to present a case of a pavement failing from the bottom up. This is one of the worst type of failures that we encounter because we have to work from the top down.

1. Preservation Option

If we can only afford a preservation mode at this time, then I recommend a good rubber seal coat. The asphalt rubber membrane will provide the flexibility and impermeability to protect from further moisture induced damage. Essentially what this accomplishes is to interrupt the self perpetuating cycle of crack/damage; damage/crack noted above. There may be some additional benefit associated with autogenous healing of the base as it dries but I would not count on it. Cleaning of the ditches and establishing some measure of positive drainage away from the base is also essential.

2. Restoration Option

APPENDIX J

A Report on Trip to Brownwood District I-20 Forensic Site on 01/27/97

BackGround

The pavement in this section showed rutting and shoving at various location during the summer of 1996. The distress was spotty with approxiamte length of 10 feet. East bound lanes had longer sections of distress. At some locations the length of the rutted pavement was about 150 to 200 feet. Eastland area maintainance milled the rutted sections and replaced with Black Base material. We requested TTI to collect GPR data. GPR analysis showed moderate stripping and disintegration of one of the layers of the hotmix. Cores taken from the pavement confirmed GPR analysis. I also got laboratory analysis done on the cores. Different layers of asphalt concrete were seperated for lab analysis. Laboratory results did not show any of the properties that would contribute to the rutting. Very high viscosity and low penetration test values were reported which are unlikely to contribute to rutting. I looked at the construction records of the top layer which was one of the very first QC/QA jobs. I noticed high air void content for some lots. High air void content may have contributed to rutting and shoving. The quantity of the sections that showed distress last summer, in my opinion, was not big enough to warrant reconstruction of the whole section, which might cost a few million dollars, unless the other sections of the pavement starts to show distresses which we expected and this was the reason for the trip to forensic site.

Observation

The patch work done last summer is holding up well. I observed small new rutted spots in the section we are observing. I expect these and more new areas to come up and get worse as spring and summer roll in. I observed more rutted areas in the east bound lanes than the west bound which is also what we expected based on GPR data analysis.

What Next

I discussed this with Elias Rmeli. I am preparing an interim report on this project and also forwarding all the documents I have on this project to Elias as he is doing a comprehensive evaluation of the condition of the Interstate Highways (about 40 miles) in Brownwood district. I will work with him on this after returning from my trip to India.

TEXAS DEPARTMENT OF TRANSPORTATIO
MATERIALS AND TESTS DIVISION
AUSTIN, TX. 78703

GENERAL TEST REPORT

Laboratory No.:	F96500408-420	Contract No.:	?	Mat'l. Code:	?
District:	Brownwood	Date Sampled:	7-1-96	Spec. Item:	?
County:	Eastland	Date Received:	9-12-96	Material:	Cores & Mix
Engr./Foreman:	Bryan Neaves	Date Reported:	9-30-96	Quantity:	?
CSJ #:	?	Contractor:	?	Unit:	?
Fed. Proj.#:	?	Producer:	?	I.D. Marks:	Various
Highway:	IH-20	Producer Code:	?	Sampled From:	?

Lab #	408	409	410	411	412	413	414	415	416	417	419	420
Ident. #	1-T, 96-802-68	WB, 96-807-68	EB, 96-808-68	2-T, 96-803-68	2-M,96-803-68	3-T, 96-804-68	3-MA, 96-804-6	3-M, 96-804-68	4-T, 96-805-68	4-M, 96-805-68	5-T, 96-806-68	5-M, 96-806-68
	1B			2A,2B	2AM	3A, 3B, 3C, 3D	3AM	3BM, 3CM	4A, 4B, 4C		5A, 5B	
Descrip.	EB Outside	WB	EB	Top, Good	Middle, Good	Top	Middle, 11'	Middle, 12'	WB Out., Top	WB Out., Middl	Good	Good
	Ref. 326-1306	Loose Matl.	Loose Matl.	Ref. 326+3590	Ref. 326+3590	Ref. 326+4860	Ref. 326+4860	Ref. 326+4860	Ref. 329-420	Ref. 329-420	Ref. 329-680	Ref. 329-680

AC%	4.5	6.3	4.9	5.0	5.1	5.0	5.3	4.9	4.5	5.9	4.7	4.4
Pen	27	23	26	27	29	27	18	12	35	26	30	14
Duct	66				73	41	43	10	76	71	63	9
Visc	25180	40800	31560	24704	20289	26016	20195	63085	9525	23147	21486	43800

Gradation

7/8"												
5/8"	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1/2"	100.0	100.0	99.8	100.0	93.1	100.0	100.0	100.0	100.0	100.0	100.0	95.3
3/8"	98.7	98.5	98.0	99.3	85.1	98.8	99.7	99.4	99.3	92.9	98.0	92.7
#4	61.3	54.9	62.9	59.3	62.3	61.5	63.9	62.8	62.7	63.3	60.6	64.0
#10	37.2	32.2	38.4	35.3	39.7	36.5	37.4	37.7	37.8	41.2	36.1	39.2
#40	23.1	18.9	22.4	20.8	21.6	22.0	21.9	22.8	22.2	25.5	22.1	23.2
#80	9.6	6.5	7.1	7.5	11.4	7.7	12.2	10.7	8.3	12.3	6.6	9.1
#200	3.5	1.8	2.3	2.6	4.8	2.6	4.0	4.2	2.9	5.3	2.0	3.6

cores →

Avg. Ga	2.292			2.371	2.359	2.272	2.391	2.294	2.34		2.372	2.362
Gr		2.442	2.488			2.467						
Density						92.1						

Remarks: ____________________

Technician Signature: Dennis Guthrie/Lisa Lukefahr

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APPENDIX K

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MEMORANDUM

To: Mr. Bobbie F. Templeton, P.E.
Assistant Executive Director, Field Operations

Date: February 27, 1996

From: Paul E. Krugler, P.E.
Materials and Tests Division

Originating Office: MAT/ADM

Subject: Executive Summary
Northeast Texas ACP Hot Mix Team Report

The team that you appointed to identify issues and make recommendations for improving the performance of crushed gravel hot mix in northeast Texas has reached a consensus on these subjects. An executive summary of the actions of the team and our recommendations is forwarded at this time so that implementation decisions may be made at an earlier date. Please contact me should you desire to discuss any of these recommendations.

A report which includes additional details of team discussions, pavement performance history information and test results which were collected and analyzed will be submitted in the near future.

PEK

Attachment

cc: Team Members
Gene Adams, Ex-Officio Member

Northeast Texas Asphaltic Concrete Pavement Team Report

Executive Summary

Several northeast Texas districts have frequently experienced poor performance from crushed gravel asphaltic concrete pavements in recent years. Performance of these mixtures lead two districts to exclude the use of crushed gravel on current projects. A joint industry-TxDOT team was appointed to identify the issues and recommend solutions designed to improve the performance of these mixtures, thereby allowing the use of crushed gravel on future projects.

The team met in early January to hear reports from personnel from Atlanta, Tyler, and Lufkin districts, and the Arkansas DOT. The reports described pavement performance experiences using various material combinations, gradations, and mixture additives. The team identified two foremost pavement performance concerns, loss of asphalt-aggregate bond (stripping) and raveling. Although rutting is also a problem in northeast Texas, it was not included as a primary concern with currently used mixture designs. After the reports, the team listed material, mix design, pavement design, and construction issues which may be contributors to the unsatisfactory pavement performance. The team requested that various team members and the Superpave Center at Austin pursue several of the issues prior to the second team meeting.

The team met again in mid-February. The results of limited testing of laboratory mixtures were presented, along with information on the quality and gradation of individual component materials in these mixtures. The list of potential contributors to unsatisfactory pavement performance was then narrowed and prioritized. The following team recommendations resulted.

Recommendations for earliest possible implementation on all projects are:

1. **The team strongly recommends that a more stringent stripping test requirement be required in local district specifications.** Crushed gravel hot mixes in northeast Texas often pass current moisture susceptibility test requirements but show moisture damage at later ages, sometimes after being sealed or overlaid. The districts should require the use of effective antistripping measures by plan note or field change until the more stringent test requirement can be developed and implemented.

2. **The team recommends that new requirements be placed on field sands.** The new requirement should restrict the amount of ultra-fine material in the field sand. The ultra-fine materials were shown to reduce asphalt content and, very likely, to also reduce the effectiveness of the asphalt to form a tenacious bond with the aggregate. The resulting "dry" mixtures will age rapidly and are raveling and stripping prone.

3. **The team recommends that surface course mixtures include asphalt modifiers to improve the thickness of asphalt coating on crushed gravel coarse aggregate.** It is believed that this measure will mitigate some of the raveling tendencies of the crushed gravel mixtures. The modified asphalts should be evaluated using Superpave PG binder

tests so that the districts will be better prepared to implement the new PG binder specifications in the future.

Additional team recommendations are:

1. **The team recommends that washed limestone screenings be required on one or more projects and that the performance of these pavements be closely evaluated.** It is believed that eliminating one of the two siliceous fine aggregates in current mixtures will positively affect stripping tendency. The affect on raveling is less certain. The Lufkin district reports good performance with this type of mixture, but relatively few projects have been under traffic for more than four years. The passing No. 200 sieve material in the limestone screenings should be limited by specification so that the mixture is not "dried up" by an overabundance of limestone fines.

2. **The team recommends that the Superpave PG binder specifications be implemented as soon as a quality assurance program is developed so that modified asphalts may be supplied in a more competitive environment.** The team understands that PG binder specification implementation is planned within a year.

The team made several additional observations. The team supports the Atlanta district's decision to specify and evaluate Type D gradation mixtures and pavement edge drains on several projects this year. The team commends the work of the Atlanta district lab to evaluate the condition of each pavement layer, particularly for stripping, during preliminary engineering and planning. Projects to mill and replace individual lanes should include adequate milling and replacement of shoulder material so that penetrating moisture is not trapped in the new asphaltic concrete. The team discussed the importance for all component materials of asphaltic concrete to be compatible. The more stringent stripping test and current asphalt-modifier compatibility testing will assist in this area. The team discussed the crushed face test method and specification requirement, and the Atlanta district expressed interest in exploring improvements in this area.

The team's recommendations are made in an effort to resolve recent pavement performance concerns without exchanging them for increased rutting or other undesirable performance characteristics.

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APPENDIX L

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Limestone Pavements

Corpus Christi District

CSJ: 1557-1-25 Highway: FM 43

Location: S. of Corpus Christi

Direction: EB RM: 558

Core #: 5-1, 5-3

ADT: 4600 VPPL: 5,000,200

Acc Traffic: 10,000,400 Age: 2174 days

1.Top Layer: LRA (seal coat)

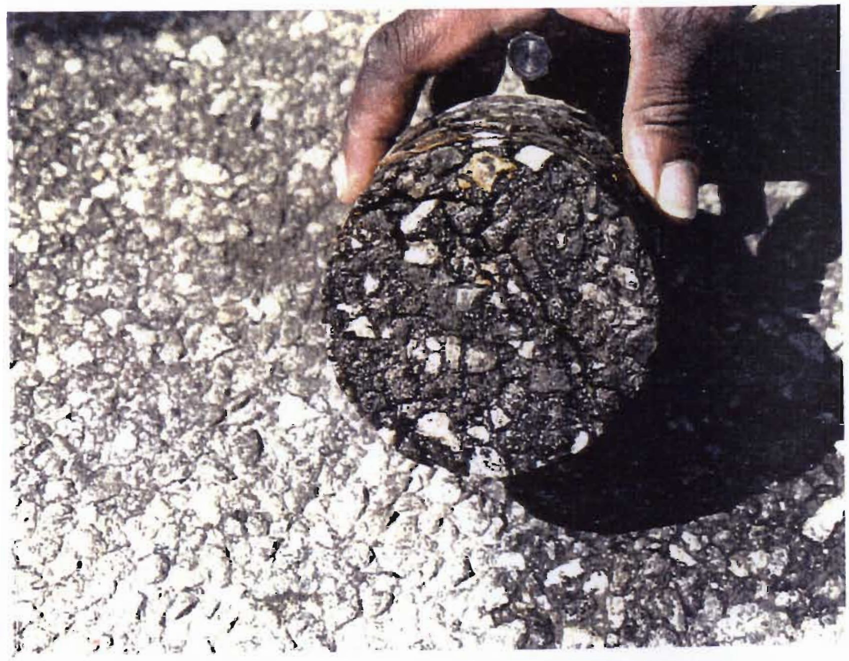
1. Producer: ________

2. Middle Layer: Limestone

2. Producer: ________

3. Bottom Layer: Shell

3.Producer: ________



Comments:

Cracked sections showed little or no stripping.

CSJ: 1657-1-21 Highway: FM 43

Location: S of Corpus Christi

Direction: EB, WB RM: 558

Core #: 6-1, 6-3

ADT: 22,000 VPPL: 13,310,000

Acc Traffic: 66,550,000 Age: 3025 days

1.Top Layer: Limestone (340

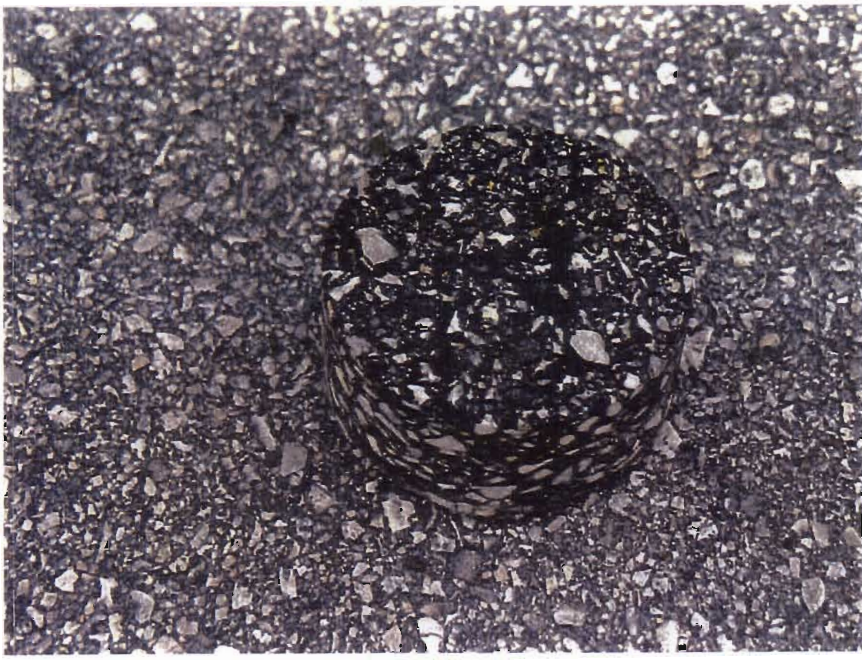
1. Producer: Redland Worth Beckn

2. Middle Layer:

2. Producer:

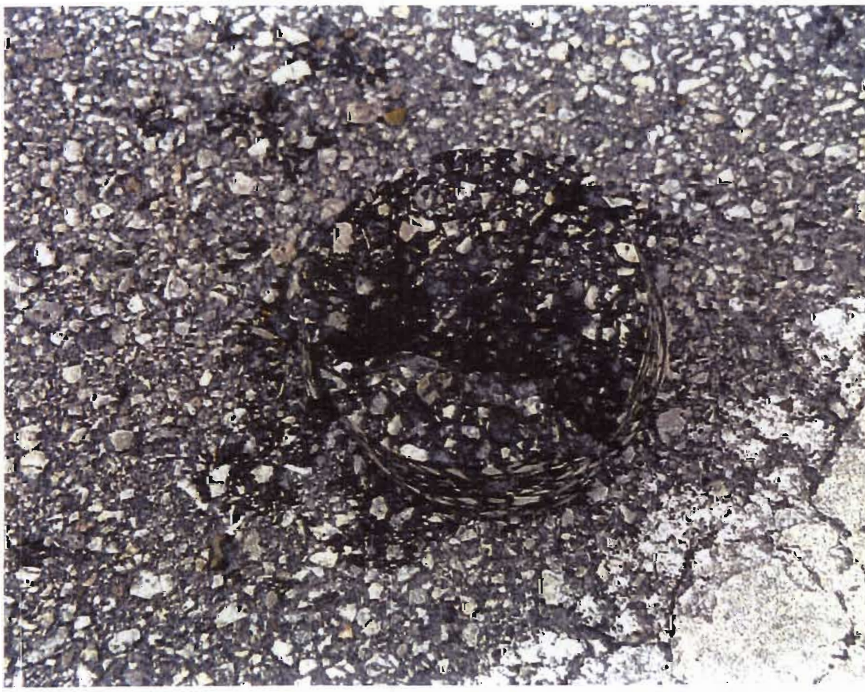
3. Bottom Layer:

3.Producer:



Comments:

Cracked sections showed little or no stripping



CSJ: 371-4-34 Highway: US 77

Location: N. of Sinton

Direction: NB RM: 642

Core #: 7-1, 7-2

ADT: 10,000 VPPL: 4,860,000

Acc Traffic: 19,440,000 Age: 1944 days

1.Top Layer: Limestone

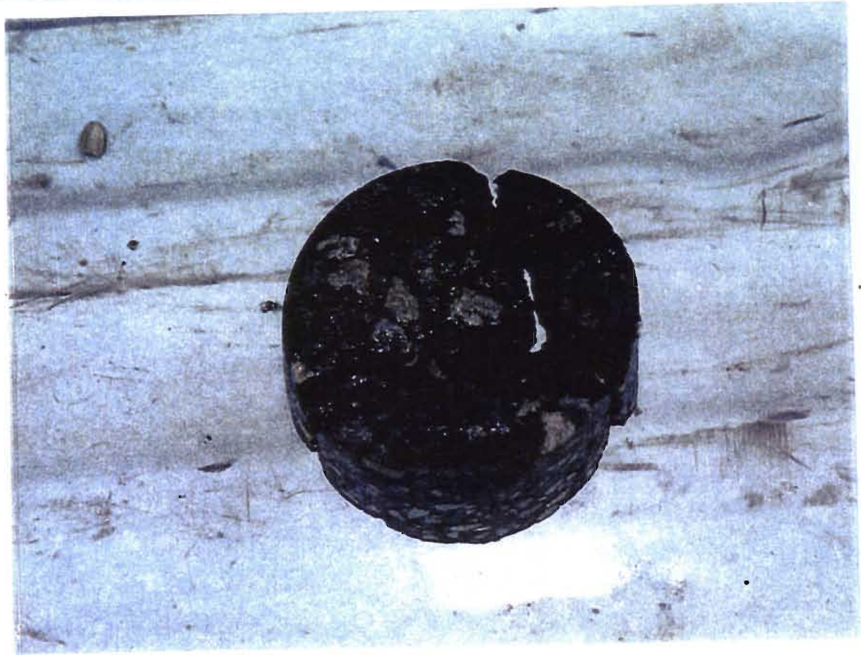
1. Producer:

2. Middle Layer: Sandstone

2. Producer:

3. Bottom Layer:

3.Producer:



Comments:

Little or no stripping in cracked areas.

CSJ: 102-4-67 Highway: US77

Location: N. of Kingsville

Direction: SB RM: 688

Core #: 11-1, 11-2

ADT: 18,400 VPPL: 12,700,600

Acc Traffic: 50,802,400 Age: 2761

1.Top Layer: Limestone

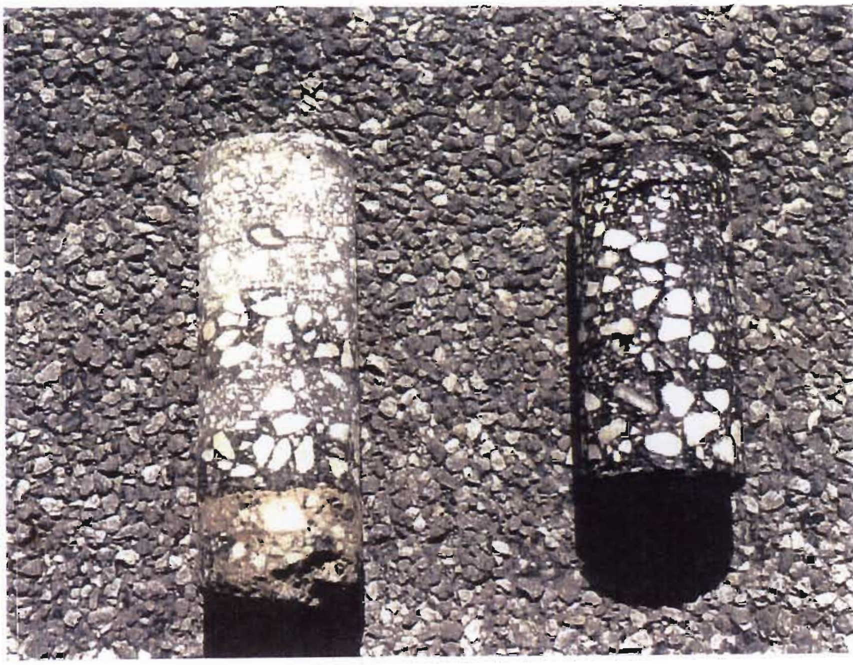
1. Producer:

2. Middle Layer: Limestone

2. Producer:

3. Bottom Layer: Limestone

3.Producer:



Comments:

Limestone not stripped even at cracked areas.

Gravel Pavements
Corpus Christi District

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CSJ: 254-1-100 Highway: US 281

Location: S. of George West

Direction: NB RM: 636

Core #: 1-1

ADT: 10,100 VPPL: 3,086,560

Acc Traffic: 15,432,800 Age: 1528 days

1. Top Layer: Gravel (340 TyD)

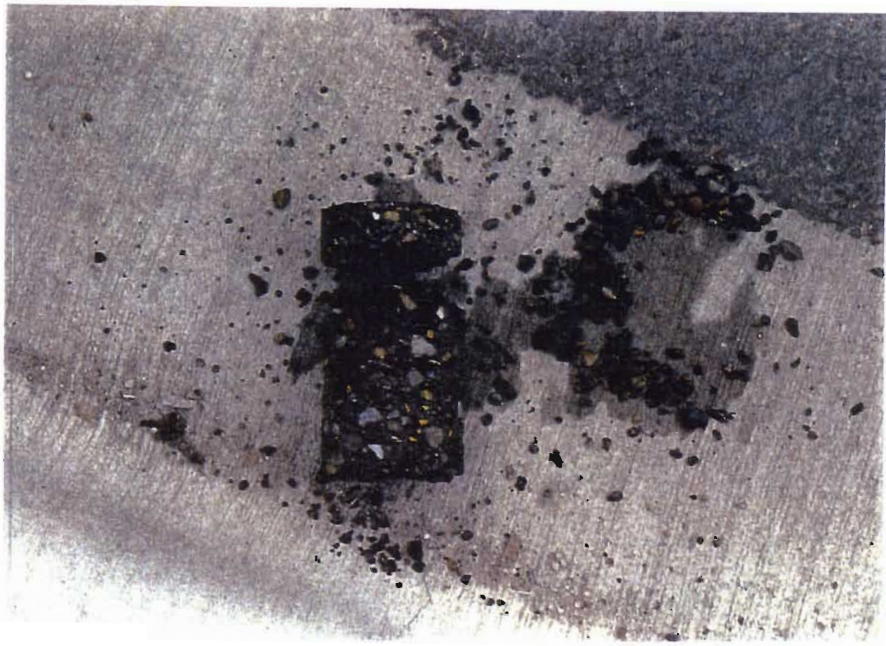
1. Producer: Bay Inc. Bruni Bay

2. Middle Layer: Gravel

2. Producer:

3. Bottom Layer: Gravel

3. Producer:



Comments:

Middle layer of gravel completely stripped.

CSJ: 2343-1-19 Highway: FM 2444

Location: S. of Corpus Christi

Direction: EB RM: 556

Core #: 2-1, 2-3

ADT: 12,300 VPPL: 14,858,400

Acc Traffic: 29,716,800 Age: 2416 days

1.Top Layer: Gravel (340 TyD)

1. Producer: Bay Inc. Perez

2. Middle Layer:

2. Producer:

3. Bottom Layer:

3.Producer:

Comments:

Slight stripping of gravel. LRA seal coat on top.

CSJ: 2343-1-23 Highway: FM 2444

Location: S. of Corpus Christi

Direction: SB RM: 550

Core #: 3-3, 3-4

ADT: 800 VPPL: 37,920

Acc Traffic: 189,600 Age: 237 days

1.Top Layer: Gravel (3063 TyC)

1. Producer: Wright Bros. Realitos

2. Middle Layer:

2. Producer:

3. Bottom Layer:

3.Producer:

Comments:

No stripping of new pavement. Surface showed some ravelling

CSJ: 1052-2-60 Highway: FM 665

Location: S. of Corpus Christi

Direction: NB RM: 546

Core #: 4-1, 4-2, 4-3

ADT: 5800 VPPL: 1,757,400

Acc Traffic: 3,514,800 Age: 606 days

1. Top Layer: Gravel (3834 TyD)

1. Producer: Wright Bros. Realitos

2. Middle Layer:

2. Producer:

3. Bottom Layer:

3. Producer:

Comments:

Slight stripping of gravel near pavement cracks.

CSJ: 102-3-65 Highway: US77

Location: S. of Driscoll

Direction: SB RM: 682

Core #: 10-1, 10-2

ADT: 19,300 VPPL: 6,504,100

Acc Traffic: 32,520,500 Age: 1685 days

1.Top Layer: Gravel (340 Ty D)

1. Producer: Wright Bros. Realitos

2. Middle Layer: Gravel

2. Producer:

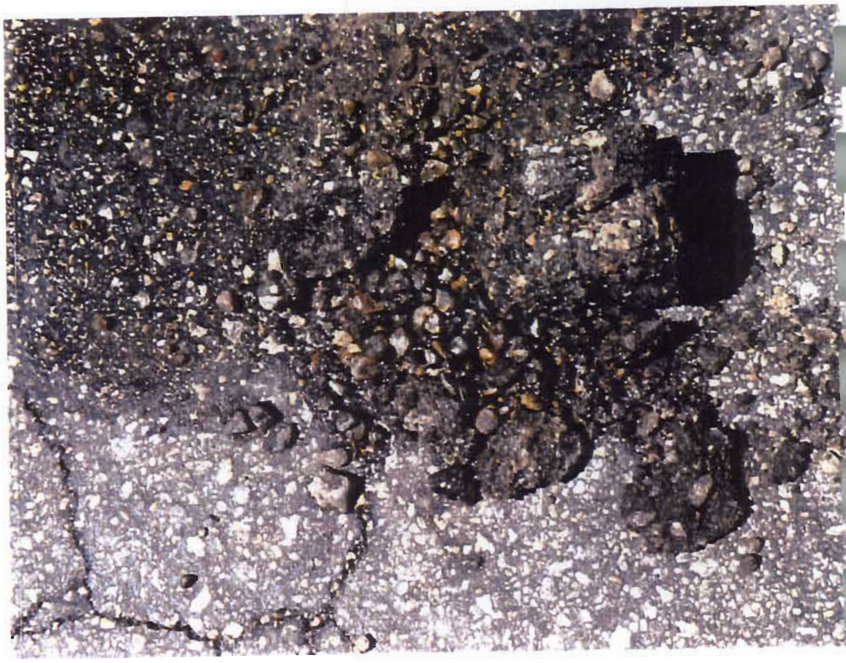
3. Bottom Layer: Gravel

3.Producer:

Comments:

Middle layer of gravel completely stripped.

CSJ: 102-11-7 Highway: US B77



Location: in Bishop

Direction: SB RM: 626

Core #: 12-1

ADT: 8600 VPPL: 2,517,650

Acc Traffic: 10,070,600 Age: 11/71

1. Top Layer: Gravel (3778 TyD)

1. Producer: Wright Bros. Realitos

2. Middle Layer: Gravel

2. Producer:

3. Bottom Layer:

3. Producer:

Comments:

Middle layer of gravel completely stripped.

CSJ: 101-4-76 Highway: US 181

Location: S of Taft

Direction: SB RM: 626

Core #: 8-1

ADT: 10,700 VPPL: 2,337,950

Acc Traffic: 9,351,800 Age: 874 days

1.Top Layer: Gravel (340 Ty D)

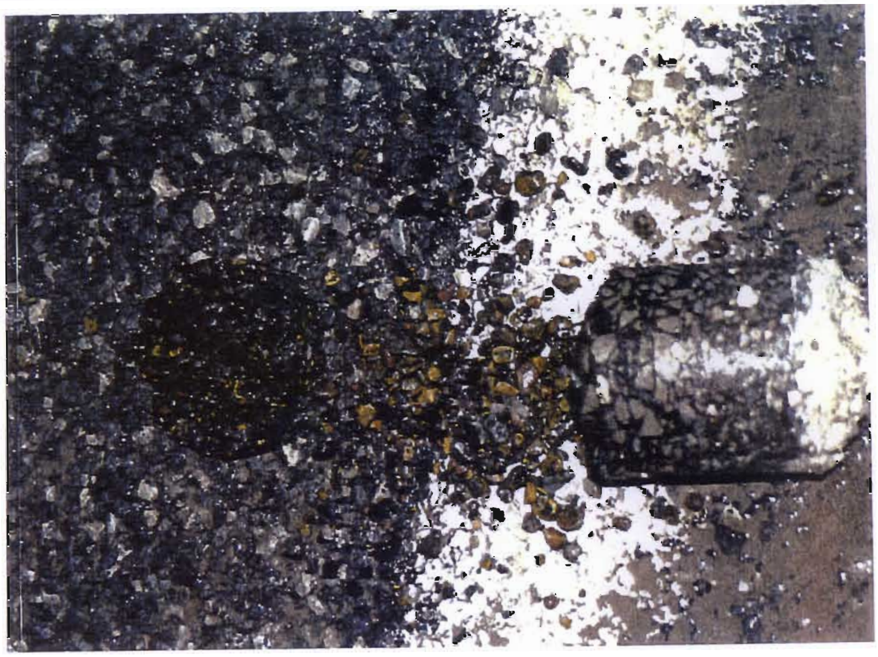
1. Producer: Bay Inc. Broni Bay

2. Middle Layer: Gravel

2. Producer:

3. Bottom Layer: Sandstone

3.Producer:



Comments:

Top layer was moderately stripped. Middle layer was completely stripped. Sandstone was not stripped.

Combination Pavements

Corpus Christi District

CSJ: 373-2-69 Highway: SH 44

Location: W. of Robstown

Direction: EB, WB RM: 544

Core #: 9-1, 9-2

ADT: 13,100 VPPL: 4,131,740

Acc Traffic: 20,658,700 Age: 1577 days

1.Top Layer: Limestone

1. Producer:

2. Middle Layer: Gravel

2. Producer:

3. Bottom Layer:

3.Producer:

Comments:

LRA (seal coat)

Gravel layer was severely stripped in some sections.

CSJ: 373-2-69 Highway: SH 44

Location: W of Robstown

Direction: EB RM: 544

Core #: 9-3

ADT: 13,100 VPPL: 4,131,740

Acc Traffic: 20,658,700 Age: 1577 days

1.Top Layer: Limestone

1. Producer:

2. Middle Layer: Gravel

2. Producer:

3. Bottom Layer:

3.Producer:

Comments:

LRA (seal coat)
Gravel layer stipped
severely in some
sections.

CSJ: 254-1-106 Highway: US 281

Location: N. of George West

Direction: SB RM: 632

Core #: 13-1, 13-2, 13-3

ADT: 11,300 VPPL: 1,514,200

Acc Traffic: 6,056,800 Age: 536

1.Top Layer: Limestone

1. Producer:

2. Middle Layer:

2. Producer:

3. Bottom Layer:

3.Producer:

Comments:

Cores taken in a section with slight rutting. Stripped aggregate varied from none to moderate.

APPENDIX M

SPECIAL PROVISION
TO ITEM 247
FLEXIBLE BASE

For this project, Item 247, Flexible Base, of the Standard Specifications, is hereby amended with respect to the clauses cited below an no other clauses or requirements of this item are waived or changed hereby.

Article 247.2 Materials is supplemented by the following:

(f) Type E. Type E material shall meet the requirements of **either** Type A or C at the contractor's option. All material used on the project shall be of the same type.

Article 247.5 Payment. The first paragraph is supplemented by the following:

Any additives required and/or allowed will be subsidiary to this pay item