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15. Supplementary Notes

This study was conducted in cooperation with the US Department of Transportation, Federal Highway Administration

16. Abstract

The purpose of this study was to systematically evaluate the cost and performance of recycled materials in roadway construction applications. Specifications and guidelines for using recycled materials were developed in previous research efforts. Several non-hazardous recycled materials (NRMs) exhibited high potential for roadway construction applications during the earlier studies. Eight materials were selected for demonstration projects under the Federal Highway Administration Priority Technology Program. Demonstration projects were placed at several locations within the state of Texas. The eight materials selected were: Bottom ash, Compost, Crushed concrete, Glass cullet, Roofing shingles, Shredded brush, Spent blasting sand, and Tires.

The demonstration projects afforded the Texas Department of Transportation an opportunity to field test specifications and guidelines for the NRMs. Evaluations for several of the demonstration projects included load tests, visual inspection and economic analysis. This report describes each demonstration project, presents available evaluations results, and compiles applicable material guidelines, specifications, and points of contact for each demonstration project.

| | |
|---|---|
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# ROAD TO RECYCLING

By

Sanjaya Senadheera
A.S.M. Ashek Rana
Phillip T. Nash
R.T. Ervin

Project 9 – 1509

Conducted for

Texas Department of Transportation

By the

Civil Engineering Department
College of Engineering
Texas Tech University

October 1999

## Implementation Statement

This project will yield several products useful to the department, including: specifications for the use of a number of recycled materials in roadway construction and a report documenting the demonstration of those recycled materials in actual construction sites. An economic analysis on the benefits of using recycled materials is presented. Using recycled materials in roadway construction will be promoted in a subsequent project directed towards training design engineers on advantages and specification requirements of recycled materials.

## Author's Disclaimer

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

## Patent Disclaimer

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

## Engineering Disclaimer

Not intended for construction, bidding, or permit purposes. The engineer in charge of the research study was Phillip T. Nash, P.E., Texas 66985.

## Trade Names and Manufacturers' Names

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| NOTE: Volumes greater than 1000 l shall be shown in $m^3$. | | | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5(F-32)/9 or (F-32)/1.8 | Celcius temperature | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.71 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | |
| °C | Celcius temperature | 1.8C + 32 | Fahrenheit temperature | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

* SI is the symbol for the International System of Units. Appropriate

(Revised September 1993)

## Table of Contents

# CHAPTER 1: INTRODUCTION

The Priority Technology Program (PTP) of the Federal Highway Administration (FHWA) is designed to accelerate the deployment of highway technology by the testing and evaluation of new technologies. One such technology is the use of environmentally beneficial recycled materials and procedures.

Section 6005 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 established an applied research and technology program for the purpose of accelerating testing, evaluation, and implementation of technologies that are designed to improve the durability, efficiency, environmental impact, productivity, and safety of highway, transit, and intermodal transportation systems.

The research study reported herein was designed to systematically evaluate the cost and performance of recycled materials in road construction applications in Texas. The Texas Department of Transportation (TxDOT), the Texas Natural Resource Conservation Commission (TNRCC) and the FHWA invested more than $750,000 in a project which conducted literature surveys and laboratory testing of a vast array of recycled materials for use in highway construction. A listing of these research projects is given in Table 1.1. Draft specifications were also developed for the use of those materials with the most potential. The next step towards full-scale implementation of using such recycled materials was the evaluation of the performance of these materials in actual road construction applications, as addressed in this report. A listing of these test projects is given in Table 1.2.

The research was originally aimed at the evaluation of ten different recycled materials in eight different road construction applications in thirteen different field test locations throughout the state of Texas. This research project was designed to facilitate the evaluation of the use of such materials under different climatic, construction and supply conditions. It also provided more than twelve key public and private partners first hand experience with recycled materials in road construction applications. As the project progressed, candidate demonstration projects changed to accommodate construction priorities within the various TxDOT districts.

**Table 1.1.** Recent TxDOT Research Projects on Recycled Materials

| No | Project No. | Project Title | Research Institution(s) |
|---|---|---|---|
| 1 | 0-1331 | Use of Glass Cullet in Roadway Construction | Texas Tech University |
| 2 | 0-1338 | Recycled-Content Sign Blanks | Texas A&M Univ. (Kingsville)<br>Texas Transportation Institute |
| 3 | 0-1344 | Roofing Shingles and Toner in Asphalt Pavement | Texas Transportation Institute<br>Texas A&M Univ. (Kingsville) |
| 4 | 0-1348 | Recycled Materials in Roadbase, Except Glass | Center for Transportation Research |
| 5 | 0-1349 | Recycled Materials in Concrete, Except Glass | Center for Transportation Research |
| 6 | 0-1352 | Use of Compost and Shredded Brush on Right-of-Ways | Texas Transportation Institute |
| 7 | 0-1354 | Recycled Materials in Vertical Moisture Barriers | Texas Tech University |
| 8 | 0-1365 | Re-refined Oil Performance and TxDOT Used Oil Collection Procedures | Texas Tech University |
| 9 | 0-1369 | Testing Methods for Reclaimed Asphalt Pavement (RAP) | Univ. of Texas at El Paso |
| 10 | 0-1458 | Recycled Materials in Roadside Safety Devices | Texas Transportation Institute |
| 11 | 0-1460 | Research Support for the Addition of Tire Rubber in Asphalt | Texas Transportation Institute |
| 12 | 0-1463 | Recycled Tire Rubber in Concrete Pavements | Prairie View A&M University |

**Table 1.2.** Basic Information on Test Projects Using Recycled Materials

| No. | Material | Application | Location |
|---|---|---|---|
| 1 | Roofing Shingles | Hot Mix Asphalt Concrete (HMAC) | SH 31 in Navarro County, Dallas District (near Corsicana) |
| 2 | Glass Cullet | Flexible Base | Colonial Pkwy & North Teal Drive in the City of Devine |
| | | Flexible Base | Antilley Road in City of Abilene |
| | | Pipe Bedding | Intersection of SH 62 and FM 105 in Orange County, Beaumont District |
| 3 | Bottom Ash | HMAC | I-30 in Mt. Vernon, Paris District |
| 4 | Crushed Concrete | Flexible Base | SH 6 in Hempstead, Houston District |
| 5 | Compost | Erosion Control | Intersection of Ben White Blvd. and Lamar Blvd. in Southwest Austin |
| 6 | Shredded Brush | Erosion Control | SH 103 in San Augustine County, Lufkin District |
| 7 | Blasting Sand | Stabilized Base | SH 6 in Hempstead, Houston District |
| 8 | Waste tires | Embankments | Loop 375, El Paso |
| | | Crumb Rubber in HMAC | US 385 in Crane County, Odessa District |

Subsequent chapters of this report will, for each demonstration project, describe the recycled material used, the specific application of the recycled material within the demonstration project, and the findings from the demonstrations. Specifications and contact information for each project are given at the end of each chapter. No demonstration project was performed to evaluate recycled plastics, however a summary of previous research on the use of recycled plastics in highway construction applications is given in Appendix A.

## CHAPTER 2: BOTTOM ASH

### About the Material

Coal bottom ash is a coarse, granular, incombustible by-product that is collected from the bottom of furnaces that burn coal for the generation of steam, electric power, or both (FHWA, 1998). It is porous in nature and has a dark gray color. When pulverized coal is burned in a dry-bottom boiler, about 80 percent of ash is entrained in the flue gas and is captured and recovered as fly ash while the remaining 20 percent is recovered as bottom ash. The utility industry in the United States generated 14.6 million megagrams (16.1 million tons) of bottom ash in 1996 (FHWA, 1998).

Bottom ash can be used in a number of ways including as a fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, as granular base material, in stabilized base applications, as structural fill materials in highway embankments, and in flowable fill mixes.

Previous Experience: In 1980, the Texas Department of Transportation, Paris District, in co-operation with the Federal Highway Administration, constructed three test sections of asphaltic concrete pavement using bottom ash as one of the components. The purpose was to evaluate the characteristics of bottom ash as a potential construction material. These sections were located on Farm-to-Market Road 1870, Interstate Highway 30, and State Highway 11 in Hopkins County near Sulphur Springs. The test sections were chosen because of different traffic volumes and were from 91.7 to 244.6 meters (300 to 800 feet) in length. The aggregate used in the hot mix asphalt consisted of 55% crushed gravel and 45% bottom ash. The mix was classified as a TxDOT Type D mix. The asphalt content ranged from 10% to 12%.

In addition, a test project was constructed as a TxDOT research project in 1985. It was a 22.5-kilometer (14-mile) section in I-30 in Hopkins County and included both East and West Bound lanes. The pavement consisted of 50 millimeters (2 inches) of Type C level-up overlaid by 25 millimeters (1 inch) of Type D surface. Both courses contained approximately 20 percent bottom ash by weight of total mixture. The conventional aggregate in the mix included crushed sandstone, sandstone screenings and a local field sand. The asphalt content was 7 percent. The experience gathered from the construction and performance from these test sections led to the following conclusions about using bottom ash in hot mix:

- Bottom ash mixes require more asphalt cement
- Bottom ash mixes produce lower compacted density than natural aggregate
- Bottom ash mixes promote good microtextured skid properties
- Bottom ash mixes resist rutting, cracking, and stripping
- Bottom ash mix is higher in cost because of the additional asphalt being used
- Bottom ash mixes produce high quality and economical pavements compared to local field sand mixes
- Bottom ash mixes meet standard specifications and design methods
- Bottom ash may be substituted for field sands, stone screenings, or both (Long, date unknown)

The evaluations of these sections and I-30 experimental project led to the development and extensive use of bottom ash mixes in the Paris District.

**Demonstration Project**:

Encouraged by the experience gathered from various successful projects, TxDOT Paris District constructed two 305-meter (1000-foot) sections with bottom ash as fine aggregate in asphalt concrete, as shown in Figure 2.1, one section had bottom ash in base and surface (Section 1) while the other had bottom ash in the surface only (Section 2). These two test sections are a part of a 17-kilometer (10.5-mile) rehabilitation project on I-30 near Mt. Vernon in Franklin County that starts at milepost 142.528 and ends at milepost 153.222. The average daily traffic on this highway is 17,000.

The pavement section consisted of a four-inch thick Type B Hot Mix Asphalt Concrete (HMAC) base layer and a two inches thick Type C HMAC as the surface course. Approximately 206 megagrams (187 tons) of bottom ash was used in these two sections. The construction work started in March of 1996. The bottom ash came from the Monticello plant and was supplied by Boral Materials Technologies Inc., San Antonio, Texas. The average temperature and rainfall were 29° C (85° F) and 76 mm (3.0 inches), respectively, during the construction.

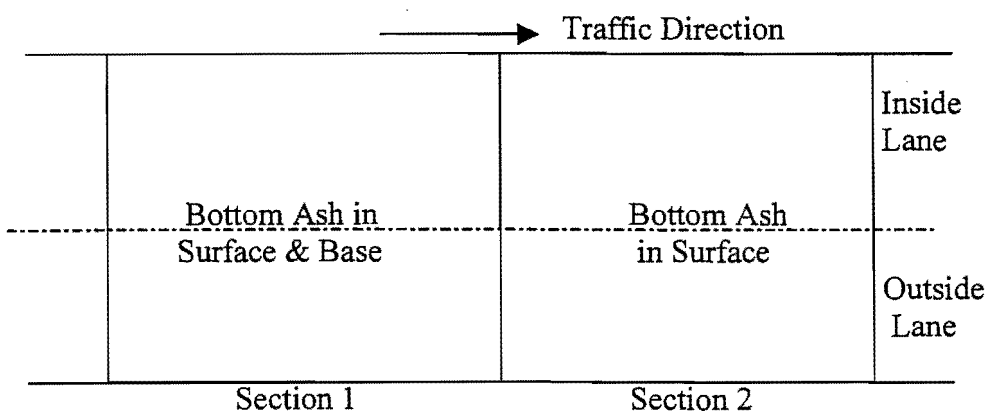



**Figure 2.1.** Bottom Ash Test Section Layout in West Bound I – 30, Franklin County

Laboratory Test Results: Bottom ash used in this project was of gray color and had fine texture. The moisture content of the ash was 20% at source. The unit weight was 62.0 lb./ft.$^3$ (995 kg/m$^3$).

For asphalt stabilized base, 87% of conventional aggregate (67% coarse aggregate and 20% fine aggregate) was blended with 13% bottom ash. The bottom ash-crushed aggregate mixture had a maximum size of 16 millimeters (5/8 inches) and a coarse surface texture. The bulk specific gravity was 2.5.

In the surface mix, 91% of conventional aggregate (58% coarse aggregate and 33% fine aggregate) was blended with 9% bottom ash. The bottom ash-crushed aggregate mixture had a maximum size of 9.5 millimeters (3/8 inches) and a medium surface texture. The bulk specific gravity was 2.5.

The gradation (cumulative passing) of bottom ash used in the stabilized base and surface course, combined gradation (cumulative passing) of aggregates used in asphalt stabilized base and surface and TxDOT specification requirements are shown in Table 2.1.

**Table 2.1.** Aggregate Gradation

| Sieve Size* | Bottom Ash Gradation in Type B Asphalt Stabilized Base | Bottom Ash Gradation in Type C HMAC Surface | Type B Asphalt Stabilized Base | | Type C HMAC Surface Course | |
|---|---|---|---|---|---|---|
| | | | Combined Mix Gradation | TxDOT Spec. | Combined Mix Gradation | TxDOT Spec. |
| 25 mm | 100.0 | 100.0 | 100.0 | 100-100 | 100.0 | 100-100 |
| 22 mm | 100.0 | 100.0 | 100.0 | 95-100 | 100.0 | 100-100 |
| 15.9 mm | 100.0 | 100.0 | 87.2 | 75-95 | 99.6 | 95-100 |
| 9.5 mm | 99.0 | 98.5 | 74.6 | 60-80 | 77.2 | 70-85 |
| 4.75 mm | 92.1 | 92.7 | 53.0 | 40-60 | 54.6 | 43-63 |
| 2.00 mm | 79.7 | 80.5 | 30.0 | 27-40 | 34.0 | 30-40 |
| 0.4 mm | 53.4 | 58.1 | 17.8 | 10-25 | 19.4 | 10-25 |
| 18 µm | 34.1 | 36.2 | 11.8 | 3-13 | 12.5 | 3-13 |
| 7.5 µm | 12.9 | 11.6 | 4.6 | 2-8 | 5.2 | 1-6 |

*25.4 mm = 1 in.

The optimum asphalt content for this Type B asphalt stabilized base and Type C surface course mix were 6.6% and 6.3% respectively. The grade of the asphalt was AC-20. Permatac 1% has been used as the anti-stripping agent. Properties of the mix at optimum asphalt content are presented in Table 2.2. Figure 2.2 shows a view of the test section of the bottom ash demonstration.

**Figure 2.2.** Photograph of Bottom Ash Section on I-30 W, Franklin County

**Table 2.2.** Mix Properties of Type B Asphalt Stabilized Base & Type C Surface Course

| Mix Properties | Type B Asphalt Stabilized Base | | Type C Surface Course | |
|---|---|---|---|---|
| | Measured Value | TxDOT Spec. Requirements | Measured Value | TxDOT Spec. Requirements |
| Asphalt Content (%) | 6.6 | N/A | 6.3 | N/A |
| Bulk Specific Gravity | 2.5 | N/A | 2.5 | N/A |
| VMA (%) | 18 | 13 (Min.) | 18 | 14 (Min) |
| Air Void (%) | 4 | 4 (+/- 1.5) | 4 | 4 (+/- 1.5) |
| Hveem Stability (%) | 51 | 35* (Min.) | 48.4 | 35* (Min.) |

* or as shown on plans

Cost Information: The market price (F.O.B) of bottom ash and field sand in the area are $ 1.00 and $ 0.50, respectively. Field sand available in the east Texas area does not meet TxDOT asphalt mix requirements. Due to this reason, Paris District and other east Texas districts have tried new materials as fine aggregates in HMAC. Paris District almost exclusively is using bottom ash as fine aggregate in HMAC. However, it has been determined that due to the glassy nature of bottom ash particles, it often does not meet the Superpave fine aggregate angularity requirements.

Field Test Results: Texas Tech University researchers, with the help of Texas Department of Transportation employees, conducted some field tests in these bottom ash sections in August of 1998 and June of 1999. A few photographs of monitoring activities are shown in Figures 2.2 through 2.5. The tests included a visual survey, skid resistance tests, falling weight deflectometer (FWD) tests and rutbar/profiler tests. FWD and skid test results are shown in Figures 2.6 through 2.9. Table 2.3 shows information on ride quality of the test sections.

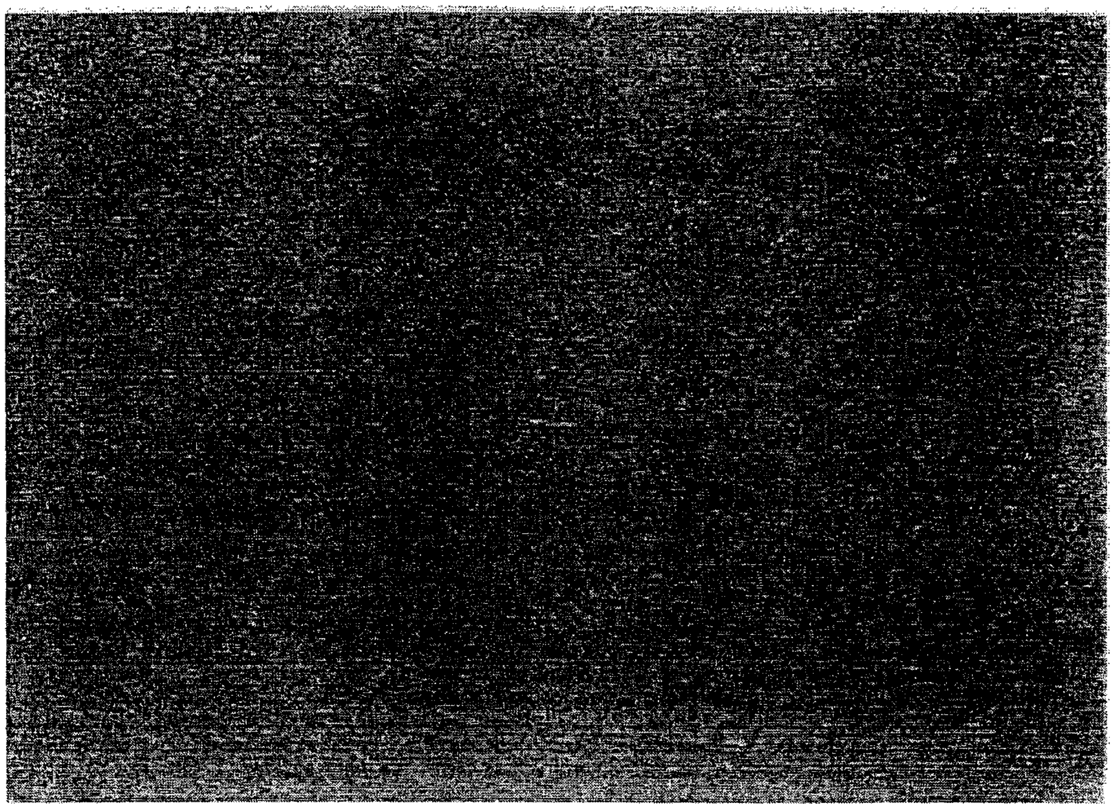


**Figure 2.3.** Closer Look of the Bottom Ash Surface on I-30 W, Franklin County

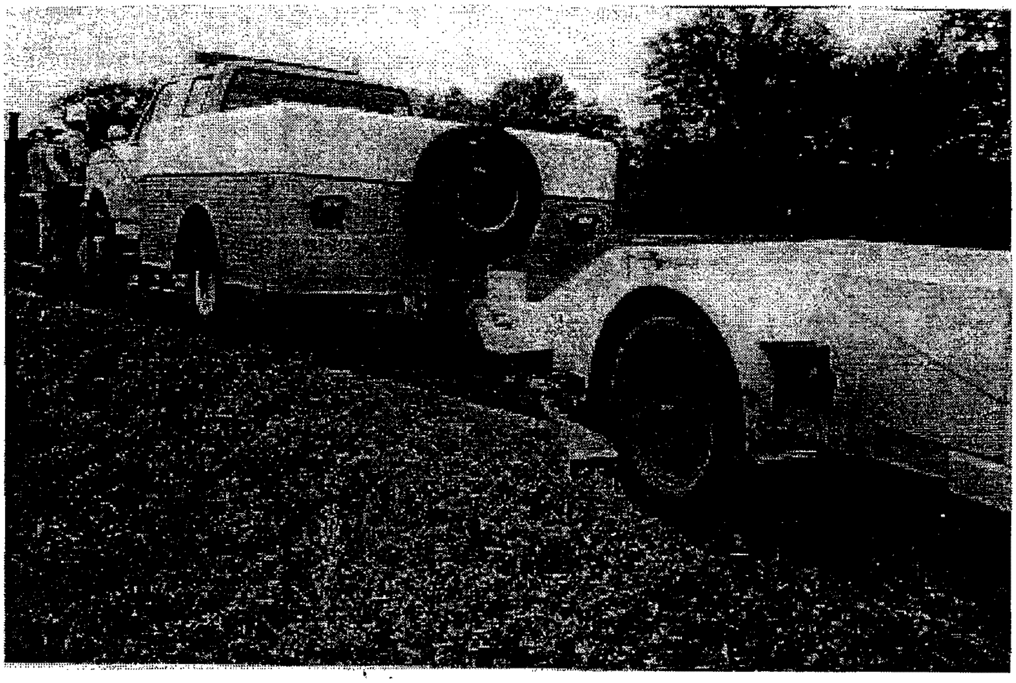


**Figure 2.4.** Photograph of Skid Truck for Skid Resistance Test

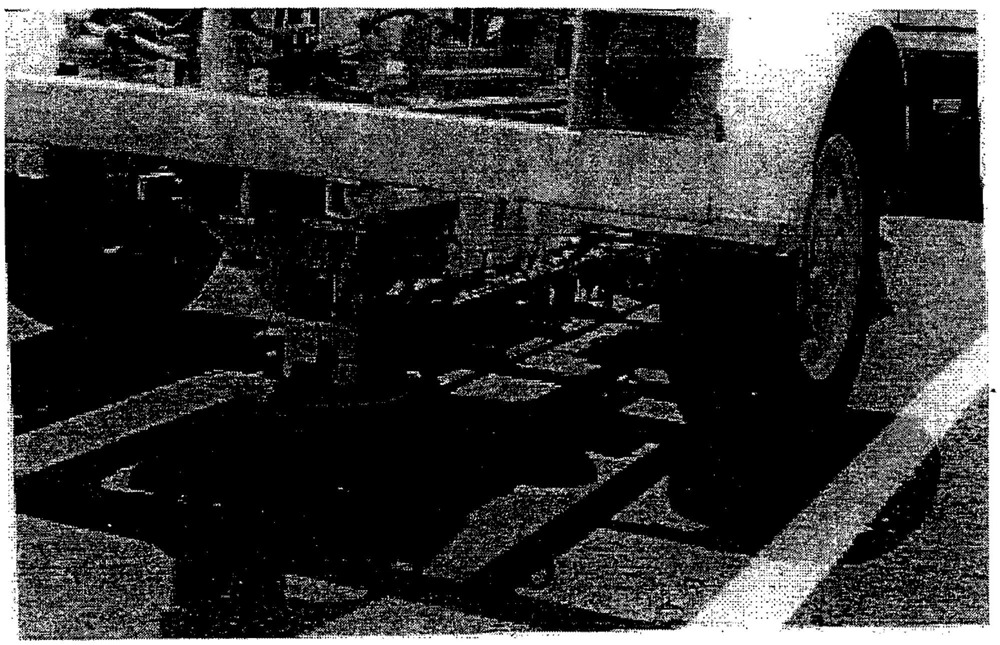


**Figure 2.5.** Photograph of Falling Weight Deflectometer (FWD) Testing

**Results, Findings & Discussion**

Visual distress surveys performed in 1998 and 1999 did not reveal any major distresses (rutting and cracking) in either of these two sections. FWD tests were performed in the summers of 1998 and 1999, and the results are shown in Figures 2.6, 2.7, and 2.8. There appears to be no significant difference in structural integrity between the two lanes in the same section and between sections in the same lanes. However, the deflection values in 1998 are slightly higher than those values in 1999, possibly due to the different climatic and pavement conditions under which tests were performed.

After a traffic application of 1,750,000, the skid number shows the value of 56 (Figure 2.9), which is well above the skid number required by TxDOT. At this rate, after 6 years, the skid number will be 34. Roughness measurements taken using the TxDOT rutbar/profiler have been presented in Table 2.3 which shows an extremely smooth pavement surface for ride scores between 4.0 and 5.0 as per TxDOT PMIS classification (TxDOT, 1994).

No control section was constructed for the bottom ash demonstration project because the engineers in the Paris District felt that a section using sand as fine aggregate would fail. Past research has shown that bottom ash has historically performed better than field sands in the Paris District (Long, undated).

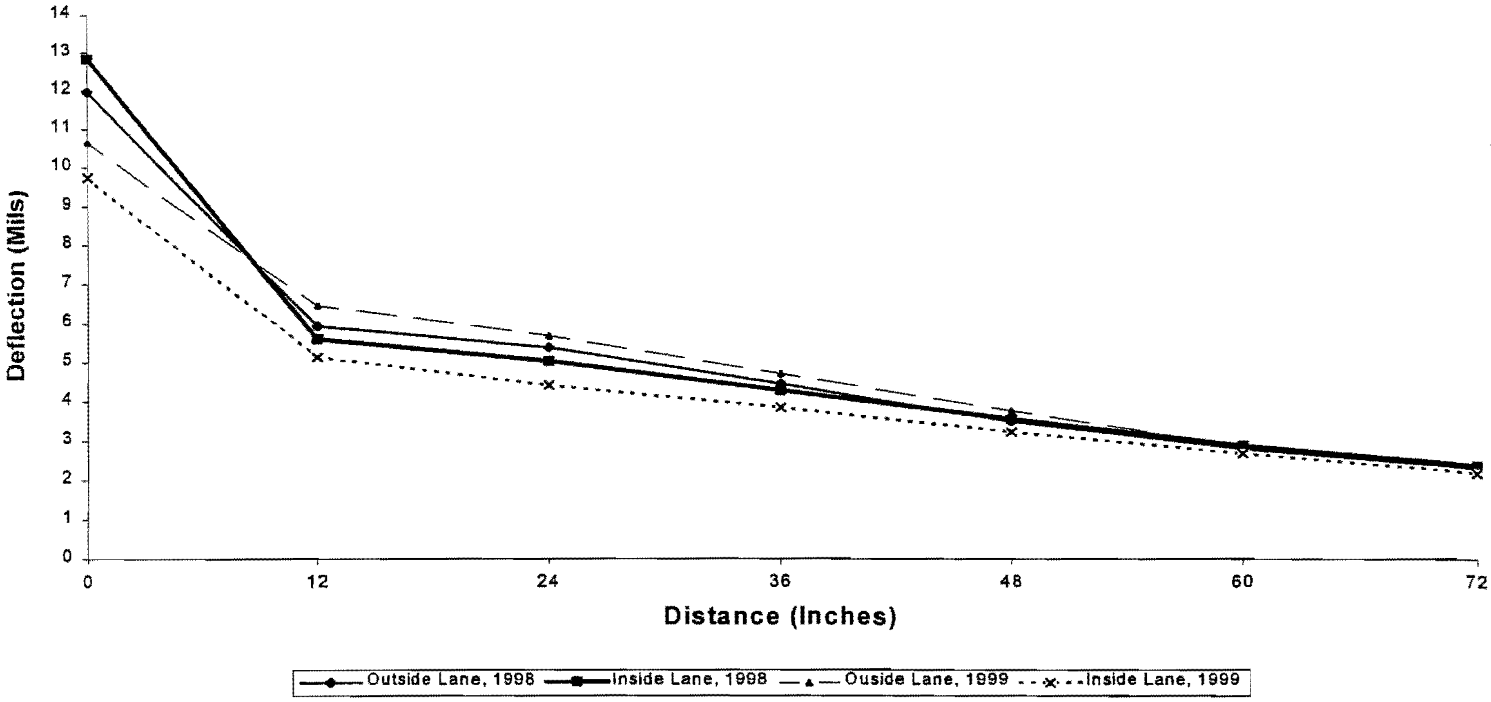



**Figure 2.6.** Comparison of FWD Test Results (15,500 lbs) in Section 1

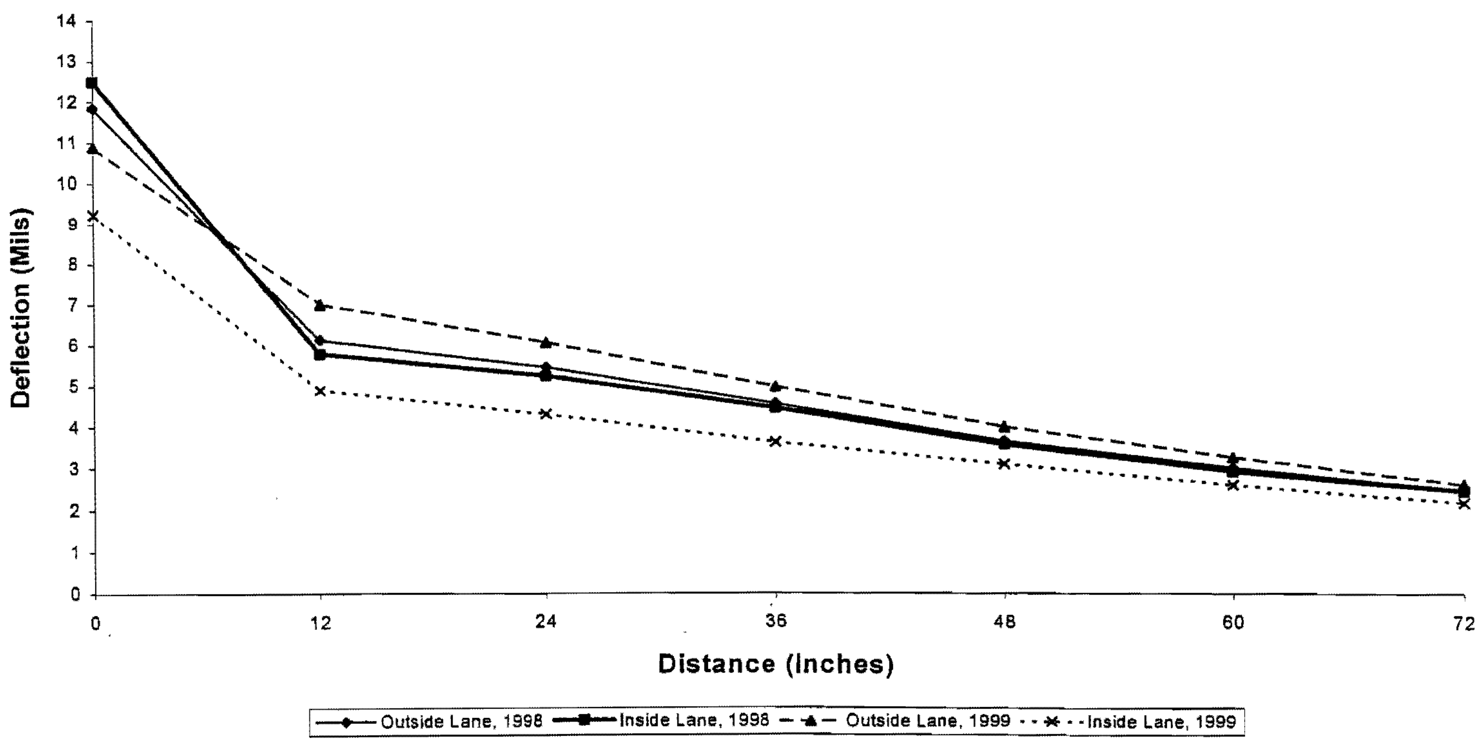



**Figure 2.7.** Comparison of FWD Test Results (15,500 lbs) in Section 2

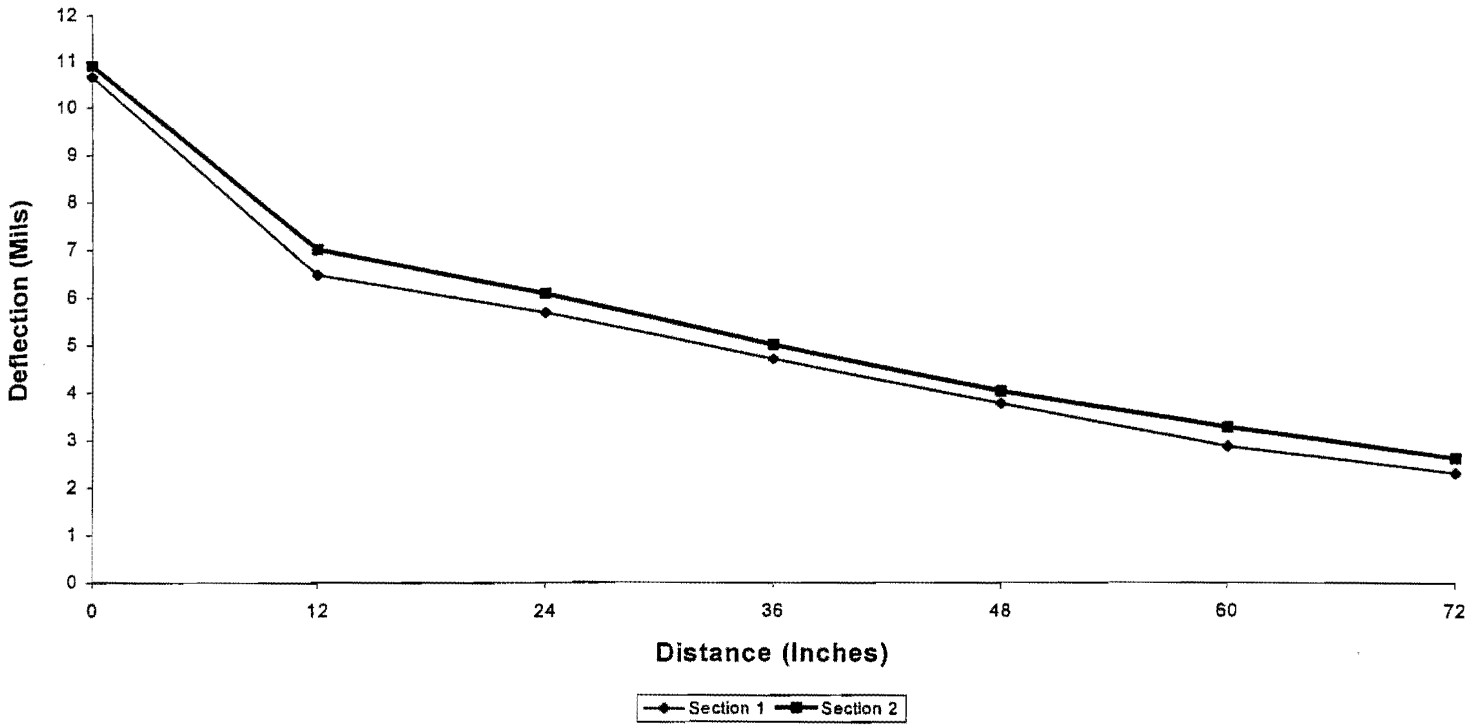



**Figure 2.8**. Comparison of FWD Test Results (15,500 lbs) for Section 1 and Section 2 in Outside Lane, 1999

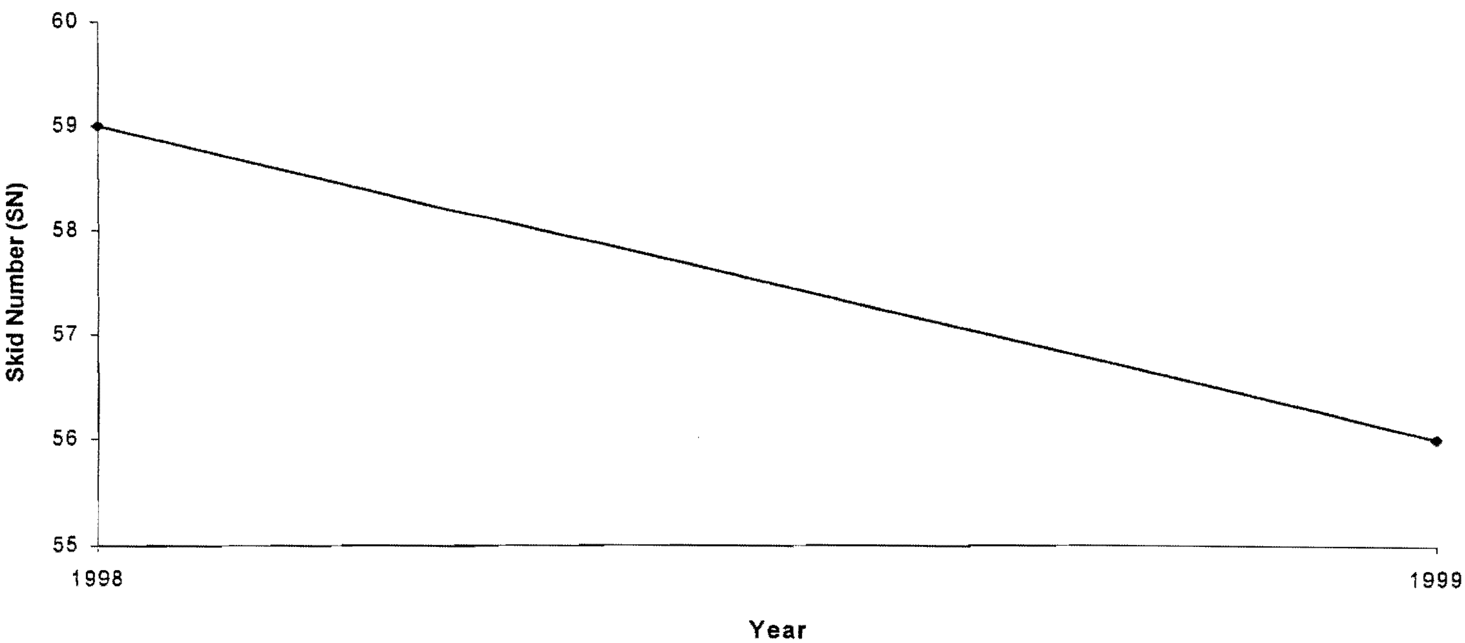



**Figure 2.9.** Skid Number in Outside Lane

**Table 2.3.** International Roughness Index (IRI) and Ride Score Information

| Test Section Location | IRI | | Ride Score |
|---|---|---|---|
| | Left | Right | |
| Section 1 (Outside Lane) | 0.79 | 0.69 | 4.8 |
| Section 1 (Inside Lane) | 1.02 | 0.69 | 4.7 |
| Section 2 (Outside Lane) | 0.70 | 0.61 | 4.8 |
| Section 2 (Inside Lane) | 0.76 | 0.67 | 4.8 |

**Specifications**

Plan Notes used in Paris District in addition to QC/QA of Hot Mix Asphalt are furnished below:

The asphalt binder used for this Item shall be PG 64-22.

All sampling for aggregate quality testing shall be performed on stockpiles at the HMAC plant.

Five cycle magnesium sulfate soundness loss (Test Method TEX-411-A) shall be no greater than 20 percent.

The blended polish value for the virgin coarse aggregate used in the surface course of the main lanes shall not be less than 30.

There is no polish value requirement for aggregates used in base courses.

The use of field sand as a fine aggregate in all HMAC designs on this project is prohibited. A minimum of 10 percent and a maximum 15 percent bottom ash, by weight of combined aggregates, will be required as a replacement.

Bottom ash shall conform to the following gradation requirements:

| Sieve | Percent Passing |
|---|---|
| 15.9 mm / 3/8 in. | 100 |
| 4.75 mm / # 4 | 90 – 100 |
| 2.00 mm / # 10 | 70 – 100 |
| 7.5 μm / # 200 | 0 – 20 |

The contractor is advised that the physical characteristics of bottom ash typically dictate that additional asphalt be required in bottom ash mixes. Any additional asphalt that fills coarse aggregate mixes shall be considered subsidiary to this bid Item.

**Contact Persons**

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| L Wayne Clement | TxDOT Paris District | Phone: (903) 737 9300 Ext. 207 |
| Bobby R. Jones | TxDOT, 1365, N. Main, Paris, TX- 75460-2650 | Phone: (903) 737 9300 Ext. 321<br>Fax: (903) 737-9332 |
| Ernest Teage | TxDOT, Sulphur Spring, TX – 75483-0298 | Phone: (903) 885-9514<br>Fax: (903) 439-3622 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

## CHAPTER 3: COMPOST

### About the Material

According to the definition by Texas Senate Bill 1340, compost is " the disinfected and stabilized product of the decomposition process that is used or sold for use as a soil amendment, artificial top soil, growing medium amendment, or other similar uses." Application of compost increases soil air space and drainage and moisture holding capacity, releases nutrients over a long period of time, helps mitigate salt concentrations, buffers against heavy metals, encourages earthworms and other beneficial insects and microorganisms, and helps buffer against extremes in soil pH.

The Texas Department of Transportation (TxDOT) owns more than 800,000 acres of land adjacent to the state's transportation corridors. The establishment of right-of-way vegetation is frequently difficult because of over-compacted soils or soils with little or no nutritive value.

Several research groups in this country and abroad have effectively demonstrated the use of compost as an erosion control measure (Storey et al., 1996). Some of these studies are briefly described below:

- A five-year study conducted at Johnson City, Tennessee, where a composting facility demonstrated positive results from application of compost as a mulch to highway right-of-way. This facility composts sewage sludge and municipal solid waste (MSW). Compost was applied in conjunction with fertilizer and seed. The composted plot yielded excellent growth compared to non-composted sites. Results were attributed to the ability of the compost to reduce erosion and keep soil temperatures more stable during severe winter weather (Compost Science & Utilization, 1993).
- W & H Pacific of Portland, Oregon, conducted a study using mixed yard debris (MYD) compost-medium grade, MYD-coarse grade, and leaf compost. Compost performance was compared with sediment control fence and wood fiber hydro-mulch with tackifier. Results from this study demonstrated that application of compost as an erosion control device is at least as effective as sediment control fencing and wood fiber mulch. This study also referred to an Australian vineyard study performed on a 30% slope using compost with a bulk density of 475 kg/m$^3$ (29.6 lb./ft$^3$) was applied at 356 Mg/hectare (159 ton/acre), about 7.6 cm (3in.) cover. The Australian study showed that effective service life of this application was about three years. Results included reductions of surface runoff and soil loss. The decrease in runoff was attributed to the compost's ability to absorb large amounts of water, allowing it to percolate into the soil. This study revealed that soil loss resulting from this application was approximately 561 kg/hectare (501 lb./acre) that is well below most specified erosion control guidelines (W & H Pacific, 1993).

**Demonstration Project**

A test project was located in Austin where several previous seeding efforts had failed for establishment of vegetation. The project site is right-of-way located at the intersection of Ben White Blvd. and Lamar Blvd., in southwest Austin. There was commercial development (Malls, restaurants, movie theatres, strip centers etc.) to the east side, commercial development with some multi-family units on the northwest corner of this project-site, whereas the southern corner was primarily undeveloped with one strip center. There were no residential areas immediately adjacent to this site. The average daily traffic at this section is 60,000. Compost, marketed as Dillo Dirt$^{TM}$, was applied on an area of nine acres (Figure 3.1).

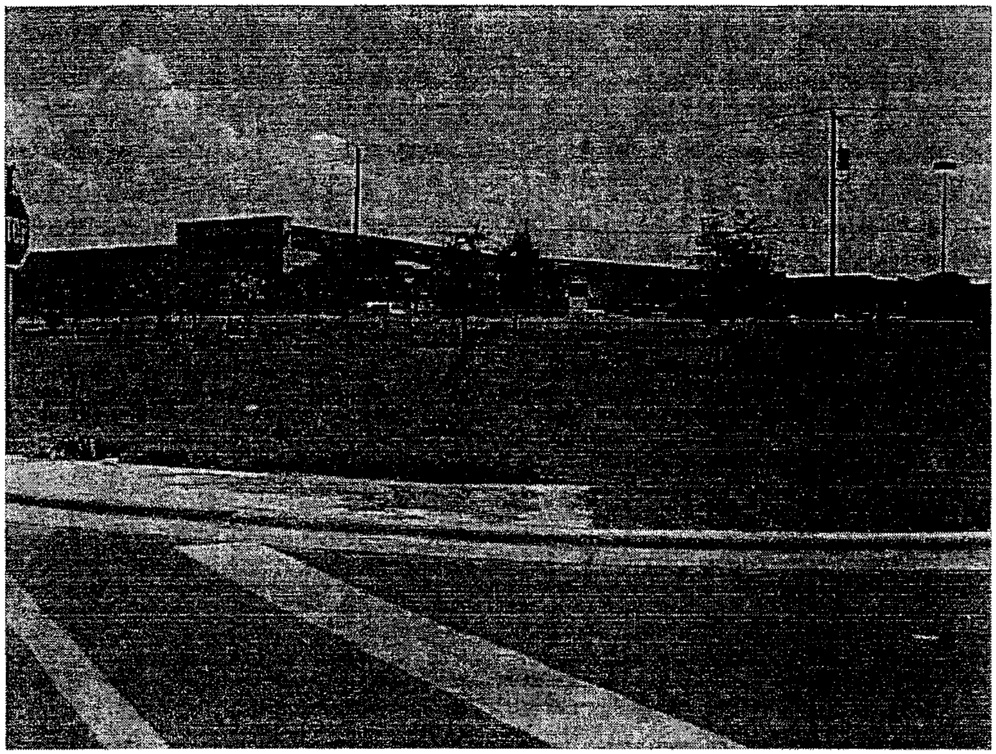


**Figure 3.1.** Project site for Compost Demonstration (Dillo Dirt$^{TM}$)

Dillo Dirt$^{TM}$ used in this project was donated by the Hornsby Bend Biosolids Management Facility in Austin, Texas (Dillo Dirt$^{TM}$ Program Brochure, Undated).

Cost information: Dillo Dirt$^{TM}$ costs \$9/m$^3$ (\$7/CY) at the Hornsby Bend facility. Costs of various erosion control materials including compost are shown in Table 3.1 (Storey et al., 1996).

**Table 3.1**. Costs of Erosion Control Materials

| Erosion Control Material | Average Cost ($/m²*) |
|---|---|
| Synthetic Blanket | 3.90 |
| Organic Blanket | 1.20 |
| Mulch | 0.34 |
| Wood Chips from ROW Cleaning | 0 |
| Compost | 0.97 |

*$\$1/m^2 = \$0.84/yd^2$

Transportation costs: Dillo Dirt™ has a bulk density of 595 kg/m³ (1000 lb./CY) and this low density may provide advantages by way of lower transportation costs. The contractor absorbed the cost of transporting the 24 truckloads of material required for this project.

Processing requirements for Dillo Dirt™: The sewage sludge from city of Austin wastewater plants go through a thickening facility to reduce the water content. Then, it undergoes anaerobic digestion to reduce odor and pathogen level. Later, the material goes to a concrete drying basin. Finally, it is mixed with chipped tree trimmings and yard waste, composted , and then screened. The final product is called Dillo Dirt™. Dillo Dirt™ is processed to meet Class A standards per federal law and meets all Texas Natural Resource Conservation Commission requirements for "uncontrolled" use as a soil amendment (Davio, 1997).

Physical and Chemical characteristics of Dillo Dirt™: Average 1996 Dillo Dirt™ characteristics are presented in Table 3.2 below (Davio 1997).

**Table 3.2.** Physical and Chemical Characteristics of Dillo Dirt™

| Test Parameter | Result |
|---|---|
| Organic Nitrogen | 1.8% (17,827 mg/kg) |
| Ammonium Nitrogen | 0.2% (2,270 mg/kg) |
| Nitrate Nitrogen | 0.035% (332 mg/kg) |
| Phosphorous | 0.9% (9,367 mg/kg) |
| Potassium | 0.4% (17,827 mg/kg) |
| Moisture | 40% |
| Bulk Density | 595 kg/m³ |
| Average pH | 7.76 |

Note: These values are provided on a dry-weight basis.

Source: The supplier of Dillo Dirt™ was Hornsby Bend Biosolids Management Plant, 2210 S. FM 973, Austin, Texas. The amount of material produced by this facility in 1996 was 46,000 cubic meters (60,000 cubic yards).

Laboratory test results: Results indicating how Dillo Dirt™ complied with the 1996 TNRCC regulatory limits are presented in Table 3.3 below (Davio 1997).

**Table 3.3.** Compliance of Dillo Dirt™ with TNRCC Regulations

| Test Parameter | Amount in Dillo Dirt™ | Regulatory Limit |
|---|---|---|
| Fecal Coliform | 11 MPN/g | 1000 MPN/g |
| Arsenic (As) | 15.3 mg/kg | 75 mg/kg |
| Cadmium (Cd) | 3.2 mg/kg | 85 mg/kg |
| Chromium (Cr) | 44.1 mg/kg | 3,000 mg/kg |
| Copper (Cu) | 194.6 mg/kg | 4,300 mg/kg |
| Lead (Pb) | 40.1 mg/kg | 840 mg/kg |
| Mercury (Hg) | 1.6 mg/kg | 57 mg/kg |
| Nickel (Ni) | 23.8 mg/kg | 420 mg/kg |
| Selenium (Se) | 11.2 mg/kg | 100 mg/kg |
| Zinc (Zn) | 456.7 mg/kg | 7,500 mg/kg |

Note: These values provided on a dry weight basis

Construction techniques: As the project area had already been finally graded, seeded, and had erosion control matting installed, the application of Dillo Dirt™ was limited to spreading at the appropriate thickness to allow for seed germination. A two-stall manure spreader was used for that purpose and care was taken not to disturb the erosion control matting already installed. However, it was recommended, on subsequent projects, the composted biosolids be disked in to the top three to four inches of soil prior to seeding and the installation of erosion control netting. The rate of application of Dillo Dirt™, based on Land Limiting Constituents was 10.8 megagrams/hectare (4.8 tons/acre). A total of 68 $m^3$ (89 CY) of Dillo Dirt™ was applied in this project.

**Results, findings and discussion:**

Vegetation growth was seen within a few weeks in the area where the Dillo Dirt™ was placed. Compost appears to offer the road construction industry a number of benefits such as rapid establishment of vegetative coverage, reduction of soil erosion, and of course, the benefit of using a recycled material.

**Specification**

**TXDOT ITEM 1009 FURNISHING AND PLACING COMPOST**

**Description.** This Item shall govern for the furnishing and placing of approved compost material to the depths and area shown on the plans or as directed by the Engineer.

**Materials.**

General

The compost material shall be an organic substance produced by the aerobic (biological) decomposition of organic matter. The compost material shall not contain any visible admixture of refuse and other physical contaminants nor any material toxic to plant growth. Composed matter may include, but are not limited to, leaves and yard trimmings, biosolids, food scraps, food processing residues, manure and/or other agricultural residuals, forest residues and bark, and soiled and/or unrecyclable paper. The use of mixed municipal solid waste compost or Class B Biosolids (as defined in 40 CFR part 503) will not be allowed.

Compost materials furnished shall meet all applicable Federal (40 CFR Part 503 Standards for Class A Biosolids) and Texas Natural Resources Conservation Commission (TNRCC) health and safety regulations (TAC Chapter 332). All compost material supplied shall be processed to meet the time and temperature standards in TAC Chapter 332 Subchapter B Part 23 to control noxious weeds, and the physical requirements shown in Table 3.4.

**Table 3.4** Physical Requirements

| Compost Manufactured Topsoil* | Erosion Control Compost* | General Use Compost* |
|---|---|---|
| Organic Matter Content: 30% (dry mass) as determined by loss on ignition (ASTM D-5268 @ 440 C) | Organic Matter Content: 40%-60% (dry mass) as determined by loss on ignition (ASTM D-5268 @ 440 C | Organic Matter Content: 40%-60% (dry mass) as determined by loss on ignition (ASTM D-5268 @ 440 C |
| Particle Size: 100% passing 25 mm | Particle Size: 100% passing 76 mm < 70% passing 50mm | Particle Size: 100% passing 19 mm <70% passing 850mm |
| Soluble Salts: 4.0 max. mmhos/cm as determined by "Method of Test for Soils Materials" (Tex-129-E) | Soluble Salts: 4.0 max. mmhos/cm as determined by "Method of Test for Soils | Soluble Salts: 4.0 max. mmhos/cm as determined by "Method of Test for Soils |
| Stability: Finished | Stability: Finished | Stability: Finished |
| pH: 5.5 - 8.5 | pH: 5.5 - 8.5 | pH: 5.5 - 8.5 |

*25.4 mm = 1 in.

Maturity Testing

Compost shall be tested and must be classified as "finished" according to the Solvita Compost Maturity Test or an approved equal. The Solvita Compost Maturity Test is available from the following information.

Woods End Research Laboratory Inc.
Box 297
Mt. Vernon, Maine 04352
1(800)451-0337
E-mail: Info@woodsend.org
or approved equal.

Prior to delivery of compost, the Contractor shall supply for TxDOT's use one unused set of compost maturity test kits, containing six (6) tests for every 400 cubic meters (525 cubic yards) of compost supplied.

Documentation

Prior to delivery, the Contractor shall provide the following information.

(a) a certification statement verifying that the compost contains a minimum of 65% by volume of recycled materials
(b) a list of the feedstock by percentage in the final compost product
(c) a certification statement verifying that the compost meets federal and state health and safety regulations
(d) a certification statement verifying that the compost meets time and temperature requirements
(e) a copy of the lab analysis and certification statement verifying that the compost meets the physical requirements described in Table 1. The analysis shall be less than three (3) months old.

**Construction Methods**

After the designated areas have been completed to the lines, grades, and cross sections shown on the plans and as provided for in other Items to the contract, compost of the type specified shall be placed in accordance with the requirements hereinafter described. Any stockpile areas shall be well drained, and shall be left in a neat and presentable condition upon completion of the removal of the materials. Where rolling is specified, the roller shall be a light corrugated drum roller of the type approved by the Engineer.

Compost shall be loose and friable and not dusty at the time of application. Compost may be required to be brought to an acceptable moisture content, as directed by the Engineer. No compost materials shall be placed within 30 meters (100 feet) of any source of surface water or drinking water supply.

Compost Manufactured Topsoil

Compost manufactured topsoil shall consist of soil constituents amended with 5 to 30 percent compost, measured by volume, as shown on the plans. Any trash, stumps, roots, weeds, or other objectionable materials in the soil shall be removed and disposed of, as approved by the Engineer, prior to beginning the mixing process.

*Blended On-Site* Compost shall be spread in a uniform layer over the previously prepared subgrade area and thoroughly incorporated into the soil materials, to the depths shown on the plans, by rototilling, harrowing, or other suitable methods. After the topsoil has been produced and shaped, it shall be sprinkled and rolled as directed by the Engineer.

*Pre-Blended.* Topsoil manufactured from source outside the right of way shall be produced in accordance with the requirements for Blended On Site topsoil as specified in Section 3.(1)(a), and spread over the prepared subgrade so as to form a uniform layer of loose material of the thickness shown on the plans. After the topsoil has been placed, it shall be raked carefully to remove all objectionable materials and to yield a consistent grade, and then sprinkled and rolled as directed by the Engineer.

Erosion Control Mulch

Composted mulch shall be spread evenly over the previously prepared subgrade or slopes so as to form a uniform layer of loose material of the thickness shown on the plans. Erosion Control Compost shall not be placed on any slope having a slope ratio steeper than 1:2. After the compost has been placed, it shall be sprinkled and rolled as directed by the Engineer.

General Use Compost

General use compost shall be applied as a top dressing by placing the material evenly upon established areas of turf, grass, or other ground cover growth to the depth specified on the plans or as directed by the Engineer. Compost applications shall not bury or kill existing vegetation. All stems, roots, or other debris larger than 50 millimeters (2 inches) diameter shall be removed from the ground's surface.

**Measurement.** "Compost Manufactured Topsoil (Blended On-Site)", "Compost Manufactured Topsoil (Pre Blended)", "Erosion Control Mulch" and "General Use Compost" will be measured by one of the following methods as shown on the plans.

When Class 1 measurement is specified, this Item will be measured by the 1-kilometer (or mile), or portion of, as measured along the baseline of each roadbed.

When Class 2 measurement is specified, this Item will be measured by the square meter (or square meter) complete in place.

When Class 3 measurement is specified, this Item will be measured by the cubic meter (or cubic yard) in vehicles at the point of delivery.

When Class 4 measurement is specified, this Item will be measured in the stockpile and the volume computed in cubic meters (or cubic yards) by the method of average end areas.

When Class 5 measurement is specified, this Item will be measured in its original position at the source and the volume computed in cubic meters (or cubic yards) by the method of average end areas.

**Payment**

The work performed and materials furnished in accordance with this Item and measured as provided for under "Measurement" will be paid for at the unit price bid for "Compost Manufactured Topsoil (Blended On Site)", "Compost Manufactured Topsoil (Pre-Blended)", "Erosion Control Mulch" or "General Use Compost" for the depth specified. This price shall be full compensation for securing any necessary source(s) and any royalty involved; for furnishing all materials, for all excavation, loading, hauling, stockpiling, placing, rototilling, harrowing, and raking; and for furnishing all labor, tools, equipment and incidentals necessary to complete the work.

"Rolling" and "Sprinkling" will not be paid for directly, but shall be considered subsidiary to this Item, unless otherwise shown on the plans.

"Seeding", if used and called for on the plans, shall be measured and paid for in accordance with Item 164, "Seeding for Erosion Control".

**Contact persons**

| **Name(s)** | **Organization** | **Telephone Number/Fax/E-mail** |
|---|---|---|
| Rebecca Davio | TxDOT, Austin, TX - 78704 | Phone: (512) 416-2086<br>Fax: (512) 416-2021 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |
| Danette Shelton | President, Roadway Specialties, Inc. | Phone: (512) 280-6666<br>Fax: (512) 280-6066 |
| Barrie Cogburn | Landscape Architect, Design Division, TxDOT | Phone: (512) 416-3086<br>Fax: (512) 416-3098 |
| Jody Slagle, P. E. | Hornsby Bend Biosolids Mgmt. Plant, Water & Wastewater Utility | Phone: (512) 929-1016<br>Fax: (512) 929-1004 |
| Russel Lenz, P. E.<br>Billy Benningfield<br>Darrel Anglin | TxDOT South Austin Area Office, 2499A, S. Capital of Texas Hwy, Suite-100, Austin, TX 78746 | Phone: (512) 328-2256<br>Fax: (512) 327-3425 |

## CHAPTER 4: CRUSHED CONCRETE

### About the Material

Recycling of Portland cement concrete started in Europe after World War II. With time and through necessity, recycled aggregates have become more and more acceptable in road construction. The United States, Japan and European countries such as Germany, Austria, the United Kingdom and the Netherlands are leaders in this industry. Reclaimed Portland cement concrete (RPCC) materials are usually generated during the removal or demolition of concrete elements of structures such as roads, airfield runways and buildings. The American Concrete Pavement Association (ACPA) indicated that approximately 322 kilometers (200 miles) of concrete pavement are being recycled each year and approximately 5,440 megagrams (6,000 tons) of crushed concrete can be reclaimed from each 1.6 km (1 mile) of concrete pavement with average thickness. This yield ratio indicates that 2.6 million megagrams (2.9 million tons) of reclaimed concrete is being recycled annually (FHWA, 1993).

Won (1999) reported that when compared to conventional aggregate, recycled crushed concrete aggregate possesses lower specific gravity, higher water absorption, higher thermal coefficient of expansion, higher sulfate soundness loss and higher LA abrasion loss. Chini (1999) reported that the values of mechanical properties of Portland cement concrete made with recycled concrete aggregate (RCA) decrease as the ratio of coarse RCA to conventional virgin aggregate (VA) in the mix increases. Chini (1999) determined that RCA concrete when compared to VA concrete is about 82% in compressive strength, 96% in tensile strength, 81% in flexural strength, and 86% in modulus of elasticity for laboratory prepared samples. Won reported that continuously reinforced concrete pavement (CRCP) sections utilizing 100% recycled coarse and fine aggregates performed well and showed no distresses such as spalling, wide cracks, punchouts, or meandering cracks. However, Frabizzio (1999) reported that jointed concrete pavement (JCP) containing recycled concrete coarse aggregate appears to have more transverse cracks than when using natural gravel or carbonate aggregates. This was attributed to a greater tendency for shrinkage cracking in recycled pavements where unique curing requirements are often neglected.

Numerous research studies published in Australia show that crushed concrete was used in roadbase construction as far back as 1986. In 1992, VicRoads, the state highway agency for Victoria, released standard specification 820Q for the use of crushed concrete in pavement subbases. VicRoads performed dynamic load tests such as the Repeated Load Triaxial test to determine the resilient modulus of laboratory prepared samples. Samples were prepared with crushed rock (conventional material) and crushed concrete for strength comparison. It was found that the average modulus values of unstabilized crushed rock and unstabilized crushed concrete were 340 MPa (49 ksi) and 830 MPa (120 ksi), respectively. When stabilized with 3% cement, these values increased to 983 MPa (143 ksi) and 1196 MPa (173 ksi) for cement stabilized crushed rock and cement stabilized crushed concrete, respectively. These values correspond to a normal stress of 300 kPa (44 psi). Therefore, it can be observed that resilient modulus of unbound crushed concrete is much higher than that for conventional crushed rock. However, cement stabilization appears to have a more significant positive impact on crushed rock than crushed concrete.

In the United States, a survey conducted by the University of Massachusetts Transportation Center (UMTC) revealed that RPCC is used in 23 states of which17 states have specifications developed for its use (Table 4.1). Applications to use reclaimed concrete pavement included its use as aggregate in unbound base courses, cement treated bases, and asphalt concrete. It is also used in non-structural applications such as embankments and riprap. The UMTC survey also indicated that RPCC has been used as aggregate for base, subbase and other granular fill in 23 states of which 17 states have specifications for such uses (UMTC, 1995).

Saeed (1995) reported an AASHTO publication (AASHTO 1994) highlighting the experiences of states using crushed concrete as roadbase. According to that report, as many as 11 states have moderate to extensive experience with this material and nine of these states rated the performance of crushed concrete from good to excellent. Maryland reported poor performance of this material and data from Michigan were unavailable.

The Center for Transportation Research (CTR) of the University of Texas at Austin conducted a study on recycled materials for TxDOT (Saeed and Hudson, 1995). According to its findings, the Pharr district had the largest stockpile (3,616 megagrams/3986 tons) of old concrete. Nine of the 21 TxDOT districts responding to the survey already had stockpiles of crushed concrete and 19 districts believed that old concrete could be used as roadbase material. TxDOT engineers from Abilene, Atlanta, Beaumont, and Dallas districts rated the performance of crushed concrete as excellent.

Andrew Andrasi (1998) identified non-hazardous recycled material processors. Table 4.2 shows some of the processors in the State of Texas who have the ability and/or willingness to process crushed concrete.

**Table 4.1.** States Using Crushed Concrete in Roadbase/Subbase (UMTC 1995)

| State | Status |
| --- | --- |
| Alabama | S |
| Connecticut | S |
| Georgia | S |
| Illinois | S |
| Indiana | S |
| Kansas | S |
| Kentucky | NS |
| Louisiana | S |
| Maryland | E |
| Massachusetts | S |
| Michigan | S |
| Minnesota | S |
| Nebraska | S |
| New Jersey | S |
| New York | S |
| North Dakota | S |
| Ohio | E |
| Oregon | NS |
| Pennsylvania | S |
| Rhode Island | S |
| South Carolina | NS |
| Virginia | NS |
| Washington | S |

'S' indicates states actively using crushed concrete and have specifications for such use
'NS' indicates states actively using crushed concrete but have no specification developed for its use
'E' indicates states that use the material only on an experimental basis.

**Table 4.2.** Information on Crushed Concrete Processors in Texas (Andrasi, 1998)

| District | Processor Name | Remarks |
|---|---|---|
| Amarillo | Amarillo Road Co. | CW |
| | E.D. Baker Corporation | CW |
| | Gilven-Terrill, Inc. | CW |
| | L.A. Fuller & Sons Construction Inc. | CW |
| | Lewis Construction Co. | CW |
| | Vega Sand and Gravel | CW |
| Dallas | Big City Crushed Concrete | CW |
| | Gifford-Hill & Co. | W |
| El Paso | Allied Paving Co. | CW |
| | Jobe Concrete Products | CW |
| Fort Worth | Gifford-Hill & Co. | W |
| | Zack Burkett Co. | W |
| Houston | American Materials Inc. | CW |
| | Durwood Greene Construction Company | CW |
| | Southern Crushed Concrete | CW |
| Odessa | Jones Bros. Dirt and Paving | CW |
| Pharr | Balanger Construction Co. | CW |
| San Antonio | Colorado Materials Co., Inc. | CW |
| | South Texas Aggregate | CW |
| Waco | Franklin Industrial Minerals | CW |
| | Gifford-Hill & Co. | W |
| Wichita Falls | Zack Burkett Co | CW |

'CW' indicates that the processor has the capability and willingness to process recycled concrete.

'W' indicates that the processor has the willingness to process concrete.

**Demonstration Project**

A test project was constructed in the Houston district using crushed concrete within a cement stabilized base layer. The project is located on State Highway 6 at Hempstead Highway. Crushed concrete has been used as coarse aggregate for stabilized base in main lanes between stations 10+97 and 38+50.

Crushed concrete has been used along with sand and cement for stabilized base construction. A total of 8,000 megagrams (8,800 tons) of crushed concrete was used in this project. The crush concrete was supplied by Southern Crushed Concrete. The proposed typical pavement section consisted of a 150-mm (6-inch) lime treated subgrade, a 150-mm (6-inch) cement treated base and a 280-mm (11-inch) continuous reinforced concrete surface.

Crushed concrete is cheaper than limestone in the Houston District. The cost of crushed concrete is $12.50/megagram ($11.40/ton) compared to $16.50/ megagram ($15.00/ton) for limestone (Rust, 1999).

<u>Laboratory Tests</u>: Tables 4.3 and 4.4 present data from laboratory tests performed on crushed concrete.

**Table 4.3.** Gradation of Crushed Concrete supplied by Southern Crushed Concrete

| Sieve Size | Cumulative Passing (%), Post Oak Facility | Cumulative Passing (%), Tanner Road Facility |
|---|---|---|
| 44.0 mm / 1 3/4 in. | 100 | 100 |
| 4.75 mm / # 4 | 50 | 55.2 |
| 0.4 mm / #40 | 26 | 38.0 |

**Table 4.4.** Properties of Crushed Concrete

| Liquid Limit | Plasticity Index |
|---|---|
| 19 | 2 |

Field Tests Table 4.5 presents the results of nuclear density test performed during the construction.

**Table 4.5.** Nuclear Density Test Results

| Test Location | Field Density Achieved as Percentage of Laboratory Optimum Dry Density* | In-Situ Moisture Content (%) |
|---|---|---|
| At Station 13+00 (20' Left of Center Line) | 96.1 | 9.5 |
| At Station 17+00 (35' Left of Center Line) | 99.2 | 10.0 |
| At Station 26+00 (30' Left of Center Line) | 96.7 | 13.0 |
| At Station 27+00 (20' Right of Center Line) | 95.6 | 13.3 |
| At Station 28+00 (20' Left of Center Line) | 95.4 | 9.1 |
| At Station 31+00 (10' Right of Center Line) | 97.3 | 12.0 |

* Laboratory Optimum Dry Density is 2.183 $Mg/m^3$ (136.3 pcf) at 7.1% Moisture Content.

**Results, Discussion & Findings**

Crushed concrete is currently being used extensively in the Houston District. Incorporation of crushed concrete in stabilized base presented no difficulties in material handling (Bunch, 1999). The particular test section on SH 6 has not been monitored closely for its performance, but there were no significant problems associated with its base. A visual survey in July of 1999 revealed no significant distresses related to crushed concrete base. Finally, based on the experience from previous jobs with crushed concrete, no difference in performance of crushed concrete base and limestone base has been observed over time (Bunch, 1999).

**Specification**

Crushed concrete must meet the following requirements as aggregates in cement stabilized base.

1. The concrete to be used for base shall be comprised of good quality material.
2. The concrete shall be substantially free of all foreign matter (Asphalt, Base, Dirt etc.) before crushing.
3. PI shall not exceed 10 and LL shall not exceed 35.
4. The crushed concrete shall be stockpiled for exclusive use of the state.
5. The gradation requirements shall be as follows.

| Square Sieve | Percent Passing | Percent Retained |
|---|---|---|
| 44.5 mm / 1-3/4 in. | 90 - 100 | 0 - 10 |
| 4.75 mm / No. 4 | 25 - 55 | 45 - 75 |
| 0.4 mm / No. 40 | 20 - 45 | 55 - 80 |

6. With permission of the Engineer, sand may be blended in to the mix.
7. The Engineer shall approve the salvaged concrete prior to crushing.

When salvaged existing base and asphaltic concrete pavement are used, the material shall be sized so that all the material, except the existing individual aggregate, shall pass the 50-mm (2-inch) sieve and be of a gradation to allow satisfactory compaction. The material is to be salvaged in a manner which will not introduce deleterious material (clay, organics, etc.). Material passing the 4.75 mm (No. 40) sieve (defined as soil binder) shall have a plasticity index not to exceed ten, and a liquid limit not to exceed 35 when tested in accordance with test method Tex-106-E.

The following additional requirements will be applicable when base and ACP are salvaged from other state projects.

1. The use of the material must be approved by the engineer in writing.
2. The salvaging and stockpiling shall be by methods approved by the engineer.
3. The material shall be stockpiled for the exclusive use of the department.

**Contact Persons**

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| Kathy Rust | TxDOT, Waller/West Harris Area Office, Houston, TX-77040 | Phone: (713) 934-5932<br>Fax: (713) 934-5999 |
| Don Bunch | TxDOT, Waller/West Harris Area Office, Houston, Tx-77040 | Phone: (713) 934-5932<br>Fax: (713) 934-5999 |
| Michael W. Alford | TxDOT, Houston District Office, Houston, Tx-77007 | Phone: (713) 802-5551 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

## CHAPTER 5: GLASS CULLET

### About the Material

Waste glass constitutes approximately seven percent of the 180 million megagrams (200 million tons) of municipal solid waste generated annually in the United States (Cosentino, 1995). According to Washington DC-based Glass Packaging Institute (GPI), an estimated 35% (3 million megagrams, 3.3 million tons) of all glass containers sold in the United States were recycled in 1997. Glass cullet is produced by crushing waste glass collected in municipal and industrial waste streams. Glass cullet is primarily used in new glass container manufacturing. Secondary applications include fiberglass insulation, roadbase, and highway reflectors.

The Clean Washington Center (CWS) conducted an exhaustive evaluation of glass cullet as a construction aggregate to open new markets in the State of Washington. This evaluation included engineering performance, environmental impact, equipment requirements, safety, handling, and economics. From an engineering standpoint, CWS considered cullet to be an excellent replacement for traditional aggregate in many construction applications. Glass in cullet particles does not possess harmful contaminants and it does not pose health risks associated with natural sand since glass is amorphous rather than crystalline silica. Glass cullet may be price-competitive in areas where good quality traditional aggregate materials are expensive and in short supply. A number of specifications or supplemental specifications have been developed by various agencies to facilitate the use of glass cullet as construction aggregates (Dames & Moore, Inc., 1993). Selected agencies and their specification titles are listed in Table 5.1.

**Table 5.1.** Agencies that Developed Specifications for Glass Cullet Use (Dames & Moore, Inc., 1993)

| Agency | Specification Item |
|---|---|
| California | Amendment to 25-1.02A(Class 1,2,3 Aggregate Subbases)<br>Amendment to 26-1.02B (Class 2 Aggregate Base)<br>Amendment to 26-1.02C(Class 3 Aggregate Base)<br>Amendment to provisions in Section 26, Aggregate Base |
| Connecticut | 1.01.01 Reclaimed Waste (definition)<br>2.02 Formation of Roadway Embankment |
| National Standard Plumbing Code | Chapter 13 Storm Drains |
| New Hampshire | 304.2.1 Materials<br>304.2.2 Processed Glass Aggregate Gradation<br>304.2.3 Processed Glass Aggregate/Base Course Blends<br>304.3.1 Construction Requirements – General<br>304.3.5 Material Testing |
| Pennsylvania | Waste Glass as Pipe Backfill and as Embankment Material |
| Washington | 9-03.21 Recycled Material (Allows up to 15% glass in most aggregates listed in Part 9-03. Permits only 10% greater than 6mm, based upon visual examination and weight) |

One of the concerns raised regarding the use of cullet mixes in roadway construction is the ability of cullet to withstand repeated traffic loads without breakdown (Shin, 1994). Shin performed laboratory repeated load testing on glass cullet specimens and compared the resilient modulus over the first 1,000 cycles for glass cullet and conventional crushed rock. The cullet samples, like crushed rock, did not show appreciable changes in the modulus value. The same study also revealed that compaction curves tend to become flatter as cullet content increases, possibly implying that maximum dry density is relatively insensitive with respect to moisture, which may prove useful in construction during wet weather.

Andrasi (1998) conducted a survey on non-hazardous recycled material processors in Texas. Table 5.2 shows some of these processors in the state of Texas who have the resources and/or willingness to process glass.

**Table 5.2.** Information on Glass Cullet Processors in Texas (Andrasi, 1998)

| District | Processor Name | Remarks |
|---|---|---|
| Amarillo | Amarillo Road Co.<br>L. A. Fuller & Sons Construction Inc. | CW<br>CW |
| Atlanta | Texarkana Asphalt Inc. | W |
| El Paso | Jobe Concrete Products | CW |
| Fort Worth | Zack Burkett Co. | CW |
| Houston | American Materials Inc.<br>Durwood Greene Construction Company | CW<br>CW |
| Odessa | Jones Bros. Dirt and Paving | CW |
| San Antonio | Redland Stone products Co.<br>South Texas Aggregates | C<br>CW |
| Wichita Falls | Zack Burkett Co. | CW |

Note: 'CW' indicates that processor has the capability and willingness to process glass, 'W' indicates that the processor has the willingness to process glass and 'C' indicates that the processor has the capability to process glass.

**Demonstration Projects**

As a part of this research study, three test projects were constructed using glass cullet in Texas during 1996 and 1997. A description of each test project is included below.

<u>Demonstration Project # 1</u>

The first test project involved the rehabilitation of Colonial Parkway and North Teel Drive in the City of Devine (Figure 5.1). Construction was done in July of 1996 and it involved reworking existing surface and base layers as the subbase for the new pavement. An blend of 80% crushed limestone and 20% glass cullet was used to construct the flexible base layer and hot mix asphalt with limestone rock asphalt (LRA) aggregate was used in the surface layer. Vista Fibers of San Antonio supplied 400 megagrams (440 tons) of waste glass for the project and Vulcan Materials of San Antonio blended it and crushed it with limestone.

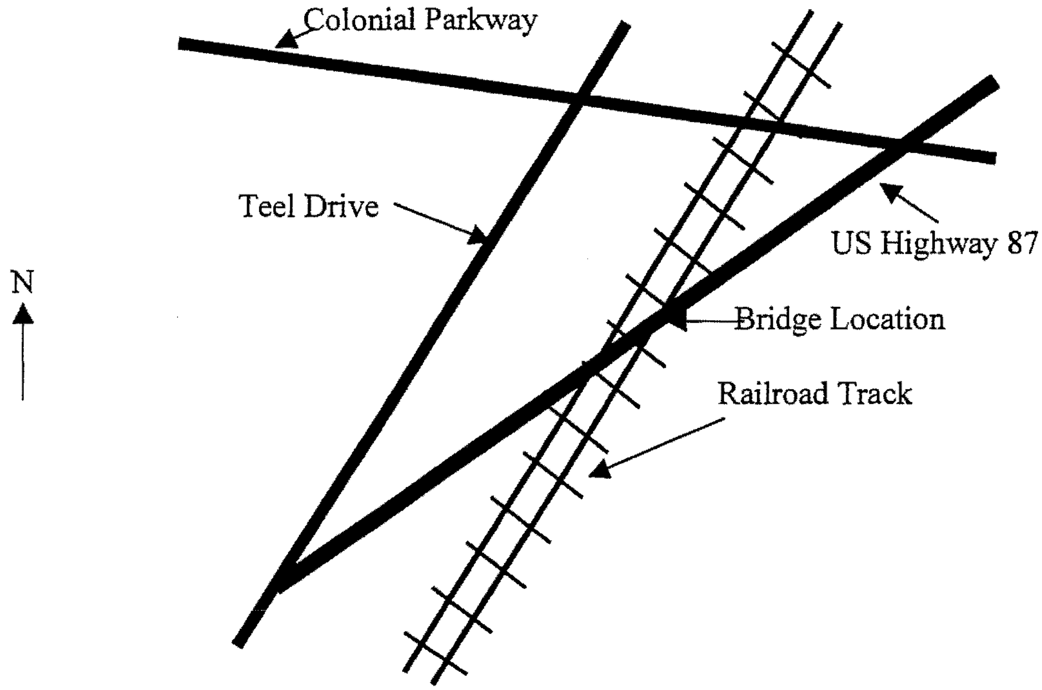



**Figure 5.1.** Schematic Drawing of the Test Project #1 Site Location

Laboratory Test Results: Laboratory test results for this project are presented in Tables 5.2 through 5.5.

**Table 5.2.** Sieve Analysis Test Results (% Retained)

| Sieve Size | Existing Subgrade | Existing Salvaged Base | Stockpile Mix with 15% Glass Cullet |
|---|---|---|---|
| 39.0 mm /1-3/4 in. | 2 | 0 | 0 |
| 22 mm / 7/8 in. | 6 | 3 | 0 |
| 9.5 mm / 3/8 in. | 14 | 12 | 30 |
| 4.75 mm / No. 4 | 21 | 19 | 53 |
| 0.40 mm / No. 40 | 35 | 33 | 83 |

**Table 5.3.** Atterburg Limits Test Results

| Material Type | Liquid Limit | Plastic Limit | Plasticity Index |
|---|---|---|---|
| Existing Subgrade | 25 | 14 | 11 |
| Existing Salvaged Base | 27 | 27 | 0 |
| Limestone Mix with 15% Glass Cullet | 23 | 13 | 10 |

**Table 5.4.** Compaction Ratio Data

| Material Type | Dry Density ($Mg/m^3$) | Optimum Moisture Content (%) |
|---|---|---|
| Existing Subgrade | 2.002 | 9.5 |
| Existing Salvaged Base | 1.978 | 10 |
| Limestone Mix with 15% Glass Cullet | 2.184 | 7.1 |

*1 $Mg/m^3$ = 62.4 $lb/ft^3$

**Table 5.5.** Triaxial Test Results

| Material Type | Failure Stress at '0 Kpa' Confining Pressure (kPa*) | Failure Stress at '103 kPa' Confining Pressure (kPa*) | Triaxial Classification |
|---|---|---|---|
| Existing Subgrade | 1282 | 4845 | 2.9 |
| Existing Salvaged Base | 1188 | 4275 | 3.6 |

1 kPa = 0.145 psi

Laboratory test results on constructed pavement base and surface after one year are shown in Table 5.6 & 5.7.

**Table 5.6.** Test Results of Constructed Pavement Base

| Sieve Analysis | | Compaction |
|---|---|---|
| Sieve Size* | % Retained | Dry Density** : 2.196 $Mg/m^3$<br>Optimum Moisture Content: 5.9% |
| 44.5 mm / 1-3/4 in. | 0 | |
| 22.4 mm / 7/8 in. | 1 | |
| 9.5 mm / 3/8 in. | 34 | |
| 4.75 mm / No. 4 | 57 | |
| 0.4 mm / No. 40 | 81 | |

*25.4 mm = 1 in.
**1 $Mg/m^3$ = 62.4 $lb./ft^3$

**Table 5.7.** Test Results of Constructed HMAC Pavement Surface

| Sample Location | Percent Air Voids | Core Density ($Mg/m^3$*) | Nuclear Density ($Mg/m^3$*) |
|---|---|---|---|
| Colonial Parkway: Between Indian Rd. and J.T. Moore Rd. | 18.8 | 1.916 | 2.174 |
| Colonial Parkway: Between J.T. Moore Rd. and Gutierrez Rd. | 18.4 | 1.927 | 2.248 |
| Colonial Parkway: Between Gutierrez Rd. and Oakridge Rd. | 16.7 | 1.967 | 2.288 |
| Teel Drive | 14.5 | 2.018 | 2.195 |

*1 $Mg/m^3$ = 62.4 pcf

Field Test Results: Test Results on Glass Base during the Compaction Operation is shown in Table 5.8.

**Table 5.8.** Nuclear Density and Moisture Field Test Results, 1996

| Highway | Station | Lab Density ($Mg/m^3$*) | Lab Moisture (percent) | Field Density ($Mg/m^3$*) | Field Moisture (percent) |
|---|---|---|---|---|---|
| Teel Drive | 21+00 | 2.181 | 7.1 | 2.284 | 3.7 |
| Teel Drive | 15+00 | 2.181 | 7.1 | 2.180 | 3.9 |
| Colonial Parkway | 12+00 | 2.181 | 7.1 | 2.283 | 3.1 |
| Colonial Parkway | 12+50 | 2.181 | 7.1 | 2.321 | 3.6 |

*1 $Mg/m^3$ = 62.4 pcf

Pavement ride quality measurements using TxDOT Profiler/Rut Bar equipment was performed in October of 1997. Results are shown in Table 5.9.

**Table 5.9.** Ride Score and International Roughness Index (IRI) values for Left Wheel Path (LWP) and Right Wheel Path (RWP) on Teel Drive and Colonial Parkway

| | Average Ride Score | | Average IRI | |
|---|---|---|---|---|
| | LWP | RWP | LWP | RWP |
| Teel Drive | 3.4 | 2.8 | 1.9 | 1.8 |
| Colonial Parkway | 2.8 | 2.8 | 2.9 | 2.0 |

Demonstration Project # 2

The test project was performed on Antilley road, a city street in front of Wiley High school (Figure 5.2). Glass cullet was mixed with crushed limestone at the job site to form the flexible base. Construction involved spreading 12 inches of crushed limestone followed by glass cullet (Figure 5.3). A pavement material recycler mixed the two materials on the pavement and then the blend was compacted (Figures 5.4 and 5.5). A 38-milimeter (1.5 inch) thick hot mix asphalt concrete surface layer was placed on top of the flexible base layer containing glass. The eastern section of the road used a 10 percent glass cullet while the western section used 15 percent. Each section is 275 meters (750 feet) long and 3.66 meters (12 feet wide) and both sections are along the eastbound outside lane. Conventional limestone base was used on the remaining four lanes.

This construction project used 218 megagrams (240 tons) of glass collected by the City of Abilene over a one-year period. Pine Street Salvage, a local salvage company, provided 75 percent of the glass while Dyess Air Force Base provided the remaining 25 percent. TxDOT collected and transported the glass from Pine Street Salvage to Dyess AFB where the glass was crushed into cullet.

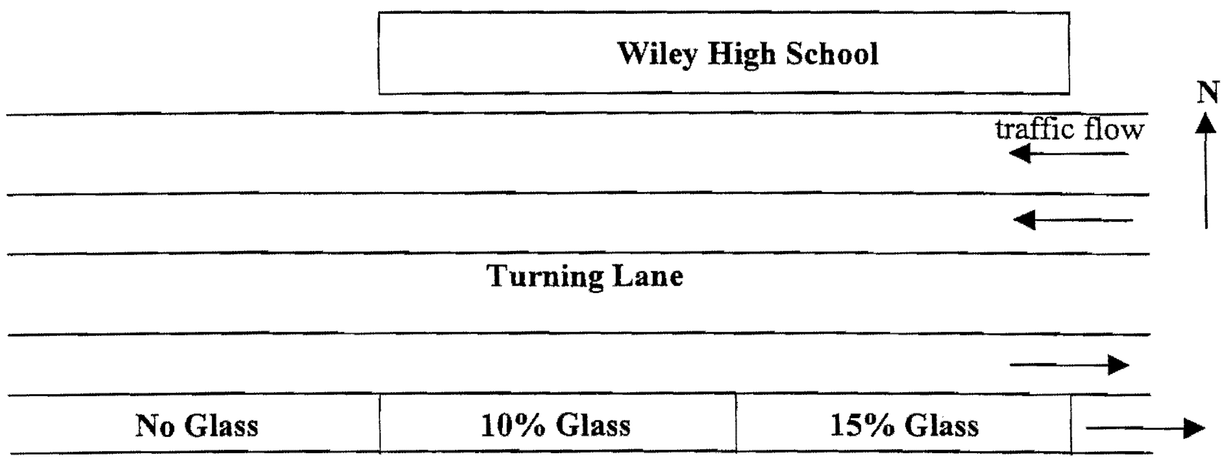



**Figure 5.2.** Schematic Drawing of the Test Project #2 Site Location

**Figure 5.3.** Dumping of Glass-Cullet by a Belly Dump Truck

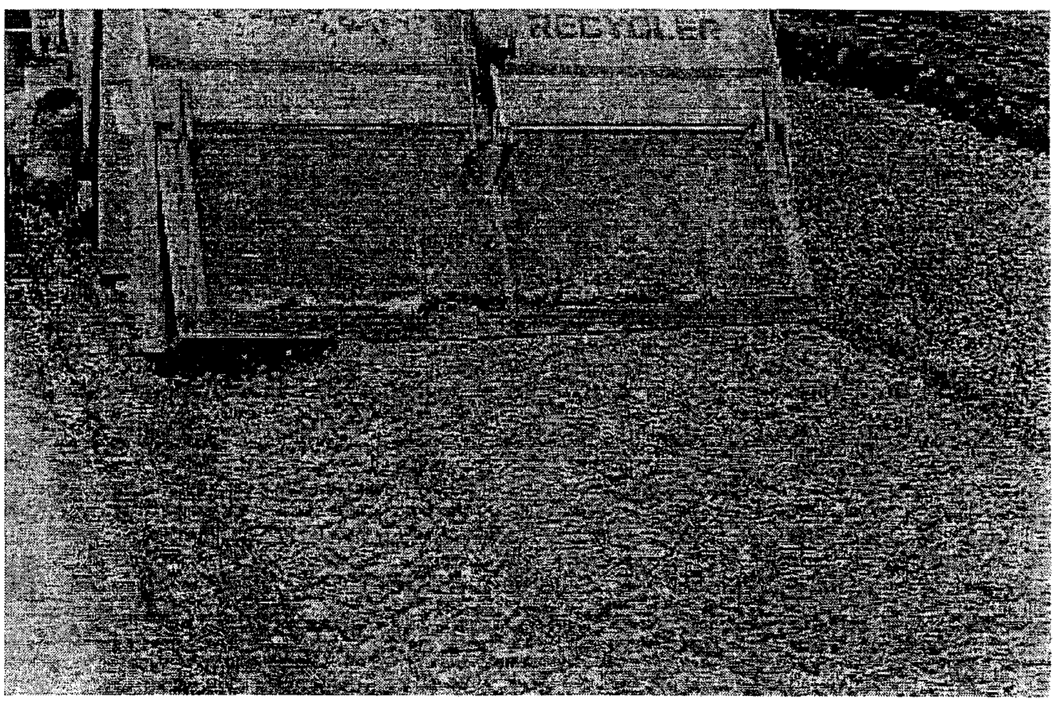


Figure 5.4. Mixing of Glass with Limestone

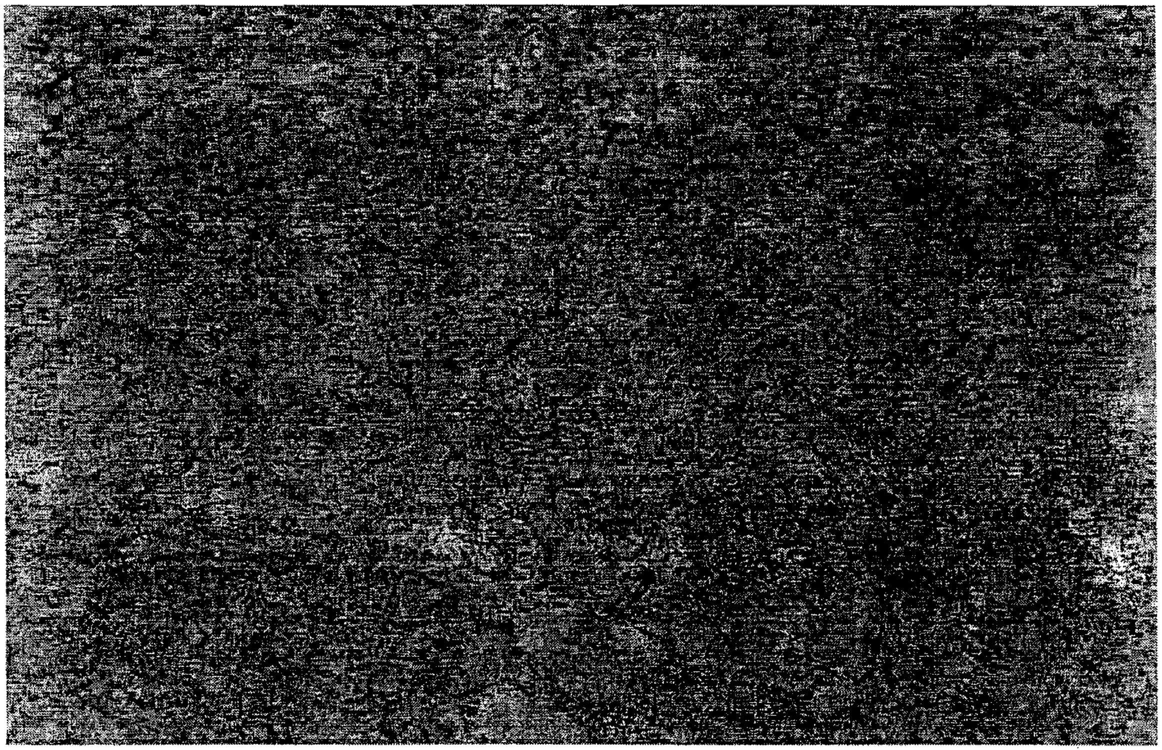


**Figure 5.5.** Compacted Limestone-Glass Base

Laboratory Test Results: Laboratory test results on limestone and limestone-glass base are presented in Table 5.10.

**Table 5.10.** Test Results on Limestone & Limestone-Glass Base

| Material Type | LL | PI | WBM Value & % Increase | Density & % Moisture | Sieve Analysis*: Sieve No & % Retained |
|---|---|---|---|---|---|
| Limestone | 22.2 | 7.1 | 19 & 13 % | 134.0 & 7.8 | 44.5 mm 0<br>25 mm 12<br>22 mm 17<br>12.5 mm 34<br>9.5 mm 39<br>4.75 mm 55<br>2.00 mm 68<br>0.4 mm 81 |
| Limestone with 10% Glass | 30.2 | 12.8 | 16 & 7 | 136.8 & 7.3 | 44.5 mm 0<br>24.5 mm 17<br>22 mm 21<br>12.5 mm 44<br>9.5 mm 53<br>4.75 mm 68<br>2.00 mm 74<br>0.4 mm 84 |
| Limestone with 15% Glass | 23.5 | 7.0 | 16 & 7 | 135.4 & 6.3 | 44.5 mm 0<br>24.5 mm 17<br>22 mm 21<br>12.5 mm 44<br>9.5 mm 53<br>4.75 mm 68<br>2.00 mm 74<br>0.4 mm 84 |

*25.4 mm = 1. in

Field Test Results: Falling Weight Deflectometer (FWD) testing was performed on limestone-glass flexible base section in April of 1999. Figure 5.6 shows FWD testing at the test section. A control (non-glass) section was also chosen to the east of 10% glass section for comparison with the glass-cullet sections. Results are shown in Figure 5.7.

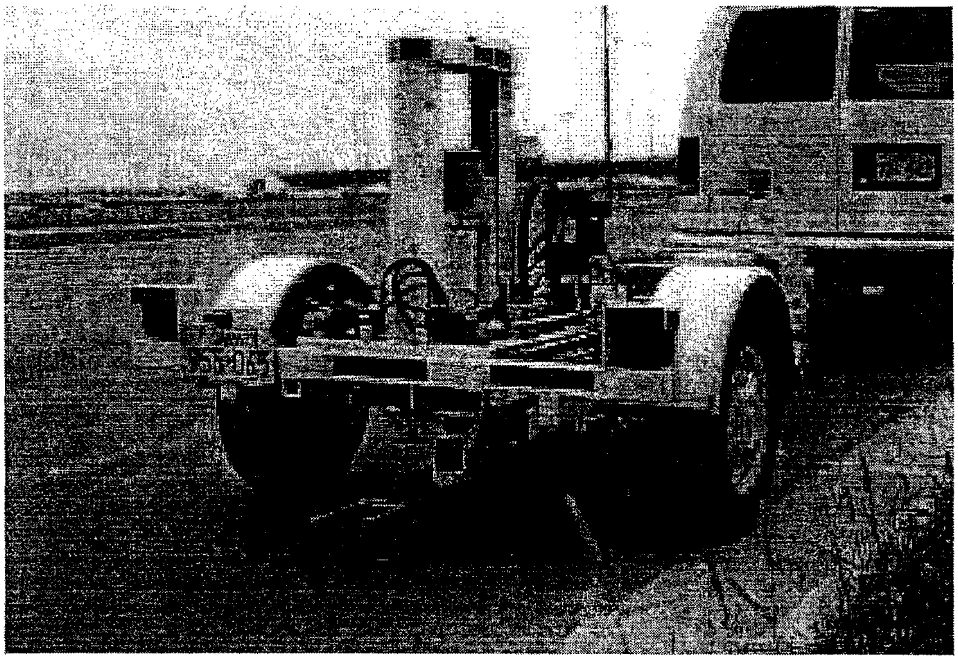


**Figure 5.6.** Falling Weight Deflectometer Testing on Antilley Road, 1999

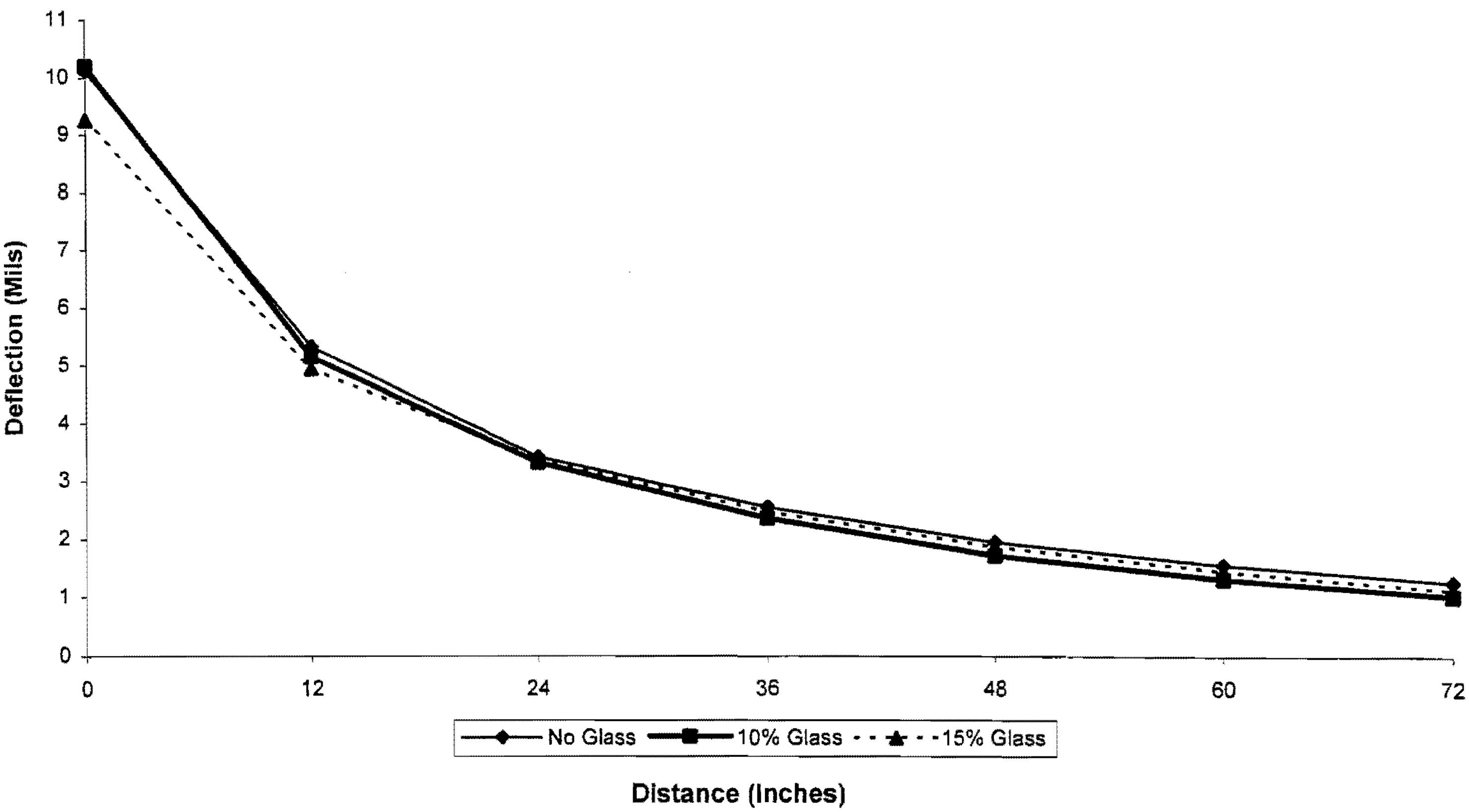



**Figure 5.7.** FWD Test Result on Antilley Road, 1999

Demonstration Project #3

The project site is located in Beaumont District at the intersection of SH 62 and FM 105 in Orange County, near the Orange County Airport. In this project, glass cullet was used as the bedding material around two culvert pipes.

**Results, Discussion & Findings**

Demonstration Project #1

The Texas Tech University research team made several visits to the Devine glass-cullet project. This test project showed premature alligator cracking. These two roads are residential streets. However, due to a train accident on US 87, a bridge was damaged and the resulting temporary closure of US 87 resulted in a significant increase of heavy truck traffic on the two streets. City officials estimated this increase in heavy traffic to be 3 to 4 times greater than the design traffic. Values in Table 5.9 indicate that the given pavements have ride qualities in the low to medium range after one year of service. The ride score is assigned to a pavement based on a scale of 1 to 5 with 5 indicating a pavement with perfect ride quality. These values indicate a rate of deterioration that can be typically rated as high. Based on what was observed in the field, this rapid deterioration was the result of unusually high levels of heavy vehicles on the road due to highway detours. Once US 87 was opened, the rate of deterioration on Colonial Parkway and North Teal Drive showed a significant decrease and the subsequent visits to the site as late as August of 1998 and June of 1999 showed that no further significant deterioration has taken place since then. These observations were supported by measurement of rutting using TxDOT rutbar profiler measurements. The reason for premature distress can possibly be attributed to unusually high heavy traffic. The FHWA also directed all states to report pavement roughness data by International Roughness Index (IRI) for all paved rural arterials and urban freeways and expressways, including Interstates, beginning in 1989. The IRI is an objective and consistent measure of pavement condition which was chosen as the FHWA Highway Planning and Monitoring System (HPMS) standard reference roughness index to provide more consistency between states. IRI values for these pavements are also shown in Table 5.9.

Demonstration Project #2

The glass-cullet project on Antilley Road, Abilene is performing well and no significant non-routine maintenance was required in these sections since it opened to traffic (Condry, 1999). FWD tests on these sections show no significant difference in structural integrity among no glass, 10% & 15% glass cullet sections (Figure 5.7).

Demonstration Project #3

Visual inspection of the culvert constructed using glass cullet indicates that the test project in Orange County is performing satisfactorily at this point.

**Specification**

## Glass Cullet: Devine Construction Project:

### TXDOT ITEM 247 GRADE 6 MATERIALS

The flexible base material shall be crushed limestone to meet the requirements herein and shall consist of durable coarse aggregate, glass cullet and binding materials.

**Physical Requirements**

Type D. Master Grading

| Sieve | % Retained |
|---|---|
| 19 mm / 3/4 in. | 0 |
| 15.9 mm / 5/8 in. | 0-15 |
| 9.5 mm / 3/8 in. | 15-40 |
| 4.75 mm / No. 4 | 35-65 |
| 0.4 mm / No. 40 | 70-90 |

Maximum Liquid Limit – 30
Maximum Plasticity Index – 12

Additives

20 percent by weight of glass cullet

Testing of flexible base materials shall be in accordance with the following standard laboratory test procedures:

| **Preparation for Soil** | |
|---|---|
| Constants and Sieve Analysis | THD Tex-101-E |
| Liquid Limit | THD Tex-104-E |
| Plastic Limit | THD Tex-105-E |
| Plasticity Index | THD Tex-106-E |
| Linear Shrinkage | THD Tex-107-E |
| Sieve Analysis | THD Tex-110-E |
| Los Angeles Abrasion | ASTM C 131– 66 (Grad. A) |

# Glass Cullet: Abilene and Beaumont Construction Projects

## TXDOT ITEM 132 EMBANKMENTS

### 132.2 Material.

Type E

This material shall consist of suitable recycled waste material such as crushed waste container glass cullet (referred to as glass cullet), which are free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use.

This material shall be suitable for forming a stable embankment and, when tested in accordance with Test Methods Tex-104-E, Tex-105-E, Tex-106-E, and Tex-107-E, Part II, and Tex-110-E shall meet the following requirements:

| | |
|---|---|
| The liquid limit shall not exceed | 45 |
| The plasticity index shall not exceed | 15 |
| The bar linear shrinkage shall not be less than | 2 |

The glass cullet material shall conform to the following gradings unless shown otherwise in plans.

| Sieve Size | Cumulative Percent Retained on Sieve |
|---|---|
| 15.9 mm / 5/8 in. | 0 |
| 9.5 mm / 3/8 in. | 0-10 |
| 4.75 mm / No. 4 | 30-50 |
| 2.00 mm / No. 10 | 50-75 |
| 0.4 mm / No. 40 | 80-90 |
| 7.5 μm mm / No. 200 | 90-100 |

Glass cullet may be used as an embankment material but only in combination with Type A, Type B, Type C or Type D embankment materials approved by the engineer. The maximum percentage of glass cullet in the embankment material mix shall not exceed 20 percent by weight of mix.

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as an embankment material shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

### 132.3 Construction Methods

General

Since all glass cullet material used in embankments shall not exceed 5/8 in. (15.9 cm), the material should be relatively safe to handle. However, precautions shall be taken for the safety of the construction personnel. When glass cullet is used in combination with other types of approved embankment materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

Embankment material containing glass cullet shall not be used on the surface of the embankment unless it is indicated in plans or without the approval of the engineer.

## TXDOT ITEM 247 FLEXIBLE BASE

### 247.2 Material.

Physical Requirements

*Type D:* Type D flexible base material shall be recycled waste material such as crushed waste container glass (glass cullet) used in combination with Type A, Type B or Type C flexible base materials. Glass cullet shall be free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use. Glass cullet shall only be used as flexible base in pavements that will be surfaced prior to opening for traffic.

The percentage of glass cullet used in Type D flexible base material shall not exceed 20 percent by weight of the total mix.

The glass cullet material shall conform to the following gradings unless shown otherwise in plans.

| Sieve Size | Cumulative Percent Retained on Sieve |
|---|---|
| 15.9 mm / 5/8 in. | 0 |
| 9.5 mm / 3/8 in. | 0-10 |
| 4.75 mm / No. 4 | 30-50 |
| 2.00 mm / No. 10 | 50-75 |
| 0.4 mm / No. 40 | 80-90 |
| 7.5 µm / No. 200 | 90-100 |

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as a flexible base material shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

*Type E* As shown on the plans.

## 247.3 Construction Methods

General

Precautions shall be taken for the safety of the construction personnel handling glass cullet. Glass cullet shall be mixed thoroughly with other approved sources of flexible base material until a uniform mix is achieved to the satisfaction of the engineer.

## TXDOT ITEM 301 ASPHALT ANTISTRIPPING AGENTS

### 301.2 Materials.

Liquid Antistripping Agent

When glass cullet is used as an aggregate in asphalt stabilized bases, lime and some liquid antistripping agents may not perform adequately. An antistripping agent such as a silane based compound may be used effectively in these instances.

## TXDOT ITEM 345 ASPHALT STABILIZED BASE (PLANT MIX)

### 345.2 Material.

Aggregate

*Description:* The aggregate shall be composed of one or more virgin (not previously used in construction) aggregates and/or reclaimed asphalt pavement (RAP). Samples of each aggregate shall be submitted for approval in accordance with Item 6, "Control of Materials".

Crushed waste container glass (glass cullet) may be used as a part of the virgin aggregate. The percent weight of glass cullet in the aggregate mix shall not exceed 5 percent of the total weight of the aggregate.

The glass cullet material shall conform to the following gradings unless shown otherwise in plans.

| Sieve Size | Cumulative Percent Retained on Sieve |
|---|---|
| 15.9 mm / 5/8 in. | 0 |
| 9.5 mm / 3/8 in. | 0-10 |
| 4.75 mm / No. 4 | 30-50 |
| 2.00 mm / No. 10 | 50-75 |
| 0.4 mm / No. 40 | 80-90 |
| 7.5 µm / No. 200 | 90-100 |

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as a flexible base material shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

Asphalt antistripping agents shall be used wherever glass cullet is used in asphalt stabilized base. These antistripping agents shall be in accordance with Item 301, "Asphalt Antistripping Agents".

## TXDOT ITEM 400 EXCAVATION AND BACKFILL FOR STRUCTURES

### 400.4 Shaping and Bedding

Waste material such as crushed waste container glass (glass cullet) may be used as utility bedding. Glass cullet used for utility bedding shall be free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use.

Utility bedding material may comprise of up to 100 percent of glass cullet material. The glass cullet material shall conform to the following gradings unless shown otherwise in plans.

| Sieve Size | Cumulative Percent Retained on Sieve |
|---|---|
| 15.9 mm / 5/8 in. | 0 |
| 9.5 mm / 3/8 in. | 0-10 |
| 4.75 mm / No. 4 | 30-50 |
| 2.00 mm / No. 10 | 50-75 |
| 0.4 mm / No. 40 | 80-90 |
| 7.5 μm / No. 200 | 90-100 |

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet when used as an utility bedding shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

Precautions shall be taken for the safety of the construction personnel handling glass cullet. When glass cullet is to be used in combination with other types of materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

### 400.5 Backfill.

General

Waste materials such as crushed waste container glass (glass cullet) may be used for many types of backfilling operations. Glass cullet used as backfill material shall be free from vegetation and other objectionable matter and reasonably free from lumps of earth. The glass cullet shall also be free of hazardous products and the contractor is responsible for furnishing the engineer with documentation certifying that the glass cullet complies with Class 3 industrial waste requirements in accordance with 30 TAC 335.507. The source shall be approved by the engineer prior to use.

The maximum allowable glass cullet content in backfill material shall be in accordance with the type of backfill. Backfill which will support any portion of the roadbed or embankment shall include a glass cullet content not more than 20 percent of the combined mix by weight. Backfill that does not support any portion of the roadbed or embankment may include a glass cullet content of up to 100 percent of the combined mix.

The glass cullet material shall conform to the following gradings unless shown otherwise in plans.

| Sieve Size | Cumulative Percent Retained on Sieve |
|---|---|
| 15.9 mm / 5/8 in. | 0 |
| 9.5 mm / 3/8 in. | 0-10 |
| 4.75 mm / No. 4 | 30-50 |
| 2.00 mm / No. 10 | 50-75 |
| 0.4 mm / No. 40 | 80-90 |
| 7.5 μm / No. 200 | 90-100 |

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as an embankment material may depend on the type of backfill. The debris level of glass cullet used in backfill which will support any portion of the roadbed or embankment shall not exceed 5 percent as estimated using the American Geological Institute Visual Method. The debris level of glass cullet used in backfill which does not support any portion of the roadbed or embankment shall not exceed 10 percent as estimated using the American Geological Institute Visual Method.

Since all glass cullet material used in embankments shall not exceed 15.9 mm (5/8 in.), the material should be relatively safe to handle. However, general precautions shall be taken for the safety of the construction personnel. When glass cullet is used in combination with other materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

Embankment material containing glass cullet shall not be used on the surface of the embankment unless it is indicated in plans or without the approval of the engineer.

Bridge Foundations, Retaining Walls, And Culverts.

Glass cullet may be used as backfill in retaining walls and culverts in combination with other backfill materials which are approved for 100 percent use as backfill. The percent of glass cullet used in different applications and the allowable debris level in glass cullet shall be based on the criteria indicated in 400.5.1 above.

Pipe

Glass cullet may be used as backfill in pipeline applications in combination with other backfill materials which are approved for 100 percent use as backfill. The percent of glass cullet used in different applications and the allowable debris level in glass cullet shall be based on the criteria indicated in 400.5.1 above.

## TXDOT ITEM 423 RETAINING WALL

### 423.2 Material

Backfill Material

Backfill for spread footing retaining walls shall be in accordance with Item 132, "Embankment", Types B or D, unless otherwise shown on the plans.

Backfill for MSE walls may include crushed waste container glass (glass cullet) except when cement stabilized backfill material is used. The backfill material shall be free from organic or otherwise deleterious materials, and shall conform to the following grading limits as determined by Test Method Tex-110-E.

The use of glass cullet as a structural backfill shall be limited to a maximum of 20 percent of the total backfill material, by weight. In non-structural backfill applications, up to 100 percent of glass cullet may be used.

The glass cullet material shall conform to the following gradations unless shown otherwise in plans.

| Sieve Size | Cumulative Percent Retained on Sieve |
|---|---|
| 15.9 mm / 5/8 in. | 0 |
| 9.5 mm / 3/8 in. | 0-10 |
| 4.75 mm / No. 4 | 30-50 |
| 2.00 mm / No. 10 | 50-75 |
| 0.4 mm / No. 40 | 80-90 |
| 7.5 μm / No. 200 | 90-100 |

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as backfill may depend on the type of retaining wall backfill. The debris level of glass cullet used in structural retaining wall backfill shall not exceed 5 percent as estimated using the American Geological Institute Visual Method. The debris level of glass cullet used in non-structural retaining wall backfill shall not exceed 10 percent as estimated using the American Geological Institute Visual Method.

Since all glass cullet material used in embankments shall not exceed 15.9 mm (5/8 in.), the material should be relatively safe to handle. However, general precautions shall be taken for the safety of the construction personnel. When glass cullet is used in combination with other materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

Embankment material containing glass cullet shall not be used on the surface of the embankment unless it is indicated in plans or without the approval of the engineer.

## TXDOT ITEM 556 PIPE UNDERDRAINS

### 556.2 Material.

Filter Material

Filter material for use in backfilling trenches under, around and over underdrains shall consist of hard, durable, clean sand, gravel, crushed stone, crushed shell, crushed waste container glass (glass cullet) or other materials specified on the plans and shall be free from organic matter, clay balls or other deleterious matter. Unless other wise shown in the plans, crushed limestone will not be permitted.

Up to 100 percent of glass cullet may be used as a filter material in pipe underdrains. The glass cullet material shall conform to the following gradations unless shown otherwise in plans.

| Sieve Size | Cumulative Percent Retained on Sieve |
|---|---|
| 16 mm / 5/8 in. | 0 |
| 9.5 mm / 3/8 in. | 0-10 |
| 4.75 mm / No. 4 | 30-50 |
| 2.00 mm / No. 10 | 50-75 |
| 0.40 mm / No. 40 | 80-90 |
| 7.5 μm / No. 200 | 90-100 |

A certain amount of debris is allowed in the glass cullet. Such debris may include pieces of paper labels, plastic caps, metal caps and cork. The level of debris allowed in glass cullet used as a filter material in pipe underdrains shall not exceed 5 percent as estimated using the American Geological Institute Visual Method.

### 556.3 Construction Methods

Precautions shall be taken for the safety of the construction personnel handling glass cullet. When glass cullet is to be used in combination with other types of materials, they shall be mixed thoroughly until a uniform mix is achieved to the satisfaction of the engineer.

## OTHER RECOMMENDED USES: OPEN GRADED BASE COURSE

### Material

Crushed waste container glass may be used as aggregate in open graded drainable base courses. The use of glass cullet in this application shall be governed by Item 345, "Asphalt Stabilized Base". It is recommended that glass cullet shall be used in combination with other approved granular base material. The percent glass cullet in such mixes shall not exceed 5 percent of the total aggregate by weight.

The master grading limits to be used in the open graded base course shall be as follows.

| Sieve Size | Cumulative Percent Passing |
|---|---|
| 37.5 mm / 1.5 in. | 100 |
| 25 mm / 1.0 in. | 95-100 |
| 12.5 mm / 1/2 in. | 25-60 |
| 4.75 mm / No. 4 | 0-10 |
| 2.5 mm / No. 8 | 0-5 |

**Contact Persons**

Demonstration Project #1

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| Roger L. Engelke, P. E. | Garcia & Wright Consulting Engg, Inc., 407 W.Rhapsody, San Antonio, TX - 78216 | Phone: (210) 349-5253 |
| Irv Dukatg | Vulcan Materials | Phone: (210) 349-3311 |
| Marshall Davis | City of Devine | Phone: (830) 663-2804 |
| Edward Hampson | TxDOT, San Antonio, TX -78284-3601 | Phone: (210) 615-6042 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

Demonstration Project #2

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| Blair W. Haynie, P. E. | TxDOT, Abilene District, TX – 79604-0150 | Phone: (915) 673-3761 |
| Jearldene T. Anderson | TxDOT, Abilene District, TX – 79604-0150 | Phone: (915) 676- 6892<br>Fax: (915) 676-6903 |
| James Ray Condry | City of Abilene, Abilene, TX-79604-0060 | Phone: (915) 676- 6489<br>Fax: (915) 676-6460 |
| Bill Brock | City of Abilene, Abilene, TX-79604-0060 | Phone: (915) 676- 6058 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

Demonstration Project # 3

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| Walter O. Crook, P. E. | TxDOT, Beaumont District, TX – 77708 | Phone: (409) 898-5731 |

# CHAPTER 6: ROOFING SHINGLES

## About the Material

Each year, roofing manufacturers produce approximately 0.9 million megagrams (1 million tons) of new waste roofing shingles and shingle trimmings (post-industrial) in the United States of America (TxDOT, 1997). In addition, residential and commercial roofing replacement activities generate 7.25 to 9 million megagrams (8 to 10 million tons) of old roofing waste (post-consumer). More than 450 million megagrams (500 million tons) of asphalt concrete is produced annually in the U.S., from which approximately 90% of which is hot mix asphalt. Using approximately 2% roofing shingle waste in all asphalt mixtures would consume all post-industrial and post-consumer roofing shingles generated each year.

Roofing shingles are black in color with a specific gravity of approximately 2.6. They are typically comprised of approximately 35% asphalt, 45% sand, and 20% percent mineral filler (Newcomb et. al, 1993).

Waste shingles must be reduced in size prior to being introduced into the mix. A schematic diagram of a two-stage shredding system is shown in Figure 6.1. This system consists of a primary feeder that delivers shingles into a large horizontal shaft impactor that is the primary crusher. The primary crusher shreds the shingles down to about 50 mm (2 in.). As the shingles are moved up a belt conveyer, a belt magnet removes any nails from the materials. It then passes under a suction device that removes lightweight contaminants such as paper, dust, and airborne particles. The shredded 50 mm shingles are then fed onto an incline vibrating screen through which the minus 50 mm material can pass. The over-sized material is fed back to the primary crusher and the minus 50 mm material is fed onto a belt conveyor that leads to a secondary horizontal shaft impactor. This machine is designed with breakers and operates at high speed, leading to a reduction of the product to less than 12.5 mm (1/2 in.). The material discharged from this secondary impactor drops onto the belt and back to the screening unit. Material discharged from the screening unit is then fed onto a conveyor leading to a surge hopper, which is automatically controlled by a blending system. In this blending system, the shredded shingles are conveyed to a pugmill and mixed with sand or screenings, and then fed to a radial stacker for stockpiling (NAPA, 1997).

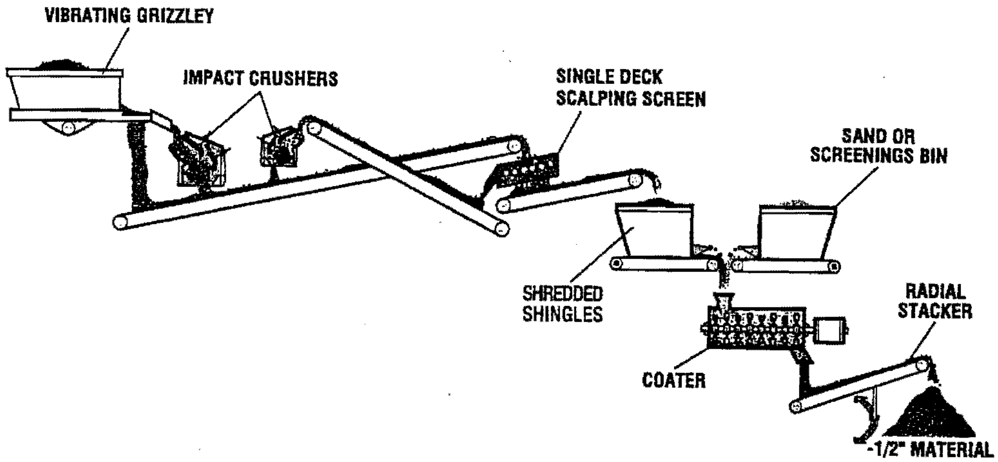



**Figure 6.1.** The Two-Stage Shingle Shredding System (NAPA 1997).

**Demonstration Project**

In 1997, test sections were constructed by the Texas Department of Transportation using both post-consumer and post-industrial shingles in hot mix asphalt concrete surface. In addition, a control section was also constructed in order to monitor any significant deviation in performance from the conventional highway surface.

The project site is located on WB SH 31 in Corsicana, Navarro County, Dallas District. It is a divided two-lane highway with a lane width of 3.66 m (12 ft.). Both post-consumer and post-industrial roofing shingles were used in the HMAC surface. The reference marker locations for the sections and test section plan are shown in Table 6.1 and Figure 6.2 respectively. The estimated average daily traffic in 1995 was between 4500 to 4700. Construction began on May 1, 1997 and ended on May 4, 1997. The average temperature during construction was 29° C (85° F) and a trace of rain was observed the night of May 5, 1997.

**Table 6.1.** Texas Reference Marker (TRM) Location of Test Project

| Section | Begin | End |
|---|---|---|
| Section 1 | 616 – 0.36 mile | 616 – 0.55 mile |
| Section 2 | 616 – 1.31 mile | 616 – 1.50 mile |
| Control | 616 – 0.55 mile | 616 – 1.31 mile |

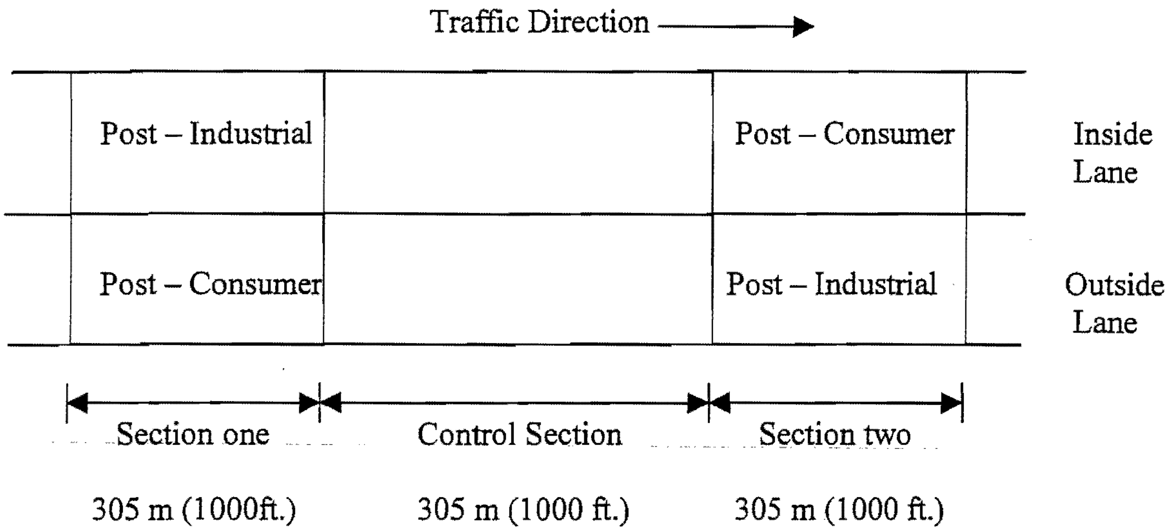



**Figure 6.2.** Test Section Plan

Sources: The supplier of roofing shingles was Thelin Recycling Company, 651 E. Highland Southlake, TX- 76092. The amount of material supplied by this facility for this project was a total of 45.8 $m^3$ (60 CY). The sources of origin for the shingles were Owens-Corning Manufacturing Inc. for the post-industrial shingles, and post consumer tear-offs.

Cost Information: Roofing shingles for this project cost \$13/$m^3$ (\$10/CY) from Thelin. The disposal cost at landfills can range from \$33/megagram (\$30/ton) to \$61/megagram (\$55/ton). Based on a unit weight of 1070 kg/$m^3$ (1800 lb./CY), roofing shingles cost \$12/megagram (\$11/ton).

Construction Techniques: The roofing shingles were stockpiled prior to construction then fed through the RAP opening in the mixing plant. Then, hot mix was hauled to the roadway where it was paved, compacted and opened to traffic as normal. The temperature was 14° C (25° F) higher than for conventional hot mix asphalt mixing (Dave Kosse, 1998). The shingles completely melted and dispersed uniformly in the HMA. No rejuvenating oil was needed to soften relatively hard roofing shingles. Figure 6.3. shows part of construction activity and Figure 6.4. shows the compacted pavement surface with shingles.

**Figure 6.3.** Photograph of Construction Activity on WB SH 31, Corsicana

**Figure 6.4.** Compacted Final Pavement Surface with Roofing Shingles

Laboratory Test Results for Asphalt Mix Constituents: Laboratory test results on roofing shingles used in the demonstration project are furnished in Tables 6.2 through 6.7. The mix designs for test sections containing roofing shingles (both post-consumer and post-industrial) were performed according to TxDOT Standard Specification Item 340. The control section mix design was based on the TxDOT Special Specification Item 3001 for QC/QA mixes.

**Table 6.2.** Constituents of Roofing Shingles used in Corsicana Test Project

| | Post-Consumer | Post-Industrial |
|---|---|---|
| Asphalt Cement | 25.1 | 22.3 |
| Mineral Filler (%) | 39.2 | 50.1 |
| Viscosity of Asphalt @ 60°C (Poise) | 37785 | 12234 |
| Penetration @ 25°C (0.1 mm) | 24 | 37 |

*°F = 5/9(°C) + 32

**Table 6.3.** Gradation of Roofing Shingle Constituents (Retained on Sieve)

| Shingle Type | 22mm | 16mm | 9.5mm | 4.75 mm | 2 mm | 0.45mm | 7.5µm | Pan |
|---|---|---|---|---|---|---|---|---|
| Post- Consumer | 0.0 | 0.0 | 2.1 | 2.9 | 2.9 | 43.4 | 9.5 | 39.2 |
| Post- Industrial | 0.0 | 0.0 | 1.4 | 0.8 | 1.1 | 35.3 | 11.3 | 50.1 |

*25.4 mm = 1 in.

**Table 6.4.** Aggregates Used in Mix

| Section Type | Smith/Bullard Type C (%) | Smith/Bullard Type D (%) | Smith/Bullard Screenings (%) | Trinity Field Sand (%) | Shingles (%) |
|---|---|---|---|---|---|
| Post- Consumer | 21 | 39 | 29 | 6 | 5 |
| Post- Industrial | 21 | 39 | 29 | 6 | 5 |
| Control | 22 | 39 | 33 | 6 | 0 |

**Table 6.5.** Gradation of Mix Design (Cumulative Pass)

| Section Type | 25mm | 22mm | 16mm | 9.5mm | 4.75mm | 2mm | 0.45mm | 7.5µm | Pan |
|---|---|---|---|---|---|---|---|---|---|
| Post- Consumer | 100.0 | 100.0 | 98.8 | 76.5 | 50.4 | 33.8 | 19.8 | 8.1 | 3.7 |
| Post- Industrial | 100.0 | 100.0 | 98.8 | 76.5 | 50.5 | 34.0 | 20.5 | 8.6 | 4.0 |
| Control | 100.0 | 100.0 | 99.5 | 74.0 | 46.5 | 31.9 | 20.6 | 12.7 | 6.3 |

*25.4mm. = 1in.

**Table 6.6.** Asphalt Contribution in Mix Design

| Mix Type | From Shingles | Virgin Asphalt Used |
|---|---|---|
| With Post-Consumer Shingles | 1.3 | 3.6 |
| With Post- Industrial Shingles | 1.1 | 3.4 |
| Control | 0.0 | 4.6 |

**Table 6.7.** Anti-Stripping Agent used in Test Sections

| Test Section | Name | Percent Used | Percent Stripping | Recommended Anti-Strip (%) |
|---|---|---|---|---|
| Post-Consumer | Perma Tac Reg. | 1.0% | 0.0% | 1.0% |
| Post-Industrial | Perma Tac Reg. | 1.0% | 0.0% | 1.0% |
| Control | Perma Tac Reg. | 1.0% | 0.0% | 1.0% |

Laboratory Test Results for Asphalt Mix at 96% Optimum Density: The asphalt concrete mix was tested for Hveem stability, Moisture susceptibility, Static creep and Voids in Mineral Aggregate (VMA). Results from these are given in Tables 6.9 through 6.11 below.

**Table 6.8.** Stability Values of Asphalt Mix

| | Post Consumer | Post Industrial | Control |
|---|---|---|---|
| Hveem Stability | 47 | 46 | 48 |

**Table 6.9.** Results from Moisture Susceptibility Tests

| | Post-Consumer | Post-Industrial | Control |
|---|---|---|---|
| Standard Test | Tex-530-C | Tex-530-C | Tex-530-C |
| TxDOT Specification | 10% (Max) | 10% (Max) | 10% (Max) |
| Test Result | 0% | 0% | 0% |

**Table 6.10.** Results from TxDOT Static Creep Tests

| | Post-Consumer | Post-Industrial |
|---|---|---|
| Creep Stiffness (MPa*) | 5.84 | 5.96 |
| Permanent strain x 1000 (mm/mm) | 0.51 | 0.47 |
| Slope of SS Curve x 100,000,000 (mm/mm/sec.) | 6.2 | 6.2 |

*1MPa = 0.1451 ksi

**Table 6.11.** Voids in Mineral Aggregate (VMA) Values Calculated from Laboratory Results

| Post-Consumer | Post-Industrial | Control |
|---|---|---|
| 15.3 | 14.5 | 15 |

Field Monitoring Test Results: Field test results are furnished in Table 6.12 and Table 6.13.

**Table 6.12:** International Roughness Index (IRI) and Ride Score for the Test Section

| Section | International Roughness Index (IRI) | | Ride Score |
|---|---|---|---|
| | Left | Right | |
| Post Consumer (Outside Lane) | 1.78 | 1.56 | 3.6 |
| Control (Outside Lane) | 1.68 | 1.91 | 3.4 |
| Post Industrial(Outside Lane) | 1.40 | 1.74 | 3.7 |
| Post Consumer (Inside Lane) | 1.73 | 1.96 | 3.4 |
| Control (Inside Lane) | 1.72 | 1.82 | 3.5 |
| Post Industrial (Inside Lane) | 1.64 | 1.82 | 3.5 |

**Table 6.13.** Skid Numbers (SN) in Different Sections and Expected Time Period before SN = 32

| Section | SN (1998) | SN (1999) | Expected Time Period (Years) |
|---|---|---|---|
| Post-Consumer | 57 | 42 | 1.4 |
| Post-Industrial | 56 | 42 | 1.4 |
| Control | 52 | 42 | 1.7 |

**Results, Findings & Discussion**

As shown in Table 6.2, post-consumer shingles contained stiffer asphalt cement, thus showing its aging effects. Post-consumer shingles also contained a higher percentage of asphalt showing a different composition than the newer shingles. The test project shows that the additional binder content in post-consumer shingles may not directly translate to an equal reduction in the quantity of new binder needed for the mix, particularly due to the higher stiffness of the asphalt cement in post-consumer shingles. However, laboratory mix designs showed a higher binder contribution from the post-consumer shingles as shown in Table 6.6. The aggregate filler in post-consumer shingles was a little coarser than in post-industrial shingles. Both gradations were well within the fine-aggregate gradation bands of asphalt concrete (Table 6.3). Hveem stability values from laboratory mix designs show that mixes with shingles did not show any significant change in the stability (strength) of the mix and they were well above the TxDOT recommended minimum value of 35. In addition, the boil test (Tex-530-C) to determine the stripping susceptibility of the mix showed that all three mixes (post-consumer, post-industrial and control showed no stripping. Creep tests were conducted on the mix even though creep tests were not required under the Item 340 specification used in the test project construction. Results from creep tests showed that

TxDOT QC/QA requirements were met for creep stiffness and permanent strain. However, the creep slope of the hot mix asphalt containing shingles showed values higher than the maximum creep slope limits specified in the QC/QA specification.

Roofing shingles appear to require more asphalt than anticipated, particularly with post-consumer shingles. The roofing felt used in the shingles raised up on the surface of the mix after the initial pass of the rollers. This was a concern at first but there was no difference in appearance compared to regular mix once the mix cooled and the section was opened to traffic. (Myers, 1998).

Roofing shingles do not "clump" in stockpile as feared. Shingles are quite heavy (about 3035 $kg/m^3$, 1800 lb./CY), and therefore, transportation cost can be an important decision factor (Milner, 1998).

Post-consumer shingles seemed harder to handle than post-industrial shingles. Shingles have a thin polyethylene film in them and with post-consumer shingles, some of the pieces of the polyethylene film were released into the air from the conveyor belt that was feeding them into the hot mix drum. This was a minor inconvenience that could be easily avoided and involved a small amount of additional cleaning of the mixing plant site. Experience, particularly with post-consumer shingles, indicates that a higher mixing temperature is needed to get proper coating of the material. Asphalt concrete with post-consumer shingles seemed too tender to roll and felt material came through the mat creating a soft area or a hole which appeared to be a drier hot mix than the recycled new shingles. However, this did not create a problem because once the section was cooled and opened for traffic, there was no apparent softness on the paved surface (Kosse, 1998).

The performances of the test sections containing roofing shingles appear to be comparable to conventional mixes. So far, no major distresses have been reported although some reflective cracking have been observed after 2 years. According to the TxDOT Area Engineer, the age at which reflective cracking has begun to show does not appear to be significantly different from the conventional mixes. To evaluate the structural integrity of the pavement, Falling Weight Deflectometer tests were performed in the summers of 1998 and 1999 and the results were analyzed (Figures 6.5 through 6.12). Pavement sections with roofing shingles did not show significantly different levels of structural integrity from the control mix. Figure 6.13 shows the decreasing trend of skid resistance over time. After 483,000 traffic application, the skid number shows values over 40, which is well above the Skid Number required by TxDOT. At this rate of polishing a skid of 32 will be reached after 1.4, 1.4 and 1.7 years for post-consumer, post-industrial and control section, respectively, on the outside lane (Table 6.13). In a real situation, this rate decreases with time and flattens out after some period of time. Visual surveys of the test section did not reveal any major distresses. Roughness measurements taken using TxDOT Rutbar/Profiler did not show significantly different values for the ride score as well as the International Roughness Index (IRI).

**Specification**

**SPECIAL SPECIFICATION ITEM 3028 FOR HMAC**

**Description**

The Item shall govern for the construction of a base course, a level-up course, a surface course or any combination of these courses as shown on the plans, each course being composed of a compacted mixture of aggregate, asphalt, and reclaimed asphalt shingles (RAS) mixed hot in a mixing plant, in accordance with the details shown on the plans and the requirements herein.

**Materials**

The Contractor shall furnish materials to the project meeting the following requirements prior to mixing. Additional test requirements affecting the quality of individual materials or the paving mixture shall be required when indicated on the plans.

Aggregate

The aggregate shall be composed of a coarse aggregate, a fine aggregate, and if required or allowed, a mineral filler and shall include RAS. Samples of each aggregate shall be submitted for approval in accordance with Item 6, "Control of Material."

Aggregate from each stockpile shall meet the quality requirements of Table 1 and other requirements as specified herein. The aggregate contained in RAS will not be required to meet Table 1 requirements except as shown on the plans.

*Coarse Aggregate:* Coarse aggregate is defined as that part of the aggregate retained on a 2.00 millimeter (No. 10) sieve. The aggregate shall be natural, and be of uniform quality throughout. When specified on the plans, certain coarse aggregate material may be allowed, required or prohibited.

Gravel from each source shall be so crushed as to have a minimum of 85 percent of the particles retained on the 4.75 millimeter (No. 4) sieve with two or more mechanically induced crushed faces, as determined by Test Method Tex-460-A (Part I). The material passing the 4.75 millimeter (No. 4) sieve and retained on the 2.00 millimeter (No. 10) sieve must be the product of crushing aggregate that was originally retained on the 4.75 millimeter (No. 4) sieve.

The polish value of the virgin (not previously used in construction) coarse aggregate used in the surface or finish coarse shall not be less than the value shown on the plans, when tested in accordance with the Test Method Tex-438-A. Unless otherwise shown on the plans, the polish value requirement will apply only to aggregate used on travel lanes. For rated sources, the Materials and Tests Division's Rated Source Polish Value (RSPV) catalog will be used to determine polish value compliance.

*Reclaimed Asphalt Shingles (RAS):* RAS may consist of manufacturing waste or consumer waste. Manufacturing waste (MW) shingles are defined as new material that is obtained from a roofing shingle production plant. The shingles used in a particular mixture shall be from one factory source, and shingles from one factory source shall not be mixed together. In addition, manufacturing waste shingles used in a particular mixture shall have a consistent binder content and aggregate gradation. Manufacturing waste shingles containing different aggregate types and gradations and different binder contents and viscosities shall not be mixed together. Consumer waste (CW) shingles are those obtained during the removal of existing roofs (Tear-offs).

The source of the RAS shall be preapproved before they may be used in HMA. The RAS supplier shall certify that the shingles contain no harmful quantities of asbestos in accordance with the guidelines provided by the Environmental Protection Agency. The addition of RAS to HMA is very similar to the addition of reclaimed asphalt pavement (RAP) to the same mixture.

RAS shall have an asphalt content of 15 to 25% by mass of shingle. The gradation of the aggregate in the RAS shall be such that 100% passes the 4.75 mm (No.4) sieve and a maximum of 40% passes the 75 μm (No. 200) sieve. The RAS shall be preprocessed by the contractor so that 100% of the shingle particles pass the 19 mm (3/4 in.) sieve and 95% of the shingle particles pass the 12.5 mm sieve.

RAS can be stockpiled in one of two forms: (1) whole and/or partial shingles which have not yet been reduced in size or (2) shingles which have been shredded to meet the maximum size requirements stated above. Stockpiled RAS shall not be contaminated by dirt or other objectionable materials. Unless otherwise shown on plans, stockpiled RAS shall have either a decantation of 5% or less or a plasticity index of 8 or less when tested in accordance with test method Tex-406-A, Part I, or test method Tex-106-E, respectively. This requirement applies to stockpiled RAS from which the asphalt has not been removed by extraction. Shredded shingles may be blended with a known quantity fine aggregate and stockpiled. Blending with aggregate may be necessary when it is desirable to stockpile shredded manufacturing waste to avoid conglomeration of the sticky shingle particles. Manufacturing waste shingles and consumer waste shingles shall be in separate stockpiles.

The polish value of the aggregate in the RAS will not be used in any determination of polish value specification compliance. Any contractor-owned RAS that is to be used on the project shall remain the property of the contractor, while stockpiled. Any unused contractor-owned RAS shall be removed from the project site upon completion of the project.

*Fine Aggregate*: The fine aggregate is defined as that part of the aggregate passing the 2.00 millimeter sieve (No. 10) and shall be of uniform quality throughout. When specified on the plans, certain fine aggregate material may be allowed, required or prohibited. However, a maximum of 15 percent of the total virgin aggregate may be field sand or other uncrushed fine aggregate.

Screenings shall be supplied from sources whose coarse aggregate meets the Los Angeles abrasion and magnesium sulfate soundness loss requirements shown in the Table 1, unless otherwise shown on the plans.

Unless otherwise shown on the plans, stone Screenings are required and shall be the result of a rock crushing operation and meet the following gradation requirements, when tested in accordance with Test Method Tex-200-F, Part I.

| | **Percent by Mass** |
|---|---|
| Passing the 9.5 mm (3/8 in.) sieve | 100 |
| Passing the 2.00 mm (No. 10) sieve | 70 - 100 |
| Passing the 75 µm (No. 200) sieve | 0 – 15 |

Crushed gravel Screenings may be used with, or in lieu of, stone screenings when shown on the plans. Crushed gravel screenings must be the product of crushing aggregates that was originally retained on the 4.75 millimeter (No. 4) sieve and meet the gradation for stone screenings shown above.

*Mineral Filler:* Mineral filler shall consist of thoroughly dried stone dust, portland cement, lime, fly ash, or other mineral dust approved by the engineer. The mineral filler shall be free from foreign matter.

When a specific type of mineral filler is specified on the plans, fines collected by the baghouse or other air cleaning or dust collecting equipment shall not be used to meet this requirement. When mineral filler is not specifically required, the addition of baghouse or other collected fines will be permitted if the mixture quality is not adversely affected in the opinion of the engineer. In no case shall be amount of the material passing the 75 µm (No. 200) sieve exceed the tolerances of the job-mix formula or the master grading limits.

When mineral filler is specified or allowed by the Engineer, or baghouse fines are permitted to be added to the mixture, it shall be proportioned into the mix by a vane meter or an equivalent measuring device acceptable to the engineer. A hopper or other acceptable storage system shall be required to maintain a constant supply of mineral filler to the measuring device.

The measuring device for adding mineral filler shall be tied into the automatic plant controls so that the supply of mineral filler will be automatically adjusted to plant production and provide a consistent percentage to the mixture. When shown on the plans, the measuring device for adding baghouse fines shall have controls in the plant control room which will allow manual adjustment of feed rates to match plant production rate adjustments.

**Table 6.14.** Aggregate Quality Requirements*

| Requirement | Test Method | Manufactured or Natural Aggregate | Lightweight Aggregate |
|---|---|---|---|
| **COARSE AGGREGATE** | | | |
| Dry Loose Unit Weight, $kg/m^3$** minimum | Tex-404-A | - | 560 |
| Pressure Slaking Value, maximum | Tex-431-A | - | 4.0 |
| Freeze Thaw Loss, percent, max | Tex-432-A | - | 7.0 |
| 24 Hour water Absorption, percent, maximum | Tex-433-A | - | 12.0 |
| Deleterious Material, percent, maximum | Tex-217-F Part I | 1.5 | 1.5 |
| Decantation, percent, maximum | Tex-217-F Part II | 1.5 | 1.5 |
| Los Angeles Abrasion, percent, maximum | Tex-410-A | 40 | 35 |
| Magnesium Sulfate Soundness Loss, 5 cycle, percent, maximum | Tex-411-A | 30*** | - |
| **FINE AGGREGATE** | | | |
| Linear Shrinkage, maximum | Tex-107-E Part II | 3 | 3 |
| **COMBINED AGGREGATES******** | | | |
| Sand equivalent value, Minimum | Tex-203-F | 45 | 45 |

* Sampled during delivery to the plant or from the stockpile, unless otherwise shown on the plans.
** $1 kg/m^3 = 0.0624 lb./ft^3$
*** Unless otherwise shown on the plans.
**** Aggregates, without added mineral filler, RAP, or additives, combined as used in the job-mix formula.

When tested in accordance with Test Method Tex-200-F (Part I or Part III, as applicable), the mineral filler shall meet the following gradation requirements, unless otherwise shown on the plans. Baghouse fines are not required to meet the gradation requirements.

Percent by Mass or Volume

Passing the 600 µm (No. 30) sieve...................................95 – 100
Passing the 180 µm (No. 100) sieve, not less than ....................75
Passing the 75 µm (No. 200) sieve, not less than ..................... 55

Asphaltic Material

*Paving Mixture:* Asphalt cement for the paving mixture shall be of the grade shown on the plans or designed by the engineer and shall meet the requirements of Item 300, "Asphalts, Oils and Emulsions." The contractor shall notify the Engineer of the source of the asphaltic material prior to design of the asphaltic mixture. This source shall not be changed during the course of the project without the authorization of the engineer. Should the source of asphaltic material be changed, the moisture resistance of the new material combination will be evaluated to verify that the requirements of Subarticle 340.3 (1) are met.

*RAP Paving Mixture:* When more than 20 percent RAP is used in the produced mixture, the asphalt in the Rap shall be restored to the properties indicated below. Restoration will be made by adding asphalt recycling agent and/or virgin asphalt cement meeting the requirements of Item 300, 'Asphalts, Oils and Emulsions."

The mixture design will include recovery of asphalt from the RAP in accordance with Test Method tex-211-F. The recovered asphalt be blended in the laboratory with the amount of asphalt cement and/or asphalt recycling agent selected for the project. The following tests shall be performed on the laboratory blend.

1. Viscosity, 60°C (140°F), Pa.s – Test Method Tex-528-C
2. Thin film Oven aging Test – Test Method Tex-510-C
3. Viscosity, 60°C (140°F), Pa.s on residue from the Thin Film Oven aging Test - Test Method Tex-528-C
4. Penetration at 25°C (77°F), 100 g, 5 s, (0.1 mm), on residue from the Thin Film Oven aging Test- Test Method Tex-502-C

The viscosity in poises equivalent to the residue penetration at 25°C (77°F) shall be calculated as set forth in Test method Tex-535-C. The viscosity index of the residue shall then be calculated as follows.

*Residue Viscosity Index* = *(Residue Viscosity, Pa.s, equivalent to Penetration at 25°C, (0.1 mm) ) / (Residue Viscosity, 60°C, Pa.s)*

The aging index of the laboratory blended asphalt shall be determined as follows:

*Aging Index* = *(Residual Viscosity, 60°C, Pa.s) / (Original Viscosity, 60°C, Pa.s)*

The laboratory blended asphalt shall meet the following requirements.

Residue Viscosity Index, maximum ..............................................1500
Aging index, maximum ..............................................................3.0

Samples of asphalt recovered from plant produced mixture shall show the asphalt to meet the following requirements when tested in accordance with Test Methods Tex-211-F and Tex-502-C.

| | Minimum | Maximum |
|---|---|---|
| Penetration, 25°C (77°F), 100g, 5 s, (0.1 mm) | 30 | 55 |

*Tack Coat:* Asphaltic materials, shown on the plans or approved by the engineer, shall meet the requirement of the Item 300, "Asphalts, Oils and Emulsions."

Additives

Additives to facilitate mixing and/or improve the quality of the asphaltic mixture or tack coat shall be used when noted on the plans or may be used with the authorization of the Engineer.

Unless otherwise shown on the plans, the Contractor may choose to use either lime or a liquid antistripping agent to reduce the moisture susceptibility of the aggregate. The evaluation and addition of antistripping agents will be in accordance with Item 301, " Asphalt Antistripping Agents."

**Paving Mixtures**

The paving mixtures shall consist of a uniform mixture of aggregate, hot asphalt cement, and additives if allowed or required.

An asphalt mixture design is a laboratory process which includes the determination of the quality of the asphalt and the individual aggregates, the development of the job-mix formula, and the testing of the combined mixture.

The job-mix formula lists the quantity of each component to be used in the mix and the combined gradation of the aggregates used.

Mixture Design

The contractor shall furnish the engineer with representative samples of the materials to be used in production. Using these materials, the mix shall be designed in accordance with Test Method tex-204-F to conform with the Requirements herein. Unless otherwise shown on the plans, the engineer will furnish the mixture design for mixtures when using 5% RAS. The engineer may accept a design from the Contractor which was derived using these design procedures.

The second and subsequent mixture designs, or partial designs, for each type of paving mixture which are necessitated by changes in the material or at the request of the Contractor will be charged to the Contractor when a rate is shown on the plans.

The bulk specific gravity will be determined for each aggregate to be used in the design mixture. If the determined values vary by 0.300 or more, the Volumetric Method, Test Method Tex-204F, Part II, will be used. The bulk specific gravity of aggregates in RAP will be determined on extracted aggregates.

When properly proportioned, for the type specified, the blend of aggregates shall produce an aggregate gradation which will conform to the limits of the master grading shown in Table 2. Unless otherwise shown on the plans, the gradation of the aggregate will be determined in accordance with Test Method Tex-200-F, Part I (Dry Sieve Analysis), to develop the job-mix formula.

The master grading limits for the appropriate type and the proposed job-mix formula will be plotted on a gradation chart with sieve sizes raised to the 0.45 power. This plot must show that the proposed job-mix formula is within the limits of the master grading. Gaps in gradation shown by this plot should be avoided.

The voids in the mineral aggregate (VMA) will be determined as a mixture design requirement only, in accordance with Test Method Tex-200-F, and shall not be less than the value indicated in Table 6.15.

Unless otherwise shown on the plans, the mixture of aggregate, asphalt and additives proposed for use will be evaluated in the design stage for moisture susceptibility, in accordance with Item 301, " Asphalt Antistripping Agents." The engineer may waive this test if a similar design, using the same ingredients, has proven satisfactory.

To substantiate the design, trial mixtures shall be produced and tested using all of the proposed project materials and equipment prior to any placement. The Engineer may waive trial mixtures if similar designs have proven satisfactory.

Density

The mixture shall be designed to produce an acceptable mixture at an optimum density of 96.0 percent, when tested in accordance with Test Method Tex-207-F and Test Method Tex-227-F.

The operating range of control of laboratory density during production shall be optimum density plus or minus 1.5 percent.

Laboratory density is a mixture design and process control parameter. If the laboratory density of the mixture produced has a value outside the range specified above, the Contractor shall investigate the cause and take corrective action. If three (3) consecutive test results fall outside the specified range, production shall cease unless test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the specified range.

**Table 6.15.** Master Grading Percent Passing by Mass or Volume

| Sieve Size | Type | | | | |
|---|---|---|---|---|---|
| | A<br>Coarse Base | B<br>Fine Base | C<br>Coarse Surface | D<br>Fine Surface | F<br>Fine Mixture |
| 37.5 mm | 100 | | | | |
| 31.5 mm | 95-100 | | | | |
| 25.0 mm | | 100 | | | |
| 22.4 mm | 70-90 | 95-100 | 100 | | |
| 16.0 mm | | 75-95 | 95-100 | | |
| 12.5 mm | 50-70 | | | 100 | |
| 9.5 mm | | 60-80 | 70-85 | 85-100 | 100 |
| 6.3 mm | | | | | 95-100 |
| 4.75 mm | 30-50 | 40-60 | 43-63 | 50-70 | |
| 2.0 mm | 20-34 | 27-40 | 30-40 | 32-42 | 32-42 |
| 425 µm | 5-20 | 10-25 | 10-25 | 11-26 | 9-24 |
| 180 µm | 2-12 | 3-13 | 3-13 | 4-14 | 3-13 |
| 75 µm | 1-6* | 1-6* | 1-6* | 1-6* | 1-6* |
| VMA % minimum | 11 | 12 | 13 | 14 | 15 |

25.4 mm = 1 in.
*2-8 when test method Tex-200-F, Part II (Washed Sieve Analysis) is used.

Stability

The materials used in the mixture design shall produce a mixture with a stability value of at least 35, unless otherwise shown on the plans, when tested in accordance with Test Method Tex-208-F.

If, during production, the stability value falls below the specified minimum, the Engineer and the Contractor shall closely evaluate other test result values for specification compliance such as gradation, asphalt content, moisture content, crushed faces, etc., to determine the cause and take corrective action. If three (3) consecutive test results fall below the minimum value specified, production shall cease unless test results or other information indicate, to the satisfaction of the Engineer, that the next material to be produced will meet the minimum value specified.

Job-Mix Formula Field Adjustments

The Contractor shall produce a mixture of uniform composition closely conforming to the approved job-mix formula.

If, during initial days of production, it is determined that adjustments to the mixture design job-mix formula are necessary to achieve the specified requirements, or to more nearly match the aggregate production, the Engineer may allow adjustment of the mixture design job-mix formula within the following limits without a laboratory redesign of the mixture. The adjusted job-mix formula shall not exceed the limits of the master grading for the type of mixture specified nor shall the adjustments exceed five (5) percent on any one sieve, 12.5 millimeter (1/2 in.) size and larger, or three (3) percent on the sieve sizes below the 12.5 millimeter (1/2 in.) sieve.
When the considered adjustments exceed either the five (5) or three (3) percent limits, and the Engineer determines that the impact of these changes may adversely affect pavement performance, a new laboratory mixture design will be required.
The asphalt content will be adjusted as deemed necessary by the Engineer to maintain desirable laboratory density near the optimum value while achieving other mix requirements.

Types

The aggregate gradation of the job-mix formula shall conform to the master grading limits shown in Table 2 for the type mix specified on the plans.

Tolerances

The gradation of the aggregate and the asphalt cement content of the produced mixture shall not vary from the job-mix formula by more than the tolerances allowed herein. When within applied tolerances, the gradation of the produced mixture may fall outside the master grading limits for any of the sieve sizes from the largest sieve size on which aggregate may be retained down through the 180 micrometer (No. 100) sieve. Only the quantity of aggregate passing the 75 micrometer (No. 200) sieve is further restricted to conform to the master grading limitations shown in Table 2 or as modified in Test Method Tex-229-F. A tolerance of two (2) percent is allowed on the sieve size for each mixture type which shows 100 percent passing in Table 2.

| | **Tolerance, Percent by Mass or Volume as Applicable** |
|---|---|
| Passing the 31.5 mm to 2.00 mm sieve (1 1/4 in. to No. 10)........ | Plus or Minus 5 |
| Passing the 425 μm to 75 μm sieve (No. 40 to No. 200)............ | Plus or Minus 3 |
| Asphalt, mass .......................................................... | Plus or Minus 0.5 |
| Asphalt, volume......................................................... | Plus or Minus 1.2 |

The mixture will be tested in accordance with Test Method Tex-210-F, or Test Method Tex-228-F will be used in conjunction with combined cold feed belt samples tested in accordance with Test Method Tex-229-F. Other methods of proven accuracy may be used. The methods of test will be determined by the Engineer. However, mixtures produced by weigh-batch plants and all mixtures containing RAS will be tested for gradation in accordance with Test Method Tex-210-F. If three (3) consecutive tests indicate that the material produced exceeds the above tolerances on any individual sieve, or if two (2) consecutive tests indicate that the asphalt content tolerance is exceeded, production shall stop and not resume until test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the above tolerances.

When disagreements concerning determination of specification compliance occur between allowed sampling and testing procedures, extracted aggregates testing shall take precedence over cold feed belt testing.

When cold feed belt samples are used for job control, the Engineer will select the sieve analysis method that corresponds with the one used to determine the mixture design gradation. The tolerances will be adjusted as outlined in Test Method Tex-229-F.

**Equipment.**

General

All equipment for the handling of all materials, mixing, placing and compacting of the mixture shall be maintained in good repair and operating condition and subject to the approval of the Engineer. Any equipment found to be defective and potentially having a negative effect on the quality of the paving mixture or ride quality will not be allowed.

Mixing Plants

Mixing plants may be weigh-batch type, the modified weigh-batch type, the drum-mix type, or the specialized recycling type. All plants shall be equipped with satisfactory conveyors, power units, mixing equipment, aggregate handling equipment, bins and dust collectors.

Automatic proportioning devices are required for all plants and shall be in accordance with Item 520, "Weighing and Measuring Equipment."

It shall be the Contractor's responsibility to provide safe and accurate means to enable inspection forces to take all required samples, to provide permanent means for checking the output of any specified metering devices, and to perform calibration and mass checks as required by the Engineer. When cold feed belt sampling is to be used for gradation testing, occasional stoppage of the belt may be necessary unless other means of sampling are approved by the Engineer.

When using fuel oil heavier than Grade No. 2, or waste oil, the Contractor shall insure that the fuel delivered to the burner at a viscosity of 100 SSU or less, when tested in accordance with Test Method Tex-534-C, to insure complete burning of the fuel. Higher viscosities will be allowed if recommended by the burner manufacturer. If necessary, the Contractor shall preheat the oil to maintain the required viscosity.

The Contractor shall provide means for obtaining a sample of the fuel, just prior to entry into the burner, in order to perform the viscosity test. The contractor shall perform this test or provide a laboratory test report that will establish the temperature of the fuel necessary to meet the viscosity requirements. There shall be an in-line thermometer to check the temperature of the fuel delivered to the burner.
Regardless of the burner fuel used, the burner or combination of burners and types of fuel used shall provide a complete burn of the fuel and not leave any fuel residue that will adhere to the heated aggregate or become mixed with the asphalt.

*Weigh-Batch Type*

(i) Cold Aggregate Bin Unit and Proportioning Device: The cold aggregate bin unit shall have at least four bins of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back, and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. The proportioning device shall provide a uniform and continuous flow of aggregate in the desired proportion of the dryer. Each aggregate shall be proportioned from the separate bin.

A separate cold bin shall be required for RAS. The RAS feed system shall be equipped with scalping screen to remove particles over 19 millimeters (3/4 in.) in size. The cold bin system shall supply the proper amount of RAS to the Weigh box. RAS will not be allowed in the hot bins.

When mineral filler is used, as specified in Section 340.2.(1)(d), an additional bin shall be provided.

(ii) Dryer: The dryer shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operation.

(iii) Screening and Proportioning: The screening capacity and size of the hot aggregate bins shall be sufficient to screen and store the amount of aggregate required to properly operate the plant and keep the plant in continuous operation at full capacity. The hot bins shall be constructed so that oversize and overloaded material will be discarded through overflow chutes. Provisions shall be made to enable inspection forces to have easy and safe access to the proper location on the mixing plant where representative samples may be taken from the hot bins for testing. The aggregate shall be separated into at least four bins when producing Type "A", Type "B" or type "C" mixtures, at least three bins when producing Type "D" mixture and at least two bins when producing Type "F" mixture. These bins shall contain the following sizes of aggregates, in percentages by mass or by volume, as applicable.

**Type "A" (Coarse-Graded Base Course):**

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.0 mm (No. 10) sieve

Bin No. 2 - Shall contain aggregates of which at least 85 percent will be of such size as to pass the 12.5 mm (1/2 in.) sieve and be retained on the 2.0 mm (No. 10) sieve

Bin No. 3 - Shall contain aggregates of which at least 85 percent will be of such size as to pass the 22.4 mm (7/8 in.) sieve and be retained on the 9.5 mm (3/8 in.) sieve

Bin No. 4 - Shall contain aggregates of which at least 85 percent will be of such size as to pass the 37.5 (1 1/2 in.) mm sieve and be retained on the 22.4 mm (1 in.) sieve

**Type "B" (Fine-Graded Base Course):**

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.0 mm (No 10) sieve

Bin No. 2 - Shall contain aggregates of which at least 70 percent will be of such size as to pass the 4.75 mm (No. 4) sieve and be retained on the 2.0 mm (No. 10) sieve

Bin No. 3 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 9.5 mm (3/8 in.) sieve and be retained on the 4.75 mm (No. 4) sieve

Bin No. 4 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 25.0 mm (1 in.) sieve and be retained on the 9.5 mm (3/8 in.) sieve

**Type "C" (Coarse-Graded Surface Course):**

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.0 mm (No. 10) sieve

Bin No. 2 - Shall contain aggregates of which at least 70 percent will be of such size as to pass the 4.75 mm (No. 4) sieve and be retained on the 2.0 mm (No. 10) sieve

Bin No. 3 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 9.5 mm (3/8 in.) sieve and be retained on the 4.75 mm (No. 4) sieve

Bin No. 4 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 22.4 (7/8 in.) mm sieve and be retained on the 9.5 (3/8 in.) mm sieve

**Type "D" (Fine-Graded Surface Course):**

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.0 mm (No. 10) sieve

Bin No. 2 - Shall contain aggregates of which at least 70 percent will be of such size as to pass the 4.75 mm (No. 4) sieve and be retained on the 2.0 mm (No. 10) sieve

Bin No. 3 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 12.5 mm (1/2 in.) sieve and be retained on the 4.75 mm (No. 4) sieve

**Type "F" (Fine-Graded Mixture):**

Bin No. 1 - Shall contain aggregates of which 85 to 100 percent will pass the 2.0 mm (No. 10) sieve.

Bin No. 2 - Shall contain aggregates of which at least 75 percent will be of such size as to pass the 9.5 mm (3/8 in.) sieve and be retained on the 2.0 mm (No. 10) sieve

(iv) Aggregate Weigh Box and Batching Scale: The aggregate weigh box and batching scales shall be of sufficient capacity to hold and weigh a complete batch of aggregate. The weigh box and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment."

(v) Asphaltic Material Measuring System: If an asphaltic material bucket and scales are used, they shall be of sufficient capacity to hold and weigh the necessary asphaltic material for one batch. The bucket and scales shall conform to the requirements of Item 520, " Weighing and Measuring Equipment."

If a pressure type flow meter is used to measure the asphaltic material, the requirements of Item 520, " Weighing and Measuring Equipment," shall apply. This system shall include an automatic temperature compensation device to insure a constant percent by mass of asphaltic material in the mixture.

Provisions of a permanent nature shall be made for checking the accuracy of the asphaltic material measuring device. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material.

(vi) Mixer: The mixer shall be of the pugmill type and shall have a capacity of not less than 1350 kilograms (3000 lbs.) of natural-aggregate mixture in a shingle batch, unless otherwise shown on the plans. Any mixture that has a tendency to segregate the aggregate or fails to secure a thorough and uniform mixture with the asphaltic material shall not be used. All mixtures shall be provided with an automatic timer that will lock the discharge doors of the mixer for the required mixing period. The dump door or doors and the shaft seals of the mixer shall be tight enough to prevent spilling of aggregate or mixture from the pugmill.

(vii) Surge-Storage System and Scales: A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

When a surge-storage system is used, scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

(viii) Recording Device and Record Printer: The mixture shall be weighed for pavement. If a surge-storage system is used, an automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day, unless otherwise indicated on the plans. When surge-storage is not used, batch mass will be used as the basis for payment and automatic recording devices and automatic digital record printers in accordance with Item 520, "Weighing and Measuring Equipment," shall be required.

*Modified Weigh-Batch Type.*

(i) General: This plant is similar to weigh-batch type plant. The hot bin screens shall be removed and the aggregate control is placed at the cold feeds. The cold feed bins shall be the same as those required for the drum-mix type plant.

(ii) Cold-Aggregate Bin Unit and Feed System: The number of bins in the cold aggregate bin unit shall be equal to or greater than the number of stockpiles of individual materials to be used.

The bins shall be of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. When required by the Engineer, an approved stationary scalping screen shall be placed on top of the field sand bin to eliminate roots and other objectionable material. The feed system shall provide a uniform and continuous flow of aggregate in the desired proportion to the dryer. The contractor shall furnish a chart indicating the calibration of each cold bin in accordance with the manufacturer's recommendations or in a method acceptable to the Engineer.

When mineral filler is used, as specified in Section 340.2.(1)(d), an additional bin shall be provided
A separate cold bin shall be required for RAS. The RAS feed system shall be equipped with a scalping screen to remove particles over 19 millimeters (3/4 in.) in size. The cold bin system shall supply a uniform and proper amount of RAS to the mixture. RAS may be added at the weigh box. If not added at the weigh box, the system shall include means acceptable to the Engineer to verify that the correct amount of RAS is continuously being fed.

(iii) Scalping Screen: A scalping screen shall be required after the cold feeds and ahead of the hot aggregate surge bins.

(iv) Dryer: The dryer shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operations.

(v) Screening and Proportioning: The hot aggregate shall be separated into sizes after being dried. There shall be one or more surge bins provided between the dryer and the weigh hopper. Surge bins shall be of sufficient size to hold enough combined aggregate for one complete batch of mixture.

(vi) Aggregate Weigh Box and Batching Scale: The aggregate weigh box and batching scales shall be of sufficient capacity to hold and weigh a complete batch of aggregate. The weigh box and scales shall conform to the requirements of Item 520, " Weighing and Measuring Equipment."

(vii) Asphaltic Material Measuring System: If an asphaltic material bucket and scales are used, they shall be of sufficient capacity to hold and weigh the necessary asphaltic material for one batch. The bucket and scales shall conform to the requirements of Item 520, " Weighing and Measuring Equipment."

If a pressure type flow meter is used to measure the asphaltic material, the requirements of Item 520, " Weighing and Measuring Equipment," shall apply. This system shall include an automatic temperature compensation device to insure a constant percent by mass of asphaltic material in the mixture.

Provisions of a permanent nature shall be made for checking the accuracy of the asphaltic material measuring device. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material.

(viii) Mixer: The mixer shall be of the pugmill type and shall have a capacity of not less than 1350 kilograms (3000 lbs.) of natural-aggregate mixture in a single batch, unless otherwise shown on the plans. Any mixer that has a tendency to segregate the aggregate or fails to secure a thorough and uniform mixture with the asphaltic material shall not be used. All mixers shall be provided with an automatic timer that will lock the discharge doors of the mixer for the required mixing period. The dump door or doors and the shaft seals of the mixer shall be tight enough to prevent spilling of aggregate or mixture from the pugmill.

(ix) Surge-Storage System and Scales: A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

When a surge-storage system is used, scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, " Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

(x) Recording Device and record Printer: The mixture shall be weighed for payment. If a surge-storage system is used, an automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day, unless otherwise indicated on the plans. When surge-storage is not used, batch mass will be used as the basis for payment and automatic recording devices and automatic digital record printers in accordance with Item 520, "Weighing and Measuring Equipment," shall be required.

*Drum-Mix Type*

(i) General: The plant shall be adequately designed and constructed for the process of mixing aggregates and asphalt. The plant shall be equipped with satisfactory conveyors, power units, aggregate-handling equipment and feed controls.

(ii) Cold-Aggregate Bin Unit and Feed System: The number of bins in the cold aggregate bin unit shall be equal to or greater than the number of stockpiles of individual materials to be used.

The bins shall be of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. When required by the engineer, an approved stationary scalping screen shall be placed on top of the field sand bin to eliminate roots and other objectionable material. The feed system shall provide a uniform and continuous flow of aggregate in the desired proportion to the mixer. The contractor shall furnish a chart indicating the calibration of each cold bin in accordance with the manufacturer's recommendations or in a method acceptable to the Engineer.

The system shall provide positive mass measurement of the combined cold-aggregate feed by the use of belt scales or other approved devices. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device as required by Item 520, "Weighing and Measuring Equipment." When a belt scale is used, the mixture production shall be maintained so that the scale normally operates between 50 percent and 100 percent of its rated capacity. Belt scale operation below 50 percent of the rated capacity may be allowed by the Engineer if accuracy checks show the scale to meet the requirements of Item 520, "Weighing and Measuring Equipment," at the selected rate. It shall be satisfactorily demonstrated to the Engineer that mixture uniformity and quality have not been adversely affected.

A separate cold bin shall be required for RAS. The RAS feed system shall be equipped with a scalping screen to remove particles over 19 millimeters (3/4 in.) in size prior to the weighing device. There shall be adequate cold bin controls to provide a uniform amount of RAS to the mixtures.

When RAS is used, positive mass measurement of these materials shall be provided by the use of belt scales or other approved devices.

(iii) Scalping Screen: A scalping screen shall be required after the cold feeds and ahead of the combined aggregate belt scales

(iv) Asphaltic Material Measuring System: An asphaltic material measuring device meeting the requirements of Item 520, "Weighing and Measuring Equipment," shall be placed in the asphalt line leading to the mixer so that the cumulative amount of asphalt used can be accurately determined. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device output. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material. The measuring system shall include an automatic temperature compensation device to maintain a constant percent by mass asphaltic material in the mixture.

(v) Synchronization Equipment for Feed-Control System: The asphaltic material feed-control shall be coupled with the total aggregate mass measuring device to automatically vary the asphalt-feed rate in order to maintain the required proportion.

(vi) Mixing System: The mixing system shall control the temperature so that the aggregate and asphalt will not be damaged in the drying, heating and mixing operations. A continuously recording thermometer shall be provided which will indicate the temperature of the mixture as it leaves the mixer.

(vii) Surge-Storage System and Scales: A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

Scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, " Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

(viii) Recording Device and Record Printer: Automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day in accordance with Item 520, "Weighing and Measuring Equipment," unless otherwise indicated on the plans.

*Specialized Recycling Type*

(i) General: Alternate methods of heating may be used which will not abnormally age the asphalt cement. This type of plant shall be capable of continually producing a minimum of 136 megagrams per hour of completed asphalt mixture that will meet all the requirements of this specification.

(ii) Cold-Aggregate Bin Unit and Feed System: The cold-aggregate feed system and controls shall meet all the requirements as listed under the drum-mix plant.

(iii) Scalping Screen: A scalping screen shall be required after the cold feeds and ahead of the combined aggregate belt scales

(iv) Dryer: The dryer shall continually agitate the RAS and aggregate during heating. The temperature shall be controlled so that the aggregate and asphalt will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operation.

(v) Asphaltic Material Measuring System: An asphaltic material measuring device meeting the requirements of Item 520, "Weighing and Measuring Equipment," shall be placed in the asphalt line leading to the mixer so that the cumulative amount of asphalt used can be accurately determined. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device output. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material. The measuring system shall include an automatic temperature compensation device to maintain a constant percent by mass asphaltic material in the mixture.

(vi) Synchronization Equipment for Feed-Control System: The asphaltic material feed-control shall be coupled with the total aggregate mass measuring device to automatically vary the asphalt-feed rate in order to maintain the required proportion.

(vii) Mixer: The mixer shall be of the continuous mechanical mixing type. Any mixer that has a tendency to segregate the mixture or fails to secure a thorough and uniform mixture shall not be used. A continuously recording thermometer shall be provided which will indicate the temperature of the mixture as it leaves the mixer.

(viii) Surge-Storage System and Scales: A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge-storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

Scales shall be standard platform truck scales or other equipment such as hopper (suspended) scales and shall conform to Item 520, " Weighing and Measuring Equipment." If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

(ix) Recording Device and Record Printer: Automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day in accordance with Item 520, "Weighing and Measuring Equipment," unless otherwise indicated on the plans.

Asphaltic Material Heating Equipment.

Asphaltic material heating equipment shall be adequate to heat the required amount of asphaltic material to the desired temperature. The heating apparatus shall be equipped with a continuously recording thermometer with a 24-hour chart that will record temperature of the asphaltic material at the location of highest temperature.

Spreading and Finishing Machine

The spreading and finishing machine shall be approved by the Engineer and shall meet the requirements indicated below.

*Screed Unit* The spreading and finishing machine shall be equipped with a heated compacting screed. It shall produce a finished surface meeting the requirements of the typical cross sections and the surface tests.

Extensions added to the screed shall be provided with the same compacting action and heating capability as the main screed unit, except for use on variable depth tapered areas and/or as approved by the Engineer.

The spreading and finishing machine shall be equipped with an approved automatic dual longitudinal screed control system and automatic transverse screed control system. The longitudinal controls shall be capable of operating from any longitudinal grade reference including a string line, ski, mobile string line, or matching shoe.

The Contractor shall furnish all equipment required for grade reference. It shall be maintained in good operating condition by personnel trained in the use of this type of equipment.

The grade reference used by the Contractor may be of any type approved by the Engineer. Control points, if required by the plans, shall be established for the finished profile in accordance with Item 5, "Control of the Work." These points shall be set at intervals not to exceed 15 meters (50 feet). The Contractor shall set the grade reference from the control points. The grade reference shall have sufficient support so that the maximum deflection shall not exceed two (2) millimeters (0.08 inches) between supports.

*Tractor Unit:* The tractor unit shall be equipped with a hydraulic hitch sufficient in design and capacity to maintain contact between the rear wheels of the hauling equipment and the pusher rollers of the finishing machine while the mixture is being unloaded.

No portion of the mass of hauling equipment, other than the connection, shall be supported by the asphalt paver. No vibrations or other motions of the loading equipment, which could have a detrimental effect on the riding quality of the completed pavement, shall transmitted to the paver.

The use of any vehicle which requires dumping directly into the finishing machine and which the finishing machine cannot push or propel to obtain the desired lines and grades without resorting to hand finishing will not be allowed.

Material Transfer Equipment

Equipment to transfer mixture from the hauling units or the roadbed to the spreading and finishing machine will be allowed unless otherwise shown on the plans. A specific type of material transfer equipment shall be required when shown on the plans.

*Windrow Pick-Up Equipment:* Windrow pick-up equipment shall be constructed in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the spreading and finishing machine. The mixture shall not be contaminated with foreign material. The loading equipment shall be designed so that it does not interfere with the spreading and finishing machine in obtaining the required line, grade and surface without resorting to hand finishing.

*Material Feeding System:* Material feeding systems shall be designed to provide a continuous flow of uniform mixture to the spreading and finishing machine. When use of a material feeding system is required on the plans, it shall meet the storage capacity, remixing capability, or other requirements shown on the plans.

Motor Grader

The motor grader, when used, shall be a self-propelled power motor grader and shall be equipped with smooth tread pneumatic tired wheels unless otherwise directed. It shall have a blade length of not less than 3.6 meters (12 feet) and a wheelbase of not less 4.8 meters (15.7 feet).

Rollers

Rollers provided shall meet the requirements for their type as follows:

*Pneumatic-Tire Roller:* The roller shall be an acceptable medium pneumatic tire roller conforming to the requirements of Item 213, "Rolling (Pneumatic Tire)," Type A, unless otherwise specified on the plans. Pneumatic-tire rollers used for compaction shall provide a minimum 550 kilopascals (80 psi) ground contact pressure. When used for kneading and sealing the surface only, they shall provide a minimum of 380 kilopascals (55 psi) ground contact pressure.

*Two-Axle Tandem Roller:* The roller shall be an acceptable self-propelled tandem roller weighing not less than 7.2 megagrams (8 tons).

*Three-Wheel Roller:* This roller shall be an acceptable self-propelled three wheel roller weighing not less than 9.1 megagrams (10 tons).

*Three-Axle Tandem Roller:* The roller shall be an acceptable self-propelled three axle roller weighing not less than 9.1 megagrams (10 tons).

*Trench Roller:* This roller shall be an acceptable self-propelled trench roller equipped with a sprinkler for keeping the wheels wet an and adjustable road wheel so that the roller may be kept level during rolling. The drive wheel shall be not less than 500 millimeters

(20 inches) wide. The roller under working conditions shall produce not less than 5800 kilograms per meter (3900 pounds per foot) of roller width and be so geared that a speed of approximately three (3) kilometers per hour (2 miles per hour) is obtained in low gear.

*Vibratory Steel-Wheel Roller:* This roller shall have a minimum mass of 5.4 megagrams (6 tons). The compactor shall be equipped with amplitude and frequency controls and shall be specifically designed to compact the material on which it is used.

<u>Straightedges and Templates</u>

When directed by the Engineer, the Contractor shall provide acceptable 3-meter (10-foot) straightedges for surface testing. Satisfactory templates shall be provided as required by the Engineer.

<u>Alternate Equipment</u>

When permitted by the Engineer, equipment other than that specified herein which will consistently produce satisfactory results may be used.

**Stockpiling, Storage and Mixing.**

<u>Stockpiling of Aggregates</u>

*Weigh-Batch Plant:* Prior to stockpiling of aggregates, the area shall be cleaned of trash, weeds, grass and shall be relatively smooth and well drained. The stockpiling shall be done in a manner that will minimize aggregate degradation, segregation, mixing of one stockpile with another, and will not allow contamination with foreign material.

The plant shall have at least a two-day supply of aggregates on hand production can begin and at least a two-day supply shall be maintained through the course of the project, unless otherwise directed by the Engineer.

No stockpile shall contain aggregate from more than one source.

Coarse aggregate for mixture Types "A", "B" and "C" shall be separated into at least two stockpiles of different gradation, such as a large-coarse-aggregate and a small-coarse-aggregate stockpile, except when the use of large percentage of RAP preclude the need for two virgin coarse aggregate stockpile.

When shown on the plans, coarse aggregates for Type "D" mixtures shall also be separated into at least two stockpiles.

No coarse-aggregate stockpile shall contain more than 15 percent by mass of material that will pass a 2.00 millimeter (No. 10) sieve.

Fine-aggregate stockpiles may contain coarse aggregate in amounts up to 20 percent by mass. This requirement does apply to stone screenings stockpiles, which must meet the gradation requirements shown in Section 340.2.(1)(c), unless otherwise shown on the plans.

Prior to starting RAS stockpiling operations, the Contractor shall develop and submit in writing to the Engineer an acceptable stockpile production procedure and management plan which will ensure that homogeneous stockpiles of RAS are available. Stockpile of contractor-owned RAS material shall be completely established at the plant site or another approved location prior to submission of mixture design samples and shall be of sufficient quantity to meet the material requirements of the project for which are prepared.

When required by the Engineer, additional material shall not be added to stockpiles that have previously been sampled for approval.

Equipment of an acceptable size and type shall be furnished to work the stockpiles and prevent segregation and degradation of the aggregates.

*Modified Weigh-Batch Plant:* The stockpiling requirements for aggregate shall be the same as required for a drum-mix type plant.

*Drum-Mix Plant:* When a drum-mix plant is used, the following stockpiling requirements for coarse aggregates shall apply in addition to the aggregate stockpiling requirements listed under Section 340.5.(1)(a).

Once a job-mix formula has been established in accordance with Article 340.3, the virgin coarse aggregates delivered to the stockpiles shall not vary on any grading size fraction by more than plus or minus eight (8) percentage points from the percentage found in the samples submitted by the Contractor and upon which the job-mix formula was based. Should the gradation of virgin coarse aggregates in the stockpiles vary by more than the allowed tolerance, the Engineer may stop production. If production is stopped, new aggregates shall be furnished that meet the gradations of the aggregates submitted for the job-mix formula, or a new mix design shall be formulated in accordance with Article 340.3.

When the volume of production from a commercial plant makes sampling of all coarse aggregate delivered to the stockpiles impractical, cold feeds will sampled to determine stockpile uniformity. Should this sampling prove the stockpiles non-uniform beyond the acceptable tolerance, separate stockpiles which meet these specifications may be required.

*Specialized Recycling Plant* The stockpiling requirements for aggregate shall be the same as required for drum-mix type plant.

Storage and Heating of Asphaltic Materials

The asphaltic material storage capacity shall be ample to meet the requirements of the plant. Asphalt shall not be heated to a temperature in excess of that specified in Item 300, "Asphalts, Oils and Emulsions." All equipment used in the storage and handling of asphaltic material shall be kept in a clean condition at all times and shall be operated in such a manner that there will be no contamination with foreign matter.

Feeding and Drying of Aggregate

The feeding of various sizes of aggregate and RAS, if applicable, to the dryer shall be done through the cold aggregate bins and the proportioning device in such a manner that a uniform and constant flow of materials in the required proportions will be maintained. The aggregate shall be dried and heated to the temperature to produce a mixture having the specified temperature.

Mixing and Storage

*Weigh-Batch Plant:* In introducing the batch into the mixer, all aggregate shall be introduced first and shall be mixed thoroughly for a minimum period of five (5) seconds to uniformly distribute the various sizes throughout the batch before the asphaltic material is added. The asphaltic material shall be added and the mixing continued for a wet mixing period of not less than 15 seconds. The mixing period shall be increased if, in the opinion of the engineer, the mixture is not uniform or the aggregates are not properly coated.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be permitted during the normal day's operation. Overnight storage will not be permitted unless authorized in the plans or by the Engineer. The mixture coming out of the surge-storage bin shall be of equal quality to that coming out of the mixer.

*Modified Weigh-Batch Plant:* The mixing and storage requirements shall be the same as is required for a standard weigh-batch plant.

*Drum-Mix Plant:* The amount of aggregate and asphaltic material entering the mixer and the rate of travel through the mixing shall be so coordinated that a uniform mixture of the specified grading and asphalt content will be produced.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be required during the normal day's operation. Overnight storage will not be permitted unless authorized in the plans or by the Engineer. The mixture coming out of the surge-storage bin shall be of equal quality to that coming out of the mixer.

*Specified Recycled Plant:* The mixing and storage requirements for aggregate shall be the same as that stated for drum-mix plant.

*Discharge Temperature:* The Engineer will select the target discharge temperature of the mixture between 120°C (248°F) and 175°C (347°). The mixture, when discharged from the mixer, shall not vary from this selected temperature more than 15°C (59°F), but in no case shall the temperature exceed 180°C (356°F).

*Moisture Content:* The mixture produced from each type of mixer shall have a moisture content not greater than one (1) percent by mass when discharged from the mixer, unless otherwise shown on the plans and/or approved by the Engineer. The moisture content shall be determined in accordance with Test Method Tex-212-F.

**Construction Method.**

General

It shall be the responsibility of the contractor to produce, transparent, place and compact the specified paving mixture in accordance with the requirements herein.

The asphaltic mixture, when placed with spreading and finishing machine, or the tack coat shall not be placed when the air temperature is below 10°C and is falling, but it may be placed when the air temperature is above 5°C (40°F) and is rising.

The asphaltic mixture, when placed with motor grader, shall not be placed when the air temperature is below 15°C (59°F) and is falling, but it may be placed when the air temperature is above 10°C (50°F) and is rising.

The air temperature shall be taken in the shade away from artificial heat.

Mat thicknesses of 40 millimeters (1.6 inches) and less shall not be placed when the temperature of the surface on which the mat is to be placed is below 10°C (50°F).

Mixtures with lightweight coarse aggregate shall not be placed when the temperature of the surface on which the mat is to be placed is below 10°C (50°F).

Additional surface temperature requirements may be shown on the plans.

It is further provided that the tack coat or asphaltic mixture shall be placed only when the humidity, general weather conditions and temperature and moisture condition of the base, in the opinion of the Engineer, are suitable.
If, after being discharged from the miser and prior to placing, the temperature of the asphaltic mixture is 10°C (18°F) or more below the selected discharge temperature established by the Engineer, all or any part of the load may be rejected and payment will not be made for the rejected material.

Tack Coat

The surface upon which the tack coat is to be placed shall be cleaned thoroughly to the satisfaction of the Engineer. The surface shall be given a uniform application of tack coat using asphaltic materials of this specification. This tack coat shall be applied, as directed by the Engineer, with an approved sprayer at a rate not to exceed 0.2 liter residual asphalt per square meter of surface (0.06 gallons per square yard). Where the mixture will adhere to the surface on which it is to be placed without the use of tack coat, the tack coat may be eliminated by the

Engineer. All contact surfaces of curbs and structures and all joints shall be painted with a thin uniform application of the tack coat. During the application of tack coat, care shall be taken to prevent splattering of adjacent pavement, curb and gutter and structures. The tack coat shall be rolled with a pneumatic tire roller when directed by the Engineer.

Transporting Asphaltic Concrete

The asphaltic mixture shall be hauled to the work site in tight vehicles previously cleaned of all foreign material. The dispatching of the vehicles shall be arranged so that all material delivered is placed and all rolling completed during daylight hours unless otherwise shown on the plans. In cool weather or long hauls, covering and insulating of the truck bodies may be required. If necessary, to prevent the mixture from adhering to the body, the inside of the truck may be given a light coating of release agent satisfactory to the Engineer.

Placing

The asphaltic mixture shall be dumped and spread on the approved prepared surface with the spreading and finishing machine. When properly compacted, the finished pavement shall be smooth, of uniform texture and density and shall meet the requirements of the typical cross sections and surface tests. In addition, the placing of the asphaltic mixture shall be done without tearing, shoving, gouging or segregating the mixture and without producing streaks in the mat.

Unloading into the finishing machine shall be controlled so that bouncing or jarring the spreading and finishing machine shall not occur and the required lines and grades shall be obtained without resorting to hand finishing, except as shown under Section 340.6.(4)(d).

Unless otherwise shown on the plans, dumping of the asphaltic mixture in a windrow and then placing the mixture in the finishing machine with windrow pick-up equipment will be permitted. The windrow pick-up equipment shall be operated in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the finishing machine without contamination by foreign material. The windrow pick-up equipment will be so operated that the finishing machine will obtain the required line, grade and surface without resorting to hand finishing. Any operation of the windrow pick-up equipment resulting in the accumulation and subsequent shedding of accumulated material into the asphaltic mixture will not be permitted.

When approved by the engineer, level-up courses may be spread with a motor grader.

The spreading and finishing machine shall be operated at a uniform forward speed consistent with the plant production rate, hauling capability, and roller train capacity to result in a continuous operation. The speed shall be slow enough that stopping between trucks is not ordinarily required. If, in the opinion of the Engineer, sporadic delivery of material is adversely affecting the mat, the Engineer may require paving operations to cease until acceptable methods are provided to minimize starting and stopping of the paver.

The hopper flow gates of the spreading and finishing machine shall be adjusted to provide an adequate and consistent flow of material. These shall result in enough material being delivered to the augers so that they are operating approximately 85 percent of the time or more. The augers shall provide means to supply adequate flow of material to the center of the paver. Augers shall supply an adequate flow of material for the full width of the mat, as approved by the Engineer. Augers should be kept approximately one-half to three-quarters full of mixture at all times during the paving operation.

When the asphaltic mixture is placed in a narrow strip along the edge of an existing pavement, or used to level up small areas of an existing pavement, or placed in small irregular areas where the use of a finishing machine is not practical, the finishing machine may be eliminated when authorized by the Engineer.

Adjacent to flush curbs, gutters and structures, the surface shall be finished uniformly high so that when compacted it will be slightly above the edge of the curb or structure.

Construction joints of successive courses of asphaltic material shall be offset at least 150 millimeters (6 inches). Construction joints on surface courses shall coincide with lane lines, or as directed by the Engineer.

If a pattern of surface irregularities or segregation is detected, the Contractor shall make an investigation into the causes and immediately take the necessary corrective action. With the approval of the Engineer, placement may continue for no more than one full production day from the time the Contractor is first notified and while corrective actions are being taken. If the problem still exists after that time, paving shall cease until Contractor further investigates the causes and the Engineer approves further corrective action to be taken.

Compacting

The pavement shall be compacted thoroughly and uniformly with the necessary rollers to obtain the compaction and cross section of the finished paving mixture meeting the requirements of the plans and specifications.

When rolling with the three-wheel, tandem or vibratory rollers, rolling shall start by first rolling the joint with the adjacent pavement and then continue by rolling longitudinally at the sides and proceed toward the center of the pavement, overlapping on successive trips by at least 300 millimeters (12 inches), unless otherwise directed by the Engineer. Alternate trips of the roller shall be slightly different in length. On super-elevated curves, rolling shall begin at the low side and progress toward the high side, unless otherwise directed by the Engineer.

When rolling with vibratory steel-wheel rollers, equipment operation shall be in accordance with Item 217, " Rolling (Vibratory)," and the manufacturer's recommendations, unless otherwise directed by the Engineer. Vibratory rollers shall not be left vibrating while not rolling or when changing directions. Unless otherwise shown on the plans or approved by the Engineer, vibratory rollers shall not be allowed in the vibrating mode with a plan depth of less than 40 millimeters (1.6 inches).

The motion of the rollers shall be slow enough other than usual initial displacement of the mixture. If any displacement occurs, it shall be corrected to the satisfaction of the Engineer. The roller shall not be allowed to stand on pavement which has not been fully compacted. To present adhesion of the surface mixture to the steel-wheel rollers, the wheels shall be kept thoroughly moistened with water, but an excess of water will not be permitted. Necessary precautions shall be taken to prevent the dropping of diesel, gasoline, oil, grease or other foreign matter on the pavement, either when the rollers are in operation or when standing.

The edges of the pavement along curbs, headers and similar structures, and all places not accessible to the roller, or in such positions as will not allow thorough compaction with the rollers, shall be thoroughly compacted with lightly oiled tamps.

Rolling with a trench roller will be required on widened areas, in trenches and other limited areas satisfactory compaction cannot be obtained with the approved rollers.

<u>In-Place Compaction Control</u>

In-place compaction control is required for all mixtures. Unless otherwise shown on the plans, air void control shall be required.

*Air Void Control.* The Contractor shall be responsible for determining the number and type of rollers to be used to obtain compaction to within the air void range required herein. The rollers shall be operated in accordance with the requirements of this specification and as approved by the Engineer.

Unless otherwise shown on the plans, rolling with a pneumatic-tire roller to seal the surface shall be provided. Rolling with a tandem or other steel-wheel roller shall be provided if required to iron out any roller marks.

Asphaltic concrete shall be placed and compacted to contain from five (5) to nine (9) percent air voids. The percent air voids will be calculated using the maximum theoretical specific gravity of the mixture determined according to Test Method Tex-227-F. Roadway specimens, which shall be either cores or section of asphaltic pavement, will be tested according to Test Method Tex-207-F. the nuclear-density gauge or other methods which correlate satisfactorily with results obtained from project roadway specimens may be used when approved by the Engineer. Unless otherwise shown on the plans, the Contractor shall be responsible for obtaining the required roadway specimens at his expenses and in a manner and at locations selected by the Engineer.

If the percent air voids in the compacted placement is greater than nine (9) percent but is 10 percent or less, production may proceed with subsequent changes in the construction operations and/or mixtures. If the air void content is not reduced to five (5) and nine (9) percent within one production day from the time the Contractor is notified, production shall cease. At that point, a test section as described below shall be required.

If the percent air voids is more than 10 percent, production shall cease immediately and a test section shall be required as described below.

In either case, the Contractor shall only be allowed to place a test section of one lane width, not to exceed 300 meters (1000 feet) in length, to demonstrate that compaction to between five (5) and nine (9) percent air voids can be obtained. This procedure will continue until a test section with five (5) to nine (9) percent air voids can be produced. Only two (2) test sections per day will be allowed. When a test section producing satisfactory air void content is placed, full production may then resume.

Increasing the asphalt content of the mixture in order to reduce pavement air voids will not be allowed.

If the percent air voids is determined to be less than five (5) percent, immediate adjustments shall be made to the plant production by the Contractor, as approved by the Engineer, within the tolerances as outlined in Subarticle 340.3.(4), so that an adequate air void level results.

The Contractor is encouraged to perform supplemental compaction testing for his own information.

*Ordinary Compaction Control:* When the requirement of air void control has been removed by plan note, one (1) three-wheel roller, one (1) pneumatic-tire roller, and one (1) tandem roller shall be furnished for each compaction operation except as provided below or approved by the Engineer. The use of a tandem roller may be waived by the Engineer when the surface is already adequately smooth and further steel-wheel rolling is shown to be ineffective. With approval of the Engineer, the Contractor may substitute a vibratory roller for the three-wheel roller and/or the tandem roller. Use of at least one (1) pneumatic-tire roller is required. Additional or heavier rollers shall be furnished if required by the Engineer.

*Compaction Cessation Temperature:* Regardless of the method required for in-place compaction control, all rolling for compaction shall be completed before the mixture temperature drops below 80°C (175°F).

Ride Quality

Unless otherwise shown on the plans, Ride Quality will be required in accordance with Item 585, " Ride Quality for Pavement Surfaces."

Opening to Traffic

The pavement shall be opened to traffic when directed by the Engineer. The Contractor's attention is directed to the fact that all construction traffic allowed on the pavement open to the public will be subject to the State laws governing traffic on highways.

If the surface ravels, flushes, ruts or deteriorates in any manner prior to final acceptance of the work, it will be the Contractor's responsibility to correct this condition at his expense, to the satisfaction of the Engineer and in conformance with the requirements of this specification.

**Measurement**

The quality of asphaltic concrete will be measured by the composite mass or composite volumetric method.

Composite Mass Method

Asphaltic concrete will be measured by the megagram of the composite "Asphaltic Concrete" of the type actually used in the completed and accepted work in accordance with the plans and specifications for the project. The composite asphaltic concrete mixture is hereby defined as the asphalt, aggregate, RAS and additives as noted in the plans and/or approved by the Engineer.

If mixing is done by a drum-mix plant or specialized recycling plant, measurement will be made on scales as specified herein.

If mixing is done by a weigh-batch plant or modified weigh-batch plant, measurement will be determined on the batch scales unless surge-storage is used. Records of the number of batches, batch design and the mass of the composite "Asphaltic Concrete" shall be kept. Where surge-storage is used, measurement of the material taken from the surge-storage bin will be made on truck scales or suspended hopper scales.

Composite Volumetric Method

The asphaltic concrete will be measured by the cubic meter of compacted "Asphaltic Concrete" of the type actually used in the completed and accepted work in accordance with the plans and specifications for the project. The composite asphaltic concrete mixture is hereby defined as the asphalt, aggregate, RAS and additives as noted in the plans and/or approved by the Engineer. The volume of the composite asphaltic concrete mixture shall be calculated by the following formula.

$$V = W / (1000 * G_a)$$

V = Cubic meters of compacted " Asphaltic concrete"
W = Total mass of asphaltic concrete in kilograms
$G_a$ = average actual specific gravity of three (3) molded specimens as prepared by Test Method tex-206-F and determined in accordance with test Method Tex-207-F.

If mixing is done by a drum-mix plant or specialized recycling plant, the mass "W" will be determined by scales as specified herein.

If mixing is done by a weigh-batch plant or modified weigh-batch plant and surge-storage is not used, mass will be determined by batch scales and records of the number of batches, batch designs and the mass asphalt and aggregate shall be kept. Where surge-storage is used, measurement of the material taken from the surge-storage bin will be made on truck scales or suspended hopper scale.

**Payment**

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit bid for the "Asphaltic Concrete" of the type specified.

| Measurement Method | Bid Item | Unit of Measure |
|---|---|---|
| Composite mass | Asphaltic Concrete | Megagram |
| Composite volumetric | Asphaltic Concrete | Cubic Meter |

The payment based on the bid price shall be full compensation for quarrying, furnishing all materials, additives, freight involved, for all heating, mixing, hauling, cleaning the existing base course or pavement, tack coat, placing, rolling and finishing asphaltic concrete mixture, transportation RAP and RAS from designated sources, transporting any excess RAP and RAS to locations shown on the plans, and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work.

(2) All templates, straightedges, core drilling equipment, scales and other weighing and measuring devices necessary for the proper construction, measuring and checking of the work shall be furnished, operated and maintained by the Contractor at his expenses.

**Contact Persons**

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| Darwin Myers | Area Engineer, TxDOT, Dallas District Navarro Co. | Phone: (903) 874-4351<br>Fax: (903) 872-0414 |
| Ronnie McManus | TxDOT Dallas District Laboratory | Phone: (214) 320-4457<br>Fax: (214) 320-6117 |
| Dave Kosse | Duininck Bros (Contractor) | Phone: (817) 488-6770<br>Fax: (817) 488-2174 |
| Jack Milner | Thelin Recycling Company | Phone: (817) 481-6679<br>Fax: (817) 421-0655 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

## CHAPTER 7: SHREDDED BRUSH

### About the Material

Shredded brush mulch is made from the chippings of tree and landscape pruning. Mulch is placed on the soil surface for the purpose of protecting the soil from erosion. Some of the benefits of organic mulch include soil moisture retention, reduced soil temperature extremes, and prevention of soil erosion from heavy rain damage.

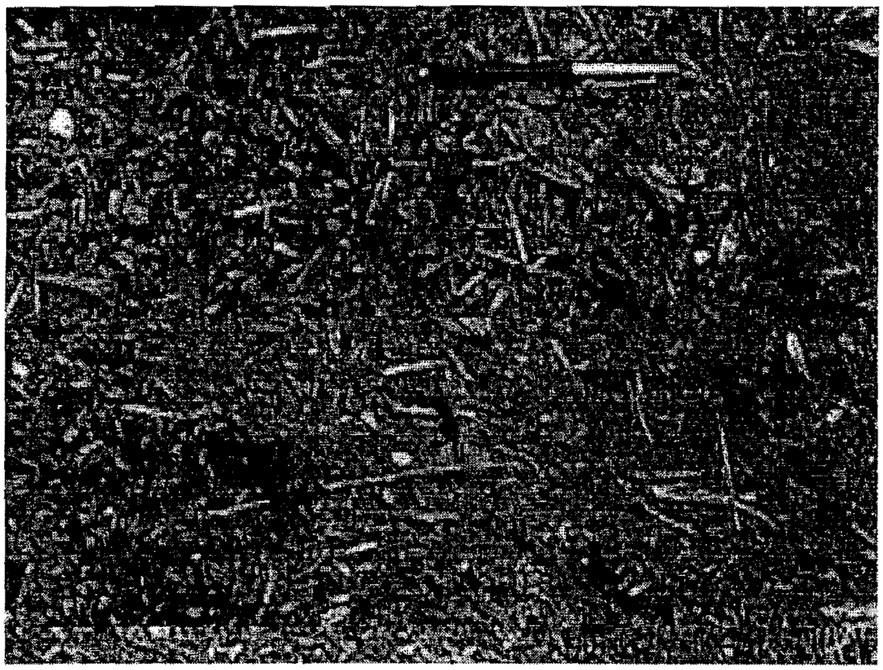


**Figure 7.1.** Shredded Brush Applied to Soil Surface

A five-year study on wood chips and other wood fragments as a soil amendment was conducted at the Connecticut Agricultural Experiment Station in New Haven. This study revealed that woodchips are not toxic to soil and had a modest but generally favorable effect on soil structure, organic matter content, and associated soil properties (Lunt, 1955). It was also found that chips are probably more effective on sandy soils than on loams.

Performance testing for a compost and shredded wood study was conducted at the TxDOT/TTI Hydraulics and Erosion Control Laboratory. The objective of this study was to determine the field performance of compost and shredded brush with tackifier as erosion-control materials for use in highway right-of-way. Table 7.1 compares the test materials to TxDOT minimum performance standards for vegetation density and sediment loss for erosion control blankets. A vertical to horizontal slope of 1:3 was used for all cases.

**Table 7.1.** Performance Analysis of Erosion Control Methods (Storey 1996).

| Product Evaluated | Soil Type | Max.Allowable Sediment Loss of 0.34 kg/10 $m^2$ | Min.Allowable Vegatation Density of 80% |
|---|---|---|---|
| Compost | Clay | 0.34 | 99 |
| Wood Chips with TERRA TACK™SC | Clay | 0.15 | 95 |
| WoodChips with RMB Plus | Clay | 0.30 | 57 |
| **Product Evaluated** | **Soil Type** | **Max. Allowable Sediment Loss of 12.21 kg/10 $m^2$** | **Min. Allowable Vegetation Density of 70%** |
| Compost | Sand | 3.88 | 92 |
| WoodChips with TERRA TACK™SC | Sand | 11.27 | 48 |
| WoodChips with RMB Plus | Sand | 10.97 | 50 |

1kg/10 $m^2$ = 1.84 lb/10 $yd^2$

**Demonstration Project:**

A test project was constructed in San Augustine County, Lufkin District to evaluate the effectiveness of shredded brush (wood chips) as an erosion control measure. The project site is located on SH103, 10.5 kilometers (6.5 miles) east of the intersection between SH103 and SH147 (Figure 7.2). The total project area was 9,104 $m^2$ (10,886 $yd^2$). The average daily traffic at this section is 1,900 vehicles per day. The shredded brush, as mulch, was applied in October of 1997. The subgrade soil in the right-of-way was of clayey type. The local average annual rainfall is 102 – 124 cm. (40 - 49 in.). The wood chips were derived from pine and hardwood trees. The types of vegetation used in this project were Ryegrass and Bermuda.

**Figure 7.2.** Shredded Brush Used as Erosion Control in Lufkin District

Cost Information: The cost of mulch for this project was $15.12/m$^3$ ($12.50/CY). The shredded brush demand in the area is low. Storey et al. (1996) presented the costs of various erosion control materials including compost as shown in Table 7.2.

**Table 7.2.** Costs of Erosion Control Materials

| Erosion Control Material | Average Cost ($\$/m^2$) |
|---|---|
| Synthetic Blanket | 3.90 |
| Organic Blanket | 1.20 |
| Mulch | 0.34 |
| Wood Chips from ROW Cleaning | 0 |
| Compost | 0.97 |

The Environmental Protection Agency (EPA) reported that the range of disposal fees for brush and yard waste was $ 5.50 to $ 151 per Megagram ($5.00 to $137 per ton). (Saini et al. 1975).

Processing requirements: There was no processing required as the material was already cured when delivered for the project.

Physical and chemical characteristics of Shredded brush:

The maximum length of shredded brush was 76 mm (3 in.). It was of brown/black color and of musky odor. Shredded brush is not toxic to plants and is aesthetically acceptable.

Source: The supplier of mulch was Elliott's Agricultrural Service Inc., US 96 Pineland, Texas. They supply mulch to a large number of clients both within Texas and in other states. According to this supplier, mulch is in high demand.

Construction techniques: At first, the embankment slope (1 to 6 grade) was prepared to grade and a dozer was run up and down to leave track marks. Then, half of the total thickness with seeds and fertilizers were placed. Shredded brush was dumped and smoothened to the desired depth. Later, the other half-thickness was applied. The shredded brush application rate was 0.9 –1.3 $kg/m^2$ (1.7-2.4 $lb/yd^2$). Spreading of shredded brush was done by track, hoe, and dozer. The 12-12-12 type of fertilizer was used at a rate of 0.162 $kg/m^2$ (0.299$lb/yd^2$). Terra Tack ™ SC, a tacking agent, was injected uniformly into shredded brush at a rate of 6.75 kilograms per hectare (6.01 lbs. per acre).

**Results, Findings and Discussion:**

Seeding before shredded brush placement is not effective. Shredded brush appears to retard germination and plant growth by reducing the amount of sunlight reaching the soil. For that reason, it is suggested that shredded brush should be considered as a temporary erosion control measure during construction in areas where other permanent erosion control measures such as re-establishment of native vegetation are planned (Slacum, 1999). Some methods of crimping or disking the shredded brush into the soil would prevent the erosion problems on steep slopes. Runoff from rainfall caused rivulets to form through the shredded brush. These rivulets must be repaired by hand to prevent erosion of the exposed soil (Slacum, 1999). A visual inspection to the project site in the Summer of 1999 revealed the performance of shredded brush as a erosion control measure to be satisfactory.

**Specification**

## TXDOT ITEM 5080 SHREDDED BRUSH FOR EROSION AND SEDIMENTATION CONTROL

**Description**

This Item shall govern for furnishing and placing of shredded brush for erosion control as shown on the plans and as approved by the Engineer.

**Material**

Shredded Brush

Shredded brush shall consist of loose organic material of shredded tree clippings or other wood material to insure adequate protection of the soil. Shredded material shall be free of excess amounts of leaves and large sticks which would prevent proper dressing of the surface. The fiber length of the shredded material shall be 50 to 76 millimeters (2 to 3 inches).

Shredded brush shall be free of harmful chemicals, noxious weeds, clay, litter or other foreign matter that would promote early compaction, matting or deterioration of the shredded brush.

All tree clippings and other acceptable wood material removed from the right of way as part of the project, shall be shredded for use on the project. In the event shredded material from the right of way does not generate sufficient quantity to complete the requirements shown on the plans, then shredded brush shall be provided from other sources as approved by the Engineer.

All fresh shredding shall be stockpiled for a minimum of three (3) months prior to use on the project or shall be treated by blending with ammonium nitrate "nitrogen" at a rate of six (6) kilograms of nitrogen per megagram (14.6 pounds per ton) of shredded brush or tree clippings material. Stockpiles of said material shall be kept in a dry condition, well drained, until applied and shall not be molded or rotted.

With the Engineer's approval onsite shredding is permitted.

All shredded brush or tree clippings shall be tackified to prevent water and wind erosion.

Tacking Agent

Tackifier agent for shredded brush or tree clippings shall be Hydrophilic Colloid, RMB-Plus, for sand material and Granular Polyacrylamide, TERRA TACK TM SC, for clay material unless otherwise shown on the plans. Other biodegradable tacking agents may be used when approved by the Engineer.

## Equipment

All equipment shall be approved by the Engineer prior to use and shall be able to efficiently produce the desired result. The equipment used for shredding will be at the Contractor's option.

## Construction Methods

After the designed areas have been seeded and as provided for in other items of this contract, the shredded brush and or the tree clippings shall be spread uniformly over the area indicated on plans or as designed by the Engineer at the rate of approximately 0.9 to 1.3 kilograms per square meter (2.7 to 2.4 pounds per square foot) unless otherwise shown on the plans to form a depth as shown on the plans.

When used, a hydromulch machine approved by the Engineer shall be equipped to inject a tacking agent into the shredded brush or the tree clippings uniformly as it leaves the equipment at a rate of 6.75 kilograms per hectare (6.01 pounds per acre) for TERRA TACK TM SC and 56 kilograms per hectare (49.88 pounds per acre) for the RMB-Plus.

## Measurement

This Item will be measured by the square meter or hectare (square foot or acre), complete in place.

## Payment

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement", will be paid for at the unit price bid for "Shredded Brush" of the depth specified on the plans. This price shall be full compensation for furnishing all materials, equipment and for performing all operations necessary to complete the work.

## Contact persons

| Name | Organization | Telephone/Fax/E-mail |
|---|---|---|
| Clark R. Slacum, P. E. | Texas Department of Transportation, San Augustine, TX-75972 | Phone: (409) 275-9671 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

## CHAPTER 8: SPENT BLASTING SAND

### About the Material

Paints have been used on steel structures for many years to protect them from corrosion. The protective paint coating deteriorates over time and must be removed before repainting. Common removal methods include abrasive blast cleaning, wet abrasive blast cleaning, high-pressure water jetting, power tool cleaning and vacuum blasting. Abrasive blast cleaning is the most cost-effective and productive method (Salt et al., 1995). In this method, compressed air is used to propel abrasives against the steel surface. The abrasives fracture the paint and remove it from the surface. Sand, slag, or metallic grit are typical abrasives. When sand is used as abrasive, it known as spent blasting sand. Spent blasting sand can be collected and processed for reuse to avoid its disposal. Another alternative is to use it as a construction material. However, spent blasting sand is likely to contain hazardous materials that could pose a threat to the environment. As of September of 1990, the official test specified by the EPA for determining whether a material is hazardous based on toxicity is the Toxicity Characteristic Leaching Procedure (TCLP). The TCLP replaced the Extraction Procedure Toxicity test (EPT) (Salt et. al, 1995). Should the material tested reach contaminants in excess of the EPA regulatory levels, the waste is determined to be hazardous and would be ineligible for inclusion in TxDOT projects.

### Demonstration Project

A test project was constructed in the Houston district using spent blasting sand within a cement stabilized base layer. Spent blasting sand was used as partial replacement of sand as fine aggregate in base material. Recycled asphalt pavement (RAP) and cement were the two other materials used during the stabilized base construction. The project is located on Hempstead Highway at State Highway 6 (Figure 8.1). Spent blast sand was used as fine aggregate in stabilized base on Hempstead highway between stations 748+00 and 753+80; and stations 755+00 and 760+00. The pavement section consisted of 6-inch (150-mm) lime treated subgrade, 6-inch (150-mm) cement treated base and an 8-inch (200-mm) continuous reinforced concrete surface.

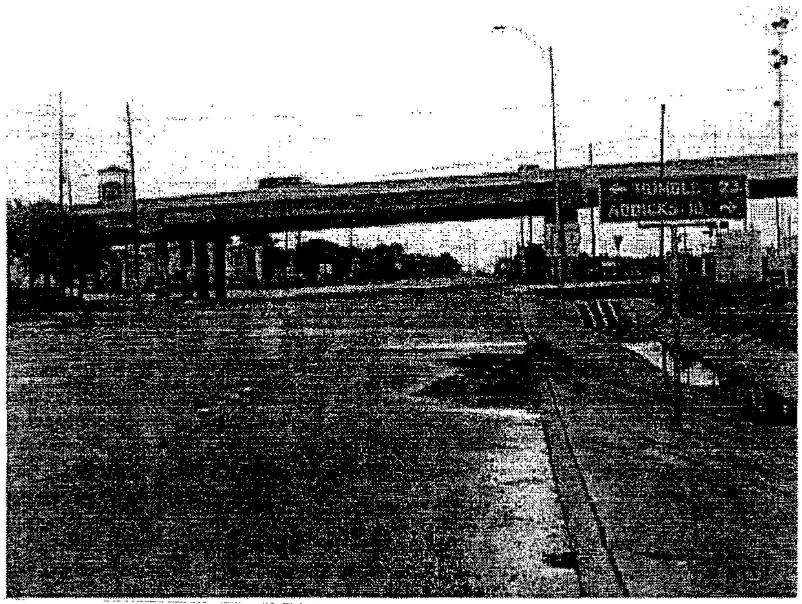


**Figure 8.1.** Demonstration Project Site – Houston, Texas

Laboratory Tests: Tables 8.1, 8.2 and 8.3 present data from laboratory tests performed on spent blast sand.

**Table 8.1.** TCLP Leachate Analysis of Spent Blast Sand

| Constituent | Results (mg/l) | Regulatory Limit (mg/l) |
|---|---|---|
| Arsenic | <0.20 | 5 |
| Barium | 0.58 | 100 |
| Cadmium | <0.10 | 1 |
| Chromium | <0.10 | 5 |
| Lead | <0.20 | 5 |
| Mercury | <0.001 | 0.2 |
| Selenium | <0.20 | 1 |
| Silver | <0.10 | 5 |

**Table 8.2.** Volatile TCLP Analysis of Spent Blast Sand

| Analyte | Amount Found (ug/l) | PQL* (ug/l) | Regulatory Level** (ug/l) |
|---|---|---|---|
| Vinyl Chloride | <80 | 80.0 | 200 |
| 1,1-Dichloroethane | <100 | 100.0 | 700 |
| 2-Butanone | <12000 | 12000.0 | 200,000 |
| Chloroform | <1000 | 1000.0 | 6,000 |
| Carbon Tetrachloride | <100 | 100.0 | 500 |
| 1,2-Dichloroethane | <100 | 100.0 | 500 |
| Benzene | <100 | 100.0 | 500 |
| Trichloroethane | <100 | 100.0 | 500 |
| Tetrachloroethane | <120 | 120.0 | 700 |
| Chlorobenzene | <120 | 120.0 | 100,000 |

*PQL: The Practical Quantitation Limit represents the level below which an analyte may be identified but not accurately quantified
**Regulatory Limit: The USEPA Maximum Contamination Limit for this analyte

**Table 8.3.** SemiVolatile TCLP Analysis on Spent Blast Sand

| Analyte | Amount Found (ug/l) | PQL* (ug/l) | Regulatory Limit** (ug/l) |
|---|---|---|---|
| Pyridine | <50 | 50 | 5,000 |
| 1,4 Dichorobenzene *CC | <50 | 50 | 7,500 |
| 2-Methylphenol | <50 | 50 | 200,000 |
| Hexachloroethane | <50 | 50 | 3,000 |
| 3- & 4-Methylphenols | <50 | 50 | 200,000 |
| Nitrobenzene | <50 | 50 | 2,000 |
| Hexachlorobutadiene *CC | <50 | 50 | 500 |
| 2,4,6 –Trichlorophenol *CC | <50 | 50 | 2,000 |
| 2,4,5 –Trichlorophenol | <50 | 50 | 400,000 |
| 2,4 Dinitrotoluene | <50 | 50 | 130 |
| Hexachlorobenzene | <50 | 50 | 130 |
| Pentachlorophenol *CC | <250 | 250 | 100,000 |

*PQL: The Practical Quantitation Limit represents the level below which an analyte may be identified but not accurately quantified
**Regulatory Limit: The USEPA Maximum Contamination Limit for this analyte

**Results, Discussion & Findings**

The TCLP test result indicates that spent blast sand used in this project can be classified as non-hazardous. This particular test section on Hempstead Highway has not been monitored closely for its performance but there was no report of significant problems associated with base. A visual survey in July of 1999 revealed no significant distresses related to spent blast sand.

**Specification**

TxDOT Specification Item 276 for Portland Cement Treated Base was used in construction.

**Contact Persons**

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| Kathy Rust | TxDOT, Waller/west Harris Area Office, Houston, TX-77040 | Phone: (713) 934-5932<br>Fax: (713) 934-5999 |
| Don Bunch | TxDOT, Waller/west Harris Area Office, Houston, TX-77040 | Phone: (713) 934-5900<br>Fax: (713) 934-5999 |
| Michael W. Alford | TxDOT, Houston District Office, Houston, TX-77007 | Phone: (713)802-5551 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

## CHAPTER 9: TIRES - SHREDDED TIRE AND CRUMB RUBBER

### About the Material

Approximately 280 million tires are discarded annually of which around 30 million are retreaded or reused. About 85 percent of the discarded tires are automobile tires, the rest are truck tires. In addition to this annual generation, it has been estimated that there may be as many as 2 to 3 billion tires that have accumulated over the years and are contained in numerous stockpiles (FHWA, 1998).

Scrap tires can be used in construction activities as a whole tire, shredded tire, and also as a crumb rubber product. Whole tires have been used to construct retaining walls where tires are stacked vertically on top of each other. Adjacent tires are then clipped together horizontally and metal posts are driven vertically through the tire openings and anchored into the underlying earth as necessary to provide lateral support and prevent later displacement. Each layer of tires is filled with compacted earth backfill (Forsyth, 1976). Shredded tires have been used as a lightweight fill material for construction of embankments. Crumb rubber has been used to modify the asphalt binder in a process in which the rubber is blended with asphalt binder. The modified binder is commonly referred to as asphalt-rubber.

### Demonstration Project 1 (Shredded Tire in Embankment)

Texas Department of Transportation has built a section of Loop 375 around El Paso with intersections at different levels. The project starts from intersection of US-54 and LP-375 and ends 0.805 kilometers (0.5 mile) east of LP-375 and Railroad Dr. Intersection (Figure 9.1).

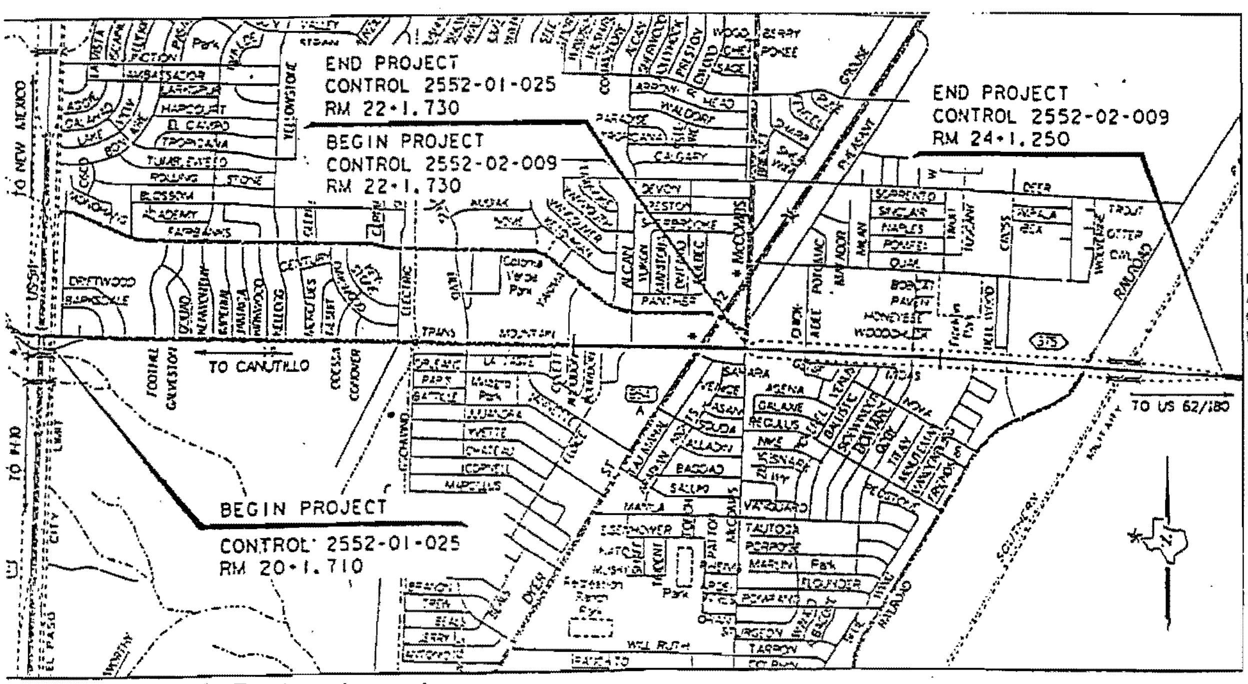



**Figure 9.1.** Project Location

Loop 375 crosses over Alcan, Dyer, McCombs and Bomarc streets. The bridges have been built by incorporating tire chips behind the earth retaining structures. Two of these embankments, one monitored and another non-monitored, have been built using 50:50 mix of soil and tire chips (by volume) and covered by compacted soil. The location is to the west side of Dyer street for the monitored section while the non-monitored section is located to the west of Bomarc street. The maximum size of the tire chip is four inches in these sections and the unit weight for the uncompacted tire chip is 400 $kg/m^3$ (25 $lb./ft.^3$). Another trial embankment has been built using 100% tire chips enclosed in a geotextile wrap and covered with compacted soil. The location for this embankment is east of Dyer street. The maximum size of the tire chip is 305 mm (12 in.) in this section and the unit weight of uncompacted tire chips was 352 $kg/m^3$ (22 $lb./ft.^3$). Conventional compacted soil has been used for other embankments. The existing and proposed typical sections are shown in Figure 9.2.

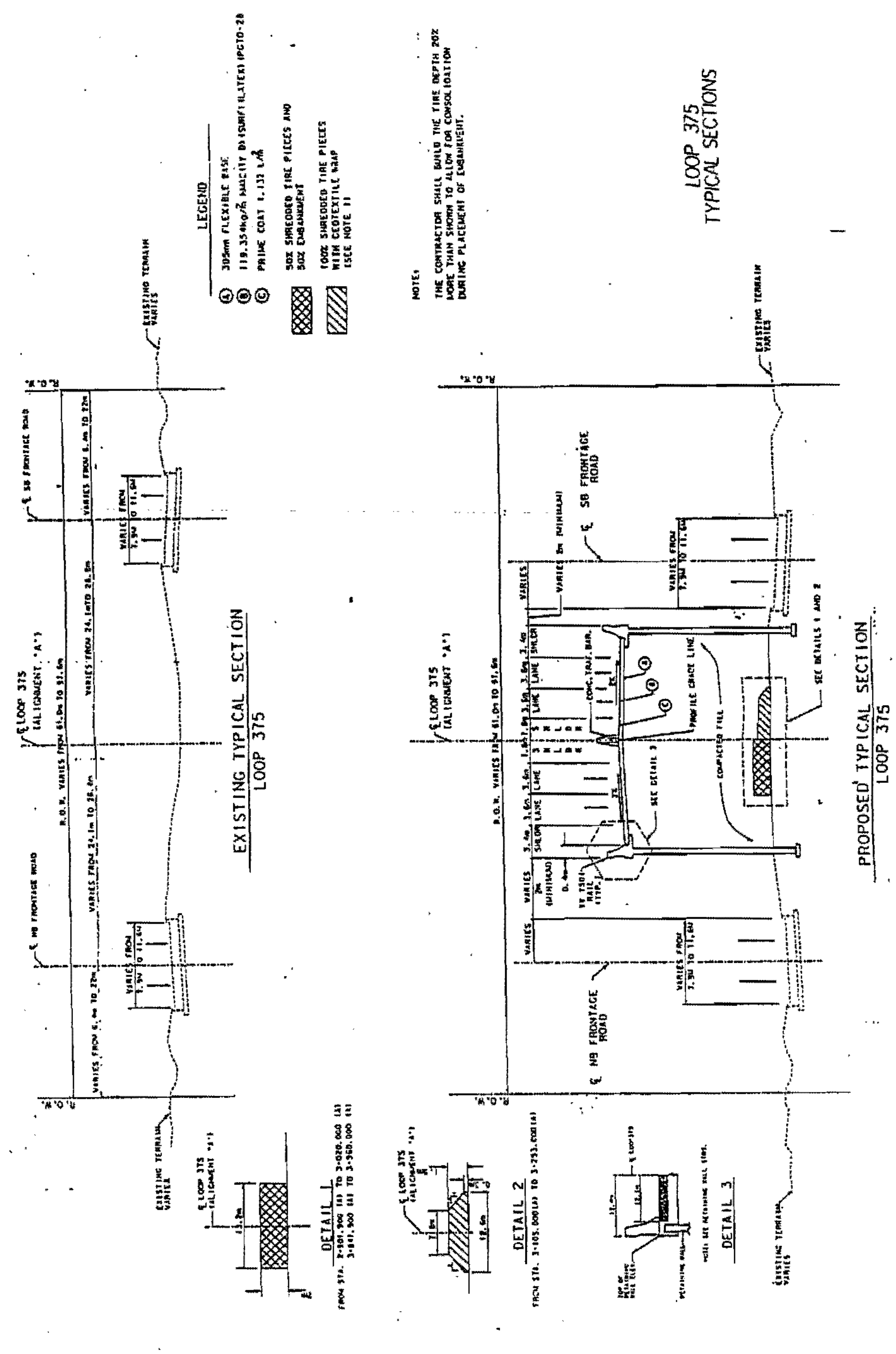



**Figure 9.2.** Existing (above) and Proposed (below) Typical Sections

A total of 5,802 $m^3$ (7576 CY) of tire chips were blended with 13,120 $m^3$ (17132 CY) of embankment material for the 50:50 soil-tire mix sections. A total of 4,895 $m^3$ (6392 CY) of tire chips have been used with 6,192 $m^3$ (8085 CY) of embankment material in constructing the geotextile fabric wrapped tire embankment section.

Cost Information: The unit construction cost of 50:50 tire embankment, geotextile fabric wrapped tire embankment and conventional compacted soil section were \$9.60/m$^3$ (\$7.35/CY) \$11.62/m$^3$ (\$8.90/CY) and \$5/m$^3$ (\$3.83/CY) respectively. The price for placing the material was considered high due to contractor's non-familiarity regarding the compaction effort of tire chips, and secondly, a thirty mile long haul (\$3.16/m$^3$, \$2.42/CY) for chips to project site (Chavez, 1999). Better understanding of this material and planning can eliminate these costs in a future project.

Equipment Installation: Three sections of the road have been instrumented, one section in each type of tire chip fill and one in a conventional embankment to serve as a reference. Instrumentation has been installed to obtain settlement, horizontal movement, moisture, air, and temperature data for short and long term evaluation (Munoz, 1998).

**Demonstration Project 2 (Crumb Rubber in HMAC)**

The project site is located on US Highway 385 in the Odessa District. It is a 29-kilometer (18-mile) long section and starts at the Crane county line and goes all the way into Crane. The existing and proposed typical sections are shown in Figures 9.3 and 9.4. According to an estimation performed in 1996, the annual daily traffic (ADT) on this highway was 6,600 and 7,200 for northbound and southbound Highway 385, respectively. The major distress with the existing pavement was reflective cracking. As part of rehabilitation, hot rubber underseal has been used in conjunction with crumb rubber modified hot mix asphalt concrete (HMAC) overlay. The rehabilitation started with the introduction of hot rubber seal in the fall of 1997, and in the spring of 1998, HMAC was placed on top of it. The construction project was completed in the summer of 1998.

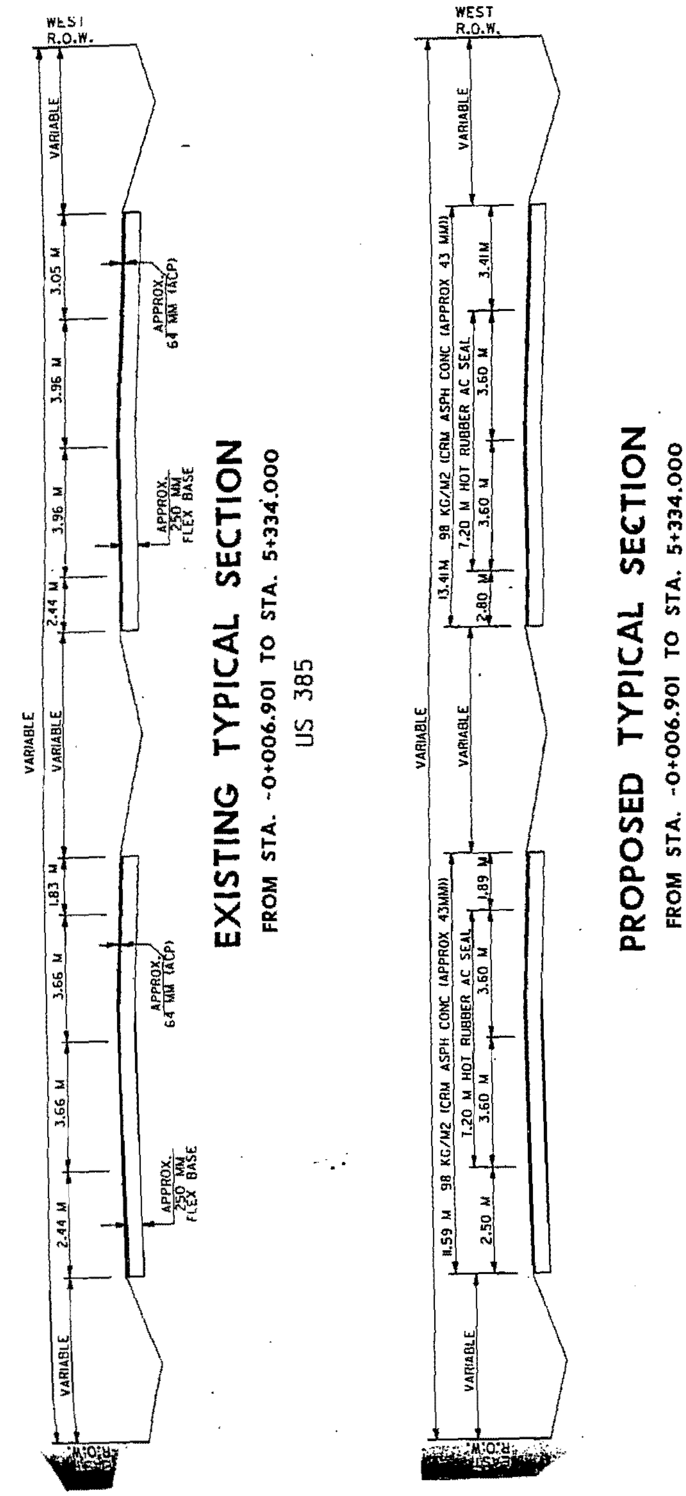



**Figure 9.3**. Existing (above) and Proposed (below) Typical Section (half) of US 385 away from Crane

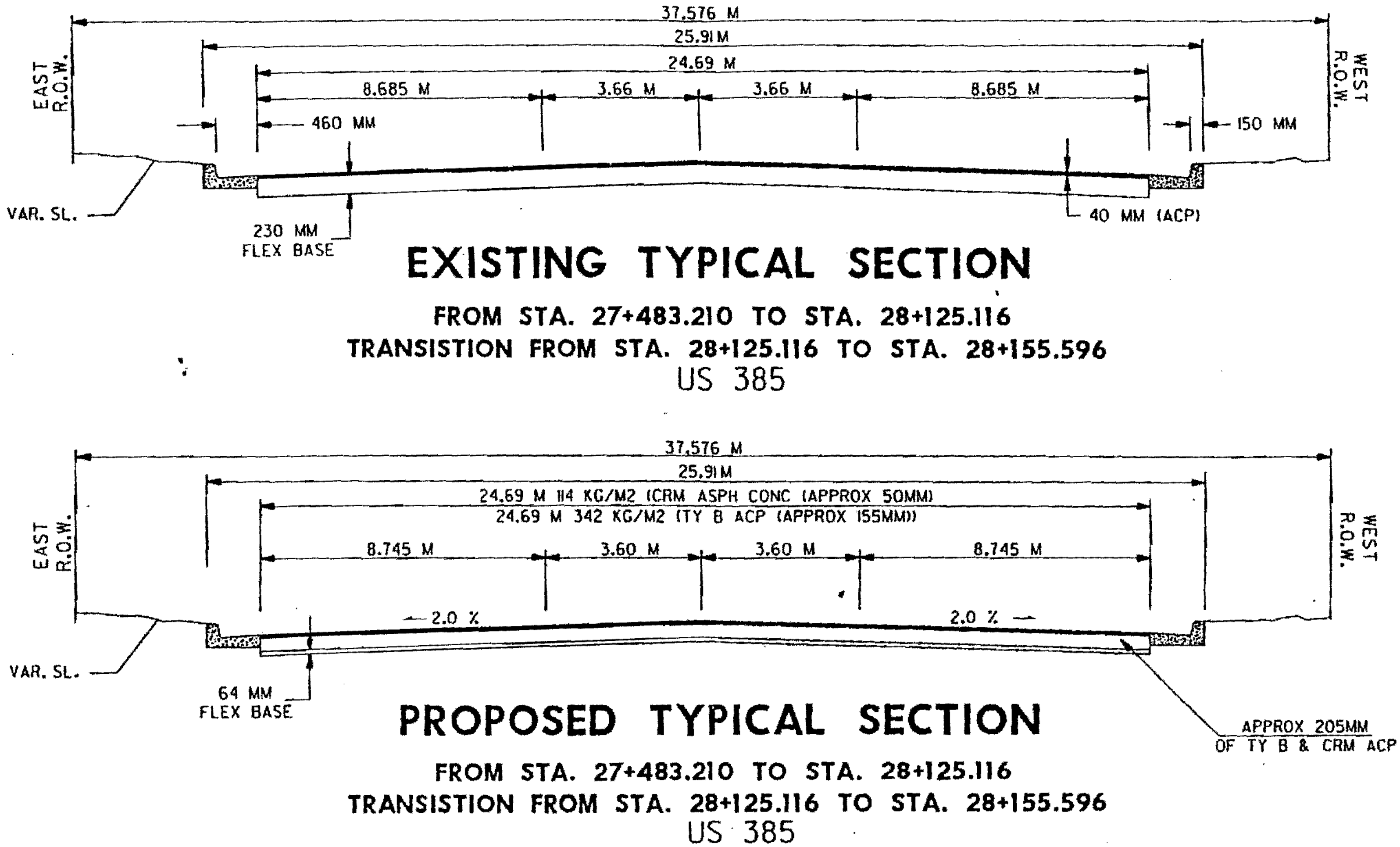



**Figure 9.4.** Existing (above) and Proposed (below) Typical Section of US 385 inside Crane

Laboratory Test Results: Laboratory result shows the specific gravity of asphalt was 1.043 and the combined bulk specific gravity for the mix was 2.638. Tables 9.1 through 9.4 show additional laboratory test results related to crumb rubber, asphalt rubber binder, aggregates and hot mix design.

**Table 9.1.** Gradation for Crumb Rubber

| Sieve Size | Result | Specified Limits |
|---|---|---|
| 1.18 mm / No. 16 | 100 | 100 |
| 0.600 mm/ No. 30 | 98 | 90 - 100 |
| 0.4 mm / No. 40 | 62 | 45 - 100 |

**Table 9.2.** Physical Properties of Asphalt-Rubber Binder (16% Crumb Rubber, 84% Asphalt Cement)

| Test Performed | Minutes of Reaction | | | | | Specified Limits |
|---|---|---|---|---|---|---|
| | 60 | 90 | 240 | 360 | 1440 | |
| Viscosity, Haake at 175°C*, Pa-S (centipoise) | 3.2 (3,200) | 2.5 (2,500) | 2.0 (2,000) | 1.8 (1,800) | 1.5 (1,500) | 1.5 – 4.5 Pa-S |
| Resilience at 25°C*, % Rebound (ASTM D3407) | 27 | - | 21 | - | 20 | 15 Min. |
| Ring & Ball Softening Point, °C* (Tex-505-C) | 63.0 | 62.0 | 61.5 | 61.0 | 60.5 | 57 Min. |
| Cone Penetration at 25°C*, 150 g, 5 sec, 1/10 mm (ASTM D3407) | 48 | - | 57 | - | 63 | 20 Min. |

* °C = 5/9 (°F - 32)

Note: the asphalt-rubber mixture was held overnight at 135°C and heated back to 175°C for the final 24 hour reaction period.

**Table 9.3**. Combined Gradation of Aggregates

| Sieve Size | Cumulative Passing (%) | Min Specification (%) | Max. Specification (%) |
|---|---|---|---|
| 1 – ¼″ | 100.0 | 100 | 100 |
| 1″ | 100.0 | 100 | 100 |
| 7/8″ | 100.0 | 100 | 100 |
| 5/8″ | 100.0 | 100 | 100 |
| ½″ | 100.0 | 100 | 100 |
| 3/8″ | 97.4 | 98 | 100 |
| ¼″ | 97.4 | 85 | 100 |
| #4 | 46.7 | 40 | 60 |
| #10 | 16.9 | 15 | 25 |
| #40 | 8.3 | 6 | 20 |
| #80 | 6.5 | 6 | 18 |
| #200 | 5.4 | 4 | 8 |

1 in. = 25.4 mm

**Table 9.4.** Mix Design Information for HMAC

| Optimum Asphalt Content (OAC) (%) | Air Void at OAC (%) | Void in Mineral Aggregate at OAC (%) | Static Creep Test | | |
|---|---|---|---|---|---|
| | | | Creep Stiffness (Psi) | Perm. Strain * 1,000 (In./In.) | Slope of SS Curve * 100,000,000 (In./In./Sec.) |
| 8.3 | 3 | 20.8 | 7409 | 0.24 | 4.0 |

<u>Field test results</u>: Visual distress survey conducted in summer 1998 and 1999 does not reveal any noticeable distress (Figure 9.5).

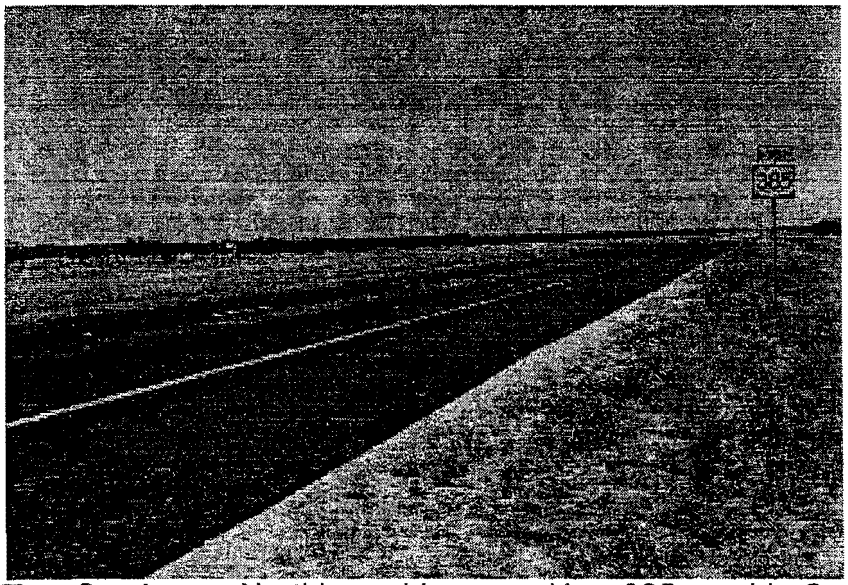


**Figure 9.5a.** Test Section on Northbound Lane on Hwy 385 outside Crane, TX

**Figure 9.5b.** Test Section on Southbound Lane on Hwy 385 outside Crane, TX

**Results, Findings & Discussion**

Shredded Tire in Embankment

The University of Texas at El Paso (UTEP) researchers are evaluating constructability, QC/QA procedures, instrumentation data, short and long term performance, costs and will develop a report with their evaluations, conclusions and recommendations. The UTEP researchers have also developed an excellent Web Page with information on this project, weekly pictorial updates on the construction activities and embankment monitoring results. Their web address is http://www.utep.edu/civil/tirechip/tirechip.htm.

Crumb Rubber in HMAC

This crumb-rubber pavement section did not require any major maintenance ever since it opened to traffic (Smith, 1999). Use of crumb rubber in HMAC reduces life cycle cost of pavement because of less maintenance required.

**Specifications**

**TXDOT ITEM 5160 TIRES FOR USE IN EMBANKMENT**

**Description**

This work shall consist of placing and compacting tire chip and/or shred fill in accordance with this specification and Item 132, "Embankment" in reasonably close conformity with the lines, grades, thicknesses and typical cross sections, as shown on the plans. Instrumentation to monitor the performance of the tire chip fills will be installed by the Departments designated representative in conjunction with this work. The Contractor shall anticipate delays due to instrumentation installation and cooperate with the Engineer as necessary to allow time for the instrumentation to be successfully installed and tested.

**Materials.**

General

The material shall be made from scrap tires which shall be shredded into the Type(s) designated on the plans. The material shall be produced by a shearing or cutting process. Tire particles produced by a hammer mill will not be allowed. The tire particles shall be free of any contaminates such as oil, gasoline, diesel, grease, etc. that could leach into the ground water. In no case shall the tire particles contain the remains of tires that have been subjected to a fire. Type A tire particles will be mixed with soil and Type B tire particles will be a cell enclosed in geotextile.

Tire particles which become contaminated and/or otherwise deemed unacceptable by the Engineer as a result of the activities of this contract shall be removed or processed as directed by the Engineer at no additional cost.

Tire Particles

The gradation shall be measured in accordance with Test Method Tex-401-A, except that the sample size shall be as shown and sample preparation shall be by drying in the 60 C (140 F) oven to a constant weight. Any tire particle shall contain no more than one (1) side wall. Free loose metal not encased in rubber shall not exceed one (1) percent by mass.

**Type A**

| Master Grading | (% Passing) |
|---|---|
| 100 mm (4 in.) | 100 min. |
| 75 mm (3 in.) | 95 min. |
| 50 mm (2 in.) | 50 min. |
| 4.75 mm (No. 4) | 15 max. |
| Sample size = 4.5 kg | (10 lb) min. |

**Type B**

| Master Grading | (% Passing) |
|---|---|
| 300 mm (12 in.) | 100 min. |
| 200 mm (8") | 75 min. |
| 37.5 mm (1.5 in.) | 25 max. |
| 4.75 mm (No. 4) | 1 max. |
| Sample size = 11.4 kg (25 lb.) min. | |

Material Storage

Tire particles shall be stored in an area acceptable to the Engineer.

## Equipment

The machinery, tools and equipment necessary for proper prosecution of the work shall be on the project and approved by the Engineer prior to the beginning of construction operations for this Item. All machinery, tools and equipment used shall be maintained in a satisfactory working condition.

## Construction Methods.

General

It is the primary requirement of this specification to secure an embankment with tire particles as noted on the plans. It shall be the responsibility of the Contractor to regulate the sequence of his work, to provide the depths as shown on the plans, maintain the work and rework the courses as necessary to meet these requirements.

Subgrade Preparation

The subgrade that will underlie the tire particle course shall meet the grade tolerance, compaction and other requirements set forth in Item 132, "Embankment".

Geotextiles

The tire particles cell shall be enclosed in a layer of geotextile as shown on the plans. The geotextile shall meet the requirements of D-9-6200, Type I, and shall be installed with a minimum 450 mm (18 inch) overlap. Holes or tears in geotextile shall be repaired or replaced as directed by the Engineer. Payment for geotextile shall be considered incidental to construction of the tire particle cell.

Placing

*Tire Particle Cell:* The compacted thickness of any tire particle layer shall be as directed by the Engineer and not exceed 300 mm (12 inches). Each layer of the tire particles shall be placed over the full width of the section to the dimensions as shown on the plans. The tire particles shall be spread with track mounted bulldozers, rubber tired motor graders, backhoes, or other equipment as needed to obtain a uniform layer thickness. The tire particles shall be well mixed, with no pockets of either fine or coarse tire particles. Segregation of large or fine particles will not be allowed. Security against vandalism will be required for tire particle stockpiles and tire cells until the stockpiles are depleted and the cell is covered with embankment. Tire particle courses will not be placed on frozen ground.

*Tire particles Mixed with Embankment:* A layer of uncompacted tire particles shall be placed in a uniform layer (300 mm/12 inches max.) as directed by the Engineer. A layer of embankment soil of equal uncompacted thickness shall be placed in a uniform layer on top of the tire particles. The two layers shall be mixed by scarifier, ripper teeth or methods and equipment as approved by the Engineer. The tire particles shall be well mixed with soil in a uniform layer as directed by the Engineer. Each layer of mixed tire particles and soil will be sampled for uniformity.

Embankment and tire particles shall be mixed off site when directed by the Engineer.

Shaping and Compacting.

*Tire Particle Cell:* Each lift of a tire particle cell be compacted with six passes of a vibratory smooth drum roller with a minimum static weight of approximately 9000 kilograms (20,000 Pounds), unless otherwise directed by the Engineer. If the top of any tire particle layer becomes contaminated by the addition of foreign materials, the contaminated material shall be processed or removed as directed by the Engineer.

The surface of each layer shall be maintained during compaction operations in such a manner that a uniform texture is produced and the tire particles are firmly keyed together.

The completed side slopes and surface of the tire article course shall be brought to a condition of uniform stability and compaction. To compensate for settlement of the tire particles caused by the weight of the overlying soil, the top surface of the tire particle fill shall be overbuilt as shown on the plans. The side slopes of the tire particle fill shall be overbuilt by the amount shown on the plans at the top of the slope. A tolerance of 75 mm (3 inches) below the required grade and cross section will be allowed.

After the embankment has been completed and the final subgrade elevations have been achieved, a minimum of 30 days shall have lapsed for tire consolidation before final paving is allowed within 61 meters (200 ft.) of the bridge abutment unless otherwise approved by the Engineer.

*Tire Particles Mixed With Embankment:* Tire particles mixed with embankment shall be shaped as approved by the Engineer. Tire particles mixed with embankment shall be compacted by "Ordinary Compaction" method as stated in Item 132, "Embankment". The embankment soil to be mixed with tire particles shall be a granular material with 100% passing the 9.5 mm (3/8 inch) sieve according to Test Method Tex-401-A and a bar Linear shrinkage not to exceed two (2) when tested according to Test Method Tes-107-E.

*General:* Tire particle compaction within 0.91 meter (3 ft.) of instrumentation and fill over conduits shall be accomplished with a walk behind vibratory smooth drum, vibratory tamping foot or vibratory pad-foot roller, with a minimum static weight of 680 kilogram (1,500 lbs.). Vibratory plate compactors are ineffective for compacting tire particles and will not be allowed. Wheeled vehicles shall not be allowed to drive over conduit placed within the tire particle fill, unless there is a minimum of 0.6-meter (2 ft.) fill over the conduit.

The Contractor shall take all necessary precautions to prevent damage, disturbance or movement of any monitoring device, once installed. The Contractor shall immediately notify the Engineer of any instrumentation damage, disturbance or movement.

**Measurement**

The tire particle course placed in accordance with the widths and thicknesses shown on the plans and compacted as specified will be measured by the cubic meter in vehicles as delivered on the road.

**Payment**

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for "Tires for Use in Embankment", of the type specified. This price shall be full compensation for furnishing and installing geotextile; placing, compacting, reworking, removal and reprocessing if needed; recompacting if needed; and for all labor, tools, equipment and incidentals necessary to complete the work.

## TXDOT ITEM 3020 CRUMB RUBBER MODIFIED (CRM) HOT MIX ASPHALTIC CONCRETE PAVEMENT

### Description

This Item shall govern for the construction of a level-up course, a surface course or any combination of these courses as shown on the plans, each course being composed of a compacted mixture of aggregate and asphalt-rubber mixed hot in a mixing plant, in accordance with the details shown on the plans and the requirements herein.

### Environmental Permitting

The Contractor shall be required to obtain the necessary permits from the Texas Natural Resource Conservation Commission to insure compliance with standards for Air quality. Additional stack emissions tests may be required to determine the levels of potentially hazardous compounds which may include, but are not limited to total Volatile Organic Compounds (VOC) and particulates emission. Permitting will be site specific and consideration will be given on a case by case basis to be determined by the levels of said compounds and site sensitivity.

### Materials

The Contractor shall furnish materials to the project meeting the following requirements prior to mixing. Additional test requirements affecting the quality of individual materials or the paving mixture shall be required when indicated on the plans.

Aggregate

The aggregate shall be composed of a coarse aggregate, a fine aggregate, and if required or allowed, a mineral filler. Samples of each aggregate shall be submitted for approval in accordance with Item 6,"Control of Materials".

Aggregate from each stockpile shall meet the quality requirements of Table 1 and other requirements as specified herein.

*Coarse Aggregate:* Coarse aggregate is defined as that Part of the aggregate retained on a 2.00 millimeter (No. 10) sieve. The aggregate shall be natural, and be of uniform quality throughout. When specified on the plans, certain coarse aggregate material may be allowed, required or prohibited.

Gravel from each source shall be so crushed as to have a minimum of 85 percent of the particles retained on the 4.75 millimeter (No. 4) sieve with two or more mechanically induced crushed faces, as determined by Test Method Tex 460-A (Part I). The material passing the 4.75 millimeter (No. 4) sieve and retained on the 2.00 millimeter (No. 10) sieve must be the product of crushing aggregate that was originally retained on the 4.75 millimeter (No. 4) sieve.

The polish value for coarse aggregate used in the surface or finish course shall not be less than the value shown on the plans, when tested in accordance with Test Method Tex 438-A. Unless otherwise shown on the plans, the polish value requirement will apply only to aggregate used on travel lanes. For rated sources, the Materials and Tests Division's Rated Source Polish Value (RSPV) catalog will be used to determine polish value compliance. Unless otherwise shown on the plans, coarse aggregates may be blended in accordance with Test Method Tex-438-A, Part II, Method B, to meet the polish value requirement. When blending is allowed, the blended aggregates shall contain non-polishing aggregates of not less than 50 percent by volume of the aggregate.

Aggregates with a satisfactory skid history that do not meet the minimum polish value or RSPV requirement may be used on this project. A list of aggregate sources with an acceptable skid history is available from the Engineer.

*Fine Aggregate:* The fine aggregate is defined as that part of the aggregate passing the 2.00 millimeter (No. 10) sieve and shall be of uniform quality throughout. When specified on the plans, certain fine aggregate material may be allowed, required or prohibited. However, a maximum of 15 percent of the total aggregate may be field sand or other uncrushed fine aggregate.

Unless otherwise shown on the plans, stone screenings are required and shall be the result of a rock crushing operation and meet the following gradation requirements, when tested in accordance with Test Method Tex-200-F,Part II.

| | **Percent by Mass** |
|---|---|
| Passing the 9.5 millimeter (3/8 inch) sieve...... | 100 |
| Passing the 2.00 millimeter (No. 10) sieve...... | 70 - 100 |

Crushed gravel screenings may be used with, or in lieu of, stone screenings when shown on the plans. Crushed gravel screenings must be the product of crushing aggregate that was originally retained on the 4.75 millimeter (No. 4) sieve and meet the gradation for stone screenings shown above.

*Mineral Filler:* Mineral filler shall consist of thoroughly dried stone dust. The mineral filler shall be free from foreign matter.

When a specific type of mineral filler is specified on the plans, fines collected by the baghouse or other air cleaning or dust collecting equipment shall not be used to meet this requirement. When mineral filler is not specifically required, the addition of baghouse or other collected fines will be permitted if the mixture quality is not adversely affected in the opinion of the Engineer. In no case shall the amount of material passing the 0.075 millimeter (No. 200) sieve exceed the tolerances of the job-mix formula or the master gradation limits.

When mineral filler is specified or allowed by the Engineer, or baghouse fines are permitted to be added to the mixture, it shall be proportioned into the mix by a vane meter or an equivalent

measuring device acceptable to the Engineer. A hopper or other acceptable storage system shall be required to maintain a constant supply of mineral filler to the measuring device.
The measuring device for adding mineral filler shall be tied into the automatic plant controls so that the supply of mineral filler will be automatically adjusted to plant production and provide a consistent percentage to the mixture. When shown on the plans, the measuring device for adding baghouse fines shall have controls in the plant control room which will allow manual adjustment of feed rates to match plant production rate adjustments.

When tested in accordance with Test Method Tex-200-F, Part II, the mineral filler shall meet the following Gradation requirements, unless otherwise shown on the plans. Baghouse fines are not required to meet the gradation requirements.

| | **Percent by Mass or Volume** |
|---|---|
| Passing 0.60 mm (No. 30) sieve | 95 - 100 |
| Passing 0.180 mm (No. 100) sieve, not less than | 75 |
| Passing 0.075 mm (No. 200) sieve, not less than | 55 |

**Table 9.5.** Aggregate Quality Requirements *

| Requirement | Test Method | Natural Aggregate |
|---|---|---|
| COARSE AGGREGATE | | |
| Deleterious Material, percent, maximum | Tex-217-F Part I | 1.5 |
| Decantation, percent, maximum | Tex-217-F Part II | 1.5 |
| Los Angeles Abrasion, percent, maximum | Tex-410-A | 35 |
| Magnesium Sulfate Soundness Loss, 5 cycle, percent, maximum | Tex-411-A | 30** |
| Flakiness Index, maximum | Tex-224-F | 17 |
| FINE AGGREGATE | | |
| Linear Shrinkage, maximum | Tex-107-E Part II | 3 |
| COMBINED AGGREGATE | | |
| Sand Equivalent Value, minimum | Tex-203-F | 45 |

* Sampled during delivery to the plant or from the stockpile, unless otherwise shown on the plans.
** Unless otherwise shown on the plans.
*** Aggregates, without added mineral filler or additives, combined as used in the job-mix formula.

Asphaltic Material

*Asphaltic Materials:* The asphaltic materials used shall be one or more of the materials prescribed in Item 300,"Asphalts, Oils and Emulsions". A change in source or grade shall require verification that the binder and moisture susceptibility requirements of this specification are met.

*Asphalt Extender Oil*: An asphalt extender oil may be added, if necessary, to meet the requirements for asphalt-rubber binder. Extender oil shall be a resinous aromatic hydrocarbon with a minimum flash point of 205 C.

*Crumb Rubber Modifier*: The crumb rubber modifier shall be produced from processing automobile and/or truck tires by ambient-temperature grinding methods. The rubber shall be substantially free from contaminants including fabric, metal, mineral and other non-rubber substances. The rubber shall be sufficiently dry to be free-flowing and not produce a foaming problem when added to hot asphalt cement. Up to 2% (by mass of rubber) of talc or other appropriate blocking agent may be added to reduce agglomeration of the rubber particles. When tested in accordance with Test Method Tex-200-F, Part I, using a 50-gram sample, the resulting rubber gradation shall meet the following gradation limits.

| **Sieve Size** | **Percent Passing** |
| --- | --- |
| 1.18 millimeter (No. 16) | 100 |
| 0.60 millimeter (No. 30) | 90-100 |
| 0.4 mm millimeter (No. 40) | 45-100 |

A change in source of crumb rubber modifier shall require verification that the binder and mixture design requirements of this specification are met.

(i) Fiber Content: The ground rubber shall have less than 0.1% by mass fiber. Fiber content shall be determined by weighing fiber agglomerations which are formed during the gradation test procedure.

(ii) Moisture Content: The moisture content shall be less than 0.75% by mass.

(iii) Metal Contamination: The rubber shall contain no visible metal particles as indicated by thorough stirring of a 50-gram (0.1 lb.) sample with a magnet.

(iv) Non-Federal Aid Projects: Ground tire rubber shall be produced from scrap tires ground in a facility in Texas, if such material is available in Texas.

*Asphalt-Rubber Binder:* The asphalt cement shall be modified by the addition of a maximum of 18 percent of crumb rubber modifier, by mass of the asphalt-rubber binder. Additionally a minimum of 10 kilograms of crumb rubber modifier shall be used per megagram of the mixture (5 pounds modifier per ton). The asphalt cement, extender oil (when required), and the crumb rubber modifier shall be blended for a period of at least one (1) hour prior to mixing with the aggregate. The temperature of the asphalt cement shall be between 175 C and 205 C (350 F and 400 F) at the addition of the crumb rubber modifier.

Temperature of the asphalt-rubber binder shall be maintained between 165 C and 190 C (330 F and 375 F) during the one (1) hour reaction period. The mixture of asphalt cement and rubber shall not be held at temperatures over 175 C (350 F) for a period over eight (8) hours. When the blended asphalt-rubber is held for more than eight (8) hours, the viscosity of the asphalt-rubber blend shall be measured prior to use and shall meet the viscosity requirements stated in this section.

The design blend of asphalt cement, rubber and, if required, extender oil, shall be provided by the Contractor along with laboratory tests showing that the following requirements are met. These requirements may be adjusted as approved by the Engineer. The Contractor shall select a target viscosity for the blend at the time of use. The Engineer may verify any or all of these required proportions at any time.

The blended asphalt-rubber binder shall meet the following requirements:

| **Property** | **Requirements** | **Test Method** |
|---|---|---|
| Viscosity, Haake, 175 C | 1.5-4.5 Pa-S | |
| Cone Penetration, 25 C, 150 g, 5 s | 20 minimum | ASTM D 1191 |
| Softening Point, C | 57 C, minimum | Tex-505-C |
| Resilience, 25 C | 15% minimum | ASTM D 3407 |

At the end of each shift, the Contractor shall provide the Engineer with documentation on the production of asphalt-rubber that includes the following.

1. The amount and temperature of the asphalt cement prior to the addition of rubber.

2. The amount of rubber added.

3. The viscosity of each batch of asphalt-rubber just prior to the mixing with the aggregates.

4. The time of the rubber additions and viscosity tests.

*Tack Coat* Asphaltic materials for tack coat shall be an asphalt cement of a grade shown on the plans or approved by the Engineer, complying with the requirements of Item 300,"Asphalts, Oils and Emulsions".

Additives

Additives to facilitate mixing and/or improve the quality of the asphaltic mixture shall be used when noted on the plans or may be used with the authorization of the Engineer.

Unless otherwise shown on the plans, the Contractor may choose to use either lime or a liquid antistripping agent to reduce the moisture susceptibility of the aggregate. The evaluation and addition of antistripping agents will be in accordance with Item 301, "Asphalt Antistripping Agents".

**Paving Mixtures**

The paving mixtures shall consist of a uniform mixture of aggregate, hot asphalt-rubber, and additives if allowed or required.
An asphalt mixture design is a laboratory process which includes the determination of the quality of the asphalt-rubber and the individual aggregates, the development of the job-mix formula, and the testing of the combined mixture.

The job-mix formula lists the quantity of each component to be used in the mix and the combined gradation of the aggregates used.

Mixture Design

The Contractor shall furnish the Engineer with representative samples of the materials to be used in production 20 working days prior to start of the production. Using these materials, the mix shall be designed in accordance with Test Method Tex-232-F to conform with the requirements herein. Unless otherwise shown on the plans, the Engineer will furnish the mix design for all mixtures. The Engineer may accept a design from the Contractor which was derived using these design procedures.

The second and subsequent mixture designs, or partial designs, for each type of paving mixture which are necessitated by changes in the material or at the request of the Contractor will be charged to the Contractor when a rate is shown on the plans.

When properly proportioned, for the type specified, the blend of aggregates shall produce an aggregate gradation which will conform to the limits of the master grading shown in Table 2. Unless otherwise shown on the plans, the gradation of the aggregate will be determined in accordance with Test Method Tex-200-F, Part II (Washed Sieve Analysis), to develop the job-mix formula.

The master grading limits for the appropriate type and the proposed job-mix formula will be plotted on a gradation chart with sieve sizes raised to the 0.45 power. This plot must show that the proposed job-mix formula is within the limits of the master grading.

The voids in the mineral aggregate (VMA) will be determined as a mixture design requirement only, in accordance with Test Method Tex-207-F, and shall not be less than the value indicated in Table 9.6.

Unless otherwise shown on the plans, the mixture of aggregate, asphalt and additives proposed for use will be evaluated in the design stage for moisture susceptibility, in accordance with Test Method Tex-530-C. The mixture will be acceptable when no visual stripping is evident after running Test Method Tex-530-C. When visual stripping is evident, suitable antistripping additives shall be used. The Engineer may waive this test if a similar design, using the same ingredients, has proven satisfactory.

To substantiate the design, trial mixtures shall be produced and tested using all of the proposed project materials and equipment prior to any placement. The Engineer may waive trial mixtures if similar designs have proven satisfactory.

Density

The mixture shall be designed to produce an acceptable mixture at an optimum density of 97.0 percent, when tested in accordance with Test Method Tex-207-F and Test Method Tex-227-F. The operating range for control of laboratory density during production shall be optimum density plus or minus 1.0 percent.

Laboratory density is a mixture design and process control parameter. If the laboratory density of the mixture produced has a value outside the range specified above, the Contractor shall investigate the cause and take corrective action. If three (3) consecutive test results fall outside the specified range, production shall cease unless test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the specified range.

Creep Properties

The materials used in the mixture design shall produce a mixture with the creep properties shown in Table 2, unless otherwise shown on the plans, when tested in accordance with Test Method Tex-231-F.

Job-Mix Formula Field Adjustments

The Contractor shall produce a mixture of uniform composition closely conforming to the approved job-mix formula.

If, during initial days of production, it is determined that adjustments to the mixture design job-mix formula are necessary to achieve the specified requirements, or to more nearly match the aggregate production, the Engineer may allow adjustment of the mixture design job-mix formula within the following limits without a laboratory redesign of the mixture. The adjusted job-mix formula shall not exceed the limits of the master grading for the type of mixture specified nor shall the adjustments exceed 5 percent on any one sieve, 12.5 millimeter (1/2 inch) size and larger, or 3 percent on the sieve sizes below the 12.5 millimeter sieve.

When the considered adjustments exceed either the 5 or 3 percent limits, and the Engineer determines that the impact of these changes may adversely affect pavement performance, a new laboratory mixture design will be required.

The asphalt-rubber content and/or gradation will be adjusted as deemed necessary by the Engineer to maintain desirable laboratory density near the optimum value while achieving other mix requirements.

Types

The aggregate gradation of the job-mix formula shall conform to the master grading limits shown in Table 9.6 for the type mix specified on the plans.

**Table 9.6.** Master Grading Limits and Required Mixture Design Properties (Percent Passing by Mass or Limits)

| Sieve Sizes* | Type | |
|---|---|---|
| (mm) | Fine Surface | Coarse Surface |
| 22.4 | | 100 |
| 16.0 | 100 | 95-100 |
| 9.5 | 85-100 | 50-70 |
| 4.75 | 40-50 | 30-45 |
| 2.00 | 15-25 | 15-25 |
| 0.4 | 6-20 | 6-20 |
| 0.180 | 6-18 | 6-18 |
| 0.075 | 4-8 | 4-8 |
| Air Voids, percent | 3 | 3 |
| VMA, % minimum | | 1209 |
| Creep Slope**, maximum | 0.00000004 mm/mm/sec | 0.00000004 mm/mm/sec |
| Creep Stiffness**, minimum | 41,400 kPa | 41,400 kPa |
| Permanent Strain**, maximum | 0.0006 mm/mm | 0.0006 mm/mm |

*25.4 mm = 1 in.
**Unless otherwise approved by the Director of Materials and Tests.

Tolerances

The gradation of the aggregate and the asphalt-rubber content of the produced mixture shall not vary from the job-mix formula by more than the tolerances allowed herein. When within applied tolerances, the gradation of the produced mixture may fall outside the master grading limits for any of the sieve sizes from the largest sieve size on which aggregate may be retained down through the 0.180 millimeter (No. 100) sieve. Only the quantity of aggregate passing the 0.075 millimeter (No. 200) sieve is further restricted to conform to the master grading limitations shown in Table 9.6 or as modified in Test Method Tex-229-F. A tolerance of two (2) percent is allowed on the sieve size for each mixture type which shows 100 percent passing in Table 9.6.

| Tolerance | Percent by Mass or Volume as Applicable |
|---|---|
| Passing the 22.4 to 2.00 mm sieve | Plus or Minus 5 |
| Passing the 0.4 mm to 0.075 mm sieve | Plus or Minus 3 |
| Asphalt, mass .................... | Plus or Minus 0.5 |
| Asphalt, volume .................... | Plus or Minus 1.2 |

The mixture will be tested in accordance with Test Method Tex-228-F used in conjunction with combined cold feed belt samples tested in accordance with Test Method Tex-229-F. Other methods of proven accuracy may be used. The methods of test will be determined by the Engineer. If three (3) consecutive tests indicate that the material produced exceeds the above tolerances on any individual sieve, or if two (2) consecutive tests indicate that the asphalt content tolerance is exceeded, production shall stop and not resume until test results or other information indicate, to the satisfaction of the Engineer, that the next mixture to be produced will be within the above tolerances.

When disagreements concerning determination of specification compliance occur between allowed sampling and testing procedures, extracted aggregate testing shall take precedence over cold feed belt testing.

When cold feed belt samples are used for job control, the Engineer will select the sieve analysis method that corresponds with the one used to determine the mixture design gradation. The tolerances will be adjusted as outlined in Test Method Tex-229-F.

**Equipment**

General

All equipment for the handling of all materials, mixing, placing and compacting of the mixture shall be maintained in good repair and operating condition and subject to the approval of the Engineer. Any equipment found to be defective and potentially having a negative effect on the quality of the paving mixture or ride quality will not be allowed.

Mixing Plants

Mixing plants may be the weigh-batch type, the modified weigh-batch type or the drum-mix type. All plants shall be equipped with satisfactory conveyors, power units, mixing equipment, aggregate handling equipment, bins and dust collectors.

Automatic proportioning devices are required for all plants and shall be in accordance with Item 520, "Weighing and Measuring Equipment".

It shall be the Contractor's responsibility to provide safe and accurate means to enable inspection forces to take all required samples, to provide permanent means for checking the output of any specified metering device, and to perform calibration and mass checks as required by the Engineer. When cold feed belt sampling is to be used for gradation testing, occasional stoppage of the belt may be necessary unless other means of sampling are approved by the Engineer.

When using fuel oil heavier than Grade No. 2, or waste oil, the Contractor shall insure that the fuel delivered to the burner is at a viscosity of 100 SSU or less, when tested in accordance with Test Method Tex-534-C, to insure complete burning of the fuel. Higher viscosities will be allowed if recommended by the burner manufacturer. If necessary, the Contractor shall preheat the oil to maintain the required viscosity.
The Contractor shall provide means for obtaining a sample of the fuel, just prior to entry into the burner, in order to perform the viscosity test. The Contractor shall perform this test or provide a laboratory test report that will establish the temperature of the fuel necessary to meet the viscosity requirements. There shall be an in-line thermometer to check the temperature of the fuel delivered to the burner.

Regardless of the burner fuel used, the burner or combination of burners and types of fuel used shall provide a complete burn of the fuel and not leave any fuel residue that will adhere to the heated aggregate or become mixed with the asphalt.
The Contractor shall provide equipment to blend the asphalt cement and ground rubber at the specified temperature and for the specified time so that an asphalt rubber is provided with uniform properties which meet the requirements of Section 3.(2)(d). The equipment shall be of adequate capacity and the system shall have the necessary supporting storage equipment to keep the plant in constant supply so that continuous plant operation may occur. A continuously reading thermometer shall be provided to show the temperature of the asphalt-rubber during the reaction and storage periods.

*Weigh-Batch Type*

(i) Cold Aggregate: Bin Unit and Proportioning Device: The cold aggregate bin unit shall have at least four bins of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back, and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. The proportioning device shall provide a uniform and continuous flow of aggregate in the desired proportion to the dryer. Each aggregate shall be proportioned from a separate bin.

When mineral filler is used, as specified in Section 3.(1)(c), an additional bin shall be provided.

(ii) Dryer: The dryer shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operation.

(iii) Screening and Proportioning: The screening capacity and size of the hot aggregate bins shall be sufficient to screen and store the amount of aggregate required to properly operate the plant and keep the plant in continuous operation at full capacity. The hot bins shall be constructed so that oversize and overloaded material will be discarded through overflow chutes. Provisions shall be made to enable inspection forces to have easy and safe access to the proper location on the mixing plant where representative samples may be taken from the hot bins for testing.

(iv) Aggregate Weigh Box and Batching Scale: The aggregate weigh box and batching scales shall be of sufficient capacity to hold and weigh a complete batch of aggregate. The weigh box and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment".

(v) Asphaltic Material Measuring System: If an Asphaltic material bucket and scales are used, they shall be of sufficient capacity to hold and weigh the necessary asphaltic material for one batch. The bucket and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment".

If a pressure type flow meter is used to measure the asphaltic material, the requirements of Item 520, "Weighing and Measuring Equipment", shall apply. This system shall include an automatic temperature compensation device to insure a constant percent by weight of asphaltic material in the mixture.

Provisions of a permanent nature shall be made for checking the accuracy of the asphaltic-rubber material measuring device. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material.

(vi) Mixer: The mixer shall be of the pugmill type and shall have a capacity of not less than 1360 kilograms (of natural-aggregate mixture) in a single batch, unless otherwise shown on the plans. Any mixer that has a tendency to segregate the aggregate or fails to secure a thorough and uniform mixture with the asphaltic material shall not be used. All mixers shall be provided with an automatic timer that will lock the discharge doors of the mixer for the required mixing period. The dump door or doors and the shaft seals of the mixer shall be tight enough to prevent spilling of aggregate or mixture from the pugmill.

(vii) Surge-Storage System and Scales: A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

When a surge-storage system is used, scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment". If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

(viii)Recording Device and Record Printer: The mixture shall be weighed for payment. If a surge-storage system is used, an automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day, unless otherwise indicated on the plans. When surge-storage is not used, batch masses will be used as the basis for payment and automatic recording devices and automatic digital record printers in accordance with Item 520, "Weighing and Measuring Equipment", shall be required.

*Modified Weigh-Batch Type*

(i) General: This plant is similar to the weigh-batch type plant. The hot bin screens shall be removed and the aggregate control is placed at the cold feeds. The cold feed bins will be the same as those required for the drum-mix type plant.

(ii) Cold-Aggregate Bin Unit and Feed System: The number of bins in the cold-aggregate bin unit shall be equal to or greater than the number of stockpiles of individual materials to be used.

The bins shall be of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. When required by the Engineer, an approved stationary scalping screen shall be placed on top of the field sand bin to eliminate roots and other objectionable material. The feed system shall provide a uniform and continuous flow of aggregate in the desired proportion to the dryer. The Contractor shall furnish a chart indicating the calibration of each cold bin in accordance with the plant manufacturer's recommended calibration procedures, or other methods of cold bin calibration acceptable to the Engineer.

When mineral filler is used, as specified in Section 3.(1)(c), an additional bin shall be provided.

(iii) Scalping Screen: A scalping screen shall be required after the cold feeds and ahead of the hot aggregate surge bins.

(iv) Dryer: The dryer shall continually agitate the aggregate during heating. The temperature shall be controlled so that the aggregate will not be damaged in the drying and heating operations. The dryer shall be of sufficient size to keep the plant in continuous operation.

(v) Screening and Proportioning: The hot aggregate shall not be separated into sizes after being dried. There shall be one or more surge bins provided between the dryer and the weigh hopper. Surge bins shall be of sufficient size to hold enough combined aggregate for one complete batch of mixture.

(vi) Aggregate Weigh Box and Batching Scale: The aggregate weigh box and batching scales shall be of sufficient capacity to hold and weigh a complete batch of aggregate. The weigh box and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment".

(vii) Asphaltic Material Measuring System: If an asphaltic material bucket and scales are used, they shall be of sufficient capacity to hold and weigh the necessary asphaltic material for one batch. The bucket and scales shall conform to the requirements of Item 520, "Weighing and Measuring Equipment".
If a pressure type flow meter is used to measure the asphaltic material, the requirements of Item 520, "Weighing and Measuring Equipment", shall apply. This system shall include an automatic temperature compensation device to insure a constant percent by mass of asphaltic material in the mixture.

Provisions of a permanent nature shall be made for checking the accuracy of the asphaltic-rubber material measuring device. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material.

(viii) Mixer: The mixer shall be of the pugmill type and shall have a capacity of not less than 1360 kilograms (of natural-aggregate mixture) in a single batch, unless otherwise shown on the plans. Any mixer that has a tendency to segregate the aggregate or fails to secure a thorough and uniform mixture with the asphaltic material shall not be used. All mixers shall be provided with an automatic timer that will lock the discharge doors of the mixer for the required mixing period. The dump door or doors and the shaft seals of the mixer shall be tight enough to prevent spilling of aggregate or mixture from the pugmill.

(ix) Surge-Storage System and Scales: A surge-storage system may be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

When a surge-storage system is used, scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment". If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require weight checks by truck scales for the basis of approval of the equipment.

(x) Recording Device and Record Printer: The mixture shall be weighed for payment. If a surge-storage system is used, an automatic recording device and a digital record printer shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day, unless otherwise indicated on the plans. When surge-storage is not used, batch masses will be used as the basis for payment and automatic recording devices and automatic digital record printers in accordance with Item 520, "Weighing and Measuring Equipment", shall be required.

*Drum-Mix Type*

(i) General: The plant shall be adequately designed and constructed for the process of mixing aggregates and asphalt. The plant shall be equipped with satisfactory conveyors, power units, aggregate handling equipment and feed controls.

(ii) Cold-Aggregate Bin Unit and Feed System: The number of bins in the cold-aggregate bin unit shall be equal to or greater than the number of stockpiles of individual materials to be used. The bins shall be of sufficient size to store the amount of aggregate required to keep the plant in continuous operation and of proper design to prevent overflow of material from one bin to another. There shall be vertical partitions between each bin and on each end of the bins of sufficient height so that any overflow will be to the front and back and not allow overflow to the sides or between bins. Overflow that might occur shall not fall onto any feeder belt. When required by the Engineer, an approved stationary scalping screen shall be placed on top of the field sand bin to eliminate roots and other objectionable material. The feed system shall provide a uniform and continuous flow of aggregate in the desired proportion to the mixer. The Contractor shall furnish a chart indicating the calibration of each cold bin in accordance with the plant manufacturer's recommended calibration procedures, or other methods of cold bin calibration acceptable to the Engineer.

The system shall provide positive mass measurement of the combined cold-aggregate feed by use of belt scales or other approved devices. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device as required by Item 520, "Weighing and Measuring Equipment". When a belt scale is used, mixture production shall be maintained so that the scale normally operates between 50 percent and 100 percent of its rated capacity. Belt scale operation below 50 percent of the rated capacity may be allowed by the Engineer if accuracy checks show the scale to meet the requirements of Item 520, "Weighing and Measuring Equipment", at the selected rate. It shall be satisfactorily demonstrated to the Engineer that mixture uniformity and quality have not been adversely affected.

(iii)Scalping Screen: A scalping screen shall be required after the cold feeds and ahead of the combined aggregate belt scales.

(iv) Asphaltic Material Measuring System: An asphaltic material measuring device meeting the requirements of Item 520, "Weighing and Measuring Equipment," shall be placed in the asphalt line leading to the mixer so that the cumulative amount of asphalt used can be accurately determined. Provisions of a permanent nature shall be made for checking the accuracy of the measuring device output. The asphalt line to the measuring device shall be protected with a jacket of hot oil or other approved means to maintain the temperature of the line near the temperature specified for the asphaltic material. The measuring system shall include an automatic temperature compensation device to maintain a constant percent by mass of asphaltic material in the mixture.

(v) Synchronization Equipment for Feed-Control System: The asphaltic material feed-control shall be coupled with the total aggregate mass measuring device to automatically vary the asphalt-feed rate in order to maintain the required proportion.

(vi) Mixing System: The mixing system shall control the temperature so that the aggregate and asphalt-rubber will not be damaged in the drying, heating and mixing operations. A continuously recording thermometer shall be provided which will indicate the temperature of the mixture as it leaves the mixer.

(vii)Surge-Storage System and Scales: A surge-storage system shall be used to minimize the production interruptions during the normal day's operations. A device such as a gob hopper or other device approved by the Engineer to prevent segregation in the surge storage bin shall be used. The mixture shall be weighed upon discharge from the surge-storage system.

Scales shall be standard platform truck scales or other equipment such as weigh hopper (suspended) scales and shall conform to Item 520, "Weighing and Measuring Equipment". If truck scales are used, they shall be placed at a location approved by the Engineer. If other weighing equipment is used, the Engineer may require mass checks by truck scales for the basis of approval of the equipment.

(viii) Recording Device and Record Printer: Automatic recording devices and automatic digital record printers shall be provided to indicate the date, project identification number, vehicle identification, total mass of the load, tare mass of the vehicle, the mass of asphaltic mixture in each load and the number of loads for the day in accordance with Item 520, "Weighing and Measuring Equipment", unless otherwise shown on the plans.

Asphalt-Rubber Blending Equipment

The Contractor shall provide equipment to blend the asphalt cement and ground rubber at the specified temperature and for the specified time so that an asphalt rubber is provided with uniform properties which meet the requirements of Section 3.(2)(d). The equipment shall be of adequate capacity and the system shall have the necessary supporting storage equipment to keep the plant in constant supply so that continuous plant operation may occur. A continuously reading thermometer shall be provided to show the temperature of the asphalt-rubber during the reaction and storage periods. Equipment to blend crumb rubber and asphalt shall be equipped with satisfactory power units, heaters, augers and other necessary equipment to positively control the rate of addition of crumb rubber to heated asphalt, blend the crumb rubber with asphalt at specified temperature and maintain the blended binder at the required reaction temperature for a minimum of one hour. Any portion of the pavement containing asphalt rubber which has not been reacted for a minimum of one hour will be removed and replaced at the Contractor's expense. Metering units shall be equipped with readout units to enable determination of the amount of asphalt and crumb rubber which are being blended. The crumb rubber and asphalt meters shall be calibrated prior to start of each project and thereafter as required by the Engineer. Portable field viscometers shall be provided by the Contractor and used to measure viscosity of the blend prior to introduction into the mixing plant.

Spreading and Finishing Machine

The spreading and finishing machine shall be approved by the Engineer and shall meet the requirements indicated below.

*Screed Unit:* The spreading and finishing machine shall be equipped with a heated compacting screed. It shall produce a finished surface meeting the requirements of the typical cross sections and the surface tests.

Extensions added to the screed shall be provided with the same compacting action and heating capability as the main screed unit, except for use on variable depth tapered areas and/or as approved by the Engineer.

The spreading and finishing machine shall be equipped with an approved automatic dual longitudinal screed control system and automatic transverse screed control system. The longitudinal controls shall be capable of operating from any longitudinal grade reference including a stringline, ski, mobile stringline or matching shoe.

The Contractor shall furnish all equipment required for grade reference. It shall be maintained in good operating condition by personnel trained in the use of this type of equipment.

The grade reference used by the Contractor may be of any type approved by the Engineer. Control points, if required by the plans, shall be established for the finished profile in accordance with Item 5, "Control of the Work". These points shall be set at intervals not to exceed 15.5 meters (50 feet). The Contractor shall set the grade reference from the control points. The grade reference shall have sufficient support so that the maximum deflection shall not exceed 1.5 millimeters (0.06 inches) between supports.

*Tractor Unit:* The tractor unit shall be equipped with a hydraulic hitch sufficient in design and capacity to maintain contact between the rear wheels of the hauling equipment and the pusher rollers of the finishing machine while the mixture is being unloaded.

No portion of the mass of hauling equipment, other than the connection, shall be supported by the asphalt paver. No vibrations or other motions of the loading equipment, which could have a detrimental effect on the riding quality of the completed pavement, shall be transmitted to the paver.

The use of any vehicle which requires dumping directly into the finishing machine and which the finishing machine cannot push or propel to obtain the desired lines and grades without resorting to hand finishing will not be allowed.

Material Transfer Equipment

Equipment to transfer mixture from the hauling units or the roadbed to the spreading and finishing machine will be allowed unless otherwise shown on the plans. A specific type of material transfer equipment shall be required when shown on the plans.

*Windrow Pick-Up Equipment*: Windrow pick-up equipment shall be constructed in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the spreading and finishing machine. The mixture shall not be contaminated with foreign material. The loading equipment shall be designed so that it does not interfere with the spreading and finishing machine in obtaining the required line, grade and surface without resorting to hand finishing.

*Material Feeding System:* Material feeding systems shall be designed to provide a continuous flow of uniform mixture to the spreading and finishing machine. When use of a material feeding system is required on the plans, it shall meet the storage capacity, remixing capability or other requirements shown on the plans.

Rollers

A minimum of two static wheel compactors and two vibratory steel wheel compactors shall be provided. For courses of 25 millimeters (1 inch) or less in nominal thickness, four static steel wheel compactors shall be provided. The compactors shall weigh not less than 7.2 megagrams (8 tons). When shown on the plans, a pneumatic compactor shall be provided. The compactors shall be self-propelled. All rollers shall be equipped with pads and a watering system to prevent sticking of the asphaltic concrete mix to the steel wheels. The steel wheels shall have adequate width such that two rollers operating in tandem can make a full coverage across the mat being compacted.

Straightedges and Templates

When directed by the Engineer, the Contractor shall provide acceptable 3 meter (10 foot) straightedges for surface testing. Satisfactory templates shall be provided as required by the Engineer.

Alternate Equipment

When permitted by the Engineer, equipment other than that specified herein which will consistently produce satisfactory results may be used.

## Stockpiling, Storage and Mixing

Stockpiling of Aggregates

*Weigh-Batch Plant*: Prior to stockpiling of aggregates, the area shall be cleaned of trash, weeds, grass and shall be relatively smooth and well drained. The stockpiling shall be done in a manner that will minimize aggregate degradation, segregation, mixing of one stockpile with another, and will not allow contamination with foreign material.

The plant shall have at least a two-day supply of aggregates on hand before production can begin and at least a two-day supply shall be maintained through the course of the project, unless otherwise directed by the Engineer.

No stockpile shall contain aggregate from more than one source. Coarse aggregates for Coarse Surface Type mixtures shall be separated into at least two stockpiles, such as coarse and intermediate aggregate stockpiles.

When shown on the plans, coarse aggregates for Fine Surface Type mixtures shall also be separated into at least two stockpiles of different gradation.

No coarse-aggregate stockpile shall contain more than 15 percent by mass of material that will pass a 2.00 millimeter (No. 10) sieve. Fine-aggregate stockpiles may contain coarse aggregate in amounts up to 20 percent by mass. This requirement does not apply to stone screenings stockpiles, which must meet the gradation requirements shown in Section 3.(1)(b), unless otherwise shown on the plans.

When required by the Engineer, additional material shall not be added to stockpiles that have previously been sampled for approval.

Equipment of an acceptable size and type shall be furnished to work the stockpiles and prevent segregation and degradation of the aggregates.

*Modified Weigh-Batch Plant*: The stockpiling requirements for aggregate shall be the same as required for a drum-mix type plant.

*Drum-Mix Plant:* When a drum-mix plant is used, the following stockpiling requirements for coarse aggregates shall apply in addition to the aggregate stockpiling requirements listed under Section 6.(l)(a).

Once a job-mix formula has been established, the coarse aggregates delivered to the stockpiles shall not vary on any grading size fraction by more than plus or minus eight (8) percentage points from the percentage found in the samples submitted by the Contractor and upon which the job-mix formula was based. Should the gradation of coarse aggregates in the stockpiles vary by more than the allowed tolerance, the Engineer may stop production. If production is stopped, new aggregates shall be furnished that meet the gradations of the aggregates submitted for the job-mix formula, or a new mix design shall be formulated.

When the volume of production from a commercial plant makes sampling of all coarse aggregate delivered to the stockpiles impractical, cold feeds will be sampled to determine stockpile uniformity. Should this sampling prove the stockpiles non uniform beyond the acceptable tolerance, separate stockpiles which meet these specifications may be required.

Storage and Heating of Asphaltic Materials

The asphaltic material storage capacity shall be ample to meet the requirements of the plant. Asphalt shall not be heated to a temperature in excess of that specified in Item 300, "Asphalts, Oils and Emulsions". The mixture of asphalt and rubber shall comply with the temperature requirements specified in Section 3.(2)(d). All equipment used in the storage and handling of asphaltic material shall be kept in a clean condition at all times and shall be operated in such a manner that there will be no contamination with foreign matter.

Feeding and Drying of Aggregate

The feeding of various sizes of aggregate to the dryer shall be done through the cold aggregate bins and the proportioning device in such a manner that a uniform and constant flow of materials in the required proportions will be maintained. The aggregate shall be dried and heated to the temperature necessary to produce a mixture having the specified temperature.

Mixing and Storage

*Weigh-Batch Plant*: In introducing the batch into the mixer, all aggregate shall be introduced first and shall be mixed thoroughly for a minimum period of 5 seconds to uniformly distribute the various sizes throughout the batch before the asphaltic material is added. The asphaltic material shall then be added and the mixing continued for a wet mixing period of not less than 15 seconds. The mixing period shall be increased if, in the opinion of the Engineer, the mixture is not uniform or the aggregates are not properly coated.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be permitted during the normal day's operation. Overnight storage will not be permitted unless authorized on the plans or in writing by the Engineer. The mixture coming out of the surge storage bin shall be of equal quality to that coming out of the mixer.

*Modified Weigh-Batch Plant*: The mixing and storage requirements shall be the same as is required for a standard weigh-batch plant.

*Drum-Mix Plant*: The amount of aggregate and asphaltic material entering the mixer and the rate of travel through the mixing unit shall be so coordinated that a uniform mixture of the specified grading and asphalt content will be produced.

Temporary storing or holding of the asphaltic mixture by the surge-storage system will be required during the normal day's operation. Overnight storage will not be permitted unless authorized on the plans or in writing by the Engineer. The mixture coming out of the surge-storage bin shall be of equal quality to that coming out of the mixer.

**Construction Methods**

Tack Coat

The surface upon which the tack coat is to be placed shall be cleaned thoroughly to the satisfaction of the Engineer. The surface shall be given a uniform application of tack coat using asphaltic materials of this specification. This tack coat shall be applied, as directed by the Engineer, with an approved sprayer at a sufficient rate to coat the entire paving surface uniformly. All contact surfaces of curbs and structures and all joints shall be painted with a thin uniform application of tack coat. During the application of tack coat, care shall be taken to prevent splattering of adjacent pavement, curb and gutter and structures. The tack coat shall be rolled with a pneumatic tire roller when directed by the Engineer.

Transporting Asphaltic Concrete

The asphaltic mixture shall be hauled to the work site in tight vehicles previously cleaned of all foreign material. The dispatching of the vehicles shall be arranged so that all material delivered is placed and all rolling completed during daylight hours unless otherwise shown on the plans. In cool weather or for long hauls, covering and insulating of the truck bodies may be required. If necessary, to prevent the mixture from adhering to the body, the inside of the truck may be given a light coating of release agent satisfactory to the Engineer.

Placing

Asphaltic concrete shall be placed only when the temperature of the surface on which the asphaltic concrete is to be placed is at least 27 C (80 F), unless otherwise approved by the Engineer. The mixture shall not be placed on a wet or damp surface. The asphaltic mixture shall be dumped and spread on the approved prepared surface with the spreading and finishing machine. When properly compacted, the finished pavement shall be smooth, of uniform texture and density and shall meet the requirements of the typical cross sections and the surface tests. In addition, the placing of the asphaltic mixture shall be done without tearing, shoving, gouging or segregating the mixture and without producing streaks in the mat.

Unloading into the finishing machine shall be controlled so that bouncing or jarring the spreading and finishing machine shall not occur and the required lines and grades shall be obtained without resorting to hand finishing.

Unless otherwise shown on the plans, dumping of the asphaltic mixture in a windrow and then placing the mixture in the finishing machine with windrow pick up equipment will be permitted. The windrow pick up equipment shall be operated in such a manner that substantially all the mixture deposited on the roadbed is picked up and loaded into the finishing machine without contamination by foreign material. The windrow pick-up equipment will be so operated that the finishing machine will obtain the required line, grade and surface without resorting to hand finishing. Any operation of the windrow pick-up equipment resulting in the accumulation and subsequent shedding of accumulated material into the asphaltic mixture will not be permitted.

In order to achieve a continuous operation, the speed of the paver shall be coordinated with the production of the plant. If the paver is stopped for more than five minutes, or there is a five minute or longer interval between the completion of delivery by one truck and the beginning of delivery by the next truck, the paver shall be pulled away from the mat in order for the rollers to compact the area in accordance with the temperature limitations given hereinafter under compaction. A transverse construction joint shall be made by a method approved by the Engineer. If, in the opinion of the Engineer, sporadic delivery of material is adversely affecting the mat, the Engineer may require paving operations to cease until acceptable methods are provided to minimize starting and stopping of the paver.

The hopper flow gates of the spreading and finishing machine shall be adjusted to provide an adequate and consistent flow of material. These shall result in enough material being delivered to the augers so that they are operating approximately 85 percent of the time or more. The augers shall provide means to supply adequate flow of material to the center of the paver. Augers shall supply an adequate flow of material for the full width of the mat, as approved by the Engineer. Augers should be kept approximately one-half to three-quarters full of mixture at all times during the paving operation.
Adjacent to flush curbs, gutters and structures, the surface shall be finished uniformly high so that when compacted it will be slightly above the edge of the curb or structure.

Construction joints of successive courses of asphaltic material shall be offset at least 150 millimeters (6 inches). Construction joints on surface courses shall coincide with lane lines, or as directed by the Engineer.

If a pattern of surface irregularities or segregation is detected, the Contractor shall make an investigation into the causes and immediately take the necessary corrective action. With the approval of the Engineer, placement may continue for no more than one full production day from the time the Contractor is first notified and while corrective actions are being taken. If the problem still exists after that time, paving shall cease until the Contractor further investigates the causes and the Engineer approves further corrective action to be taken.

<u>In-Place Compaction Control</u>

In-place compaction control is required for all mixtures. The temperature of asphaltic concrete just prior to compaction shall be at least 135 C (275 F). The wheels of compactors shall be wetted with water or, if necessary, soapy water to prevent mix pick-up during rolling.

The Engineer may change the rolling procedures if in his judgment the change is necessary to improve in place compaction. The compactors shall be operated with the drive wheel in the forward position. Vibratory rollers shall be operated in the mode required by the Engineer. The compactors shall not be used in vibratory mode for courses of 25 millimeters (1 inch) or less in nominal thickness. The two vibratory compactors shall be used for initial breakdown and be maintained no more than 91 meters (300 feet) behind the paver. The remaining two compactors shall follow as closely behind the initial breakdown as possible. As many passes as needed shall be made with the second set of compactors to obtain compaction to within the air void range required herein. All compaction shall be completed before the temperature of the asphaltic concrete falls below 104 C (220 F).

Unless otherwise shown on the plans, air void control shall be required for all mixtures. Asphaltic concrete shall be placed and compacted to contain from 5 to 9 percent air voids. The percent air voids will be calculated using the theoretical maximum specific gravity of the mixture determined according to Test Method Tex-227-F. Roadway specimens, which shall be either cores or sections of asphaltic pavement, will be tested according to Test Method Tex-207-F. The nuclear-density gauge or other methods which correlate satisfactorily with results obtained from project roadway specimens may be used when approved by the Engineer. Unless otherwise shown on the plans, the Contractor shall be responsible for obtaining the required roadway specimens at his expense and in a manner and at locations selected by the Engineer.

If the percent air voids in the compacted placement is greater than 9 percent but is 10 percent or less, production may proceed with subsequent changes in the construction operations and/or mixture. If the air void content is not reduced to between 5 and 9 percent within one production day from the time the Contractor is notified, production shall cease. At that point, a test section as described below shall be required.

If the percent air voids is more than 10 percent, Production shall cease immediately and a test section shall be required as described below.

In either case, the Contractor shall only be allowed to place a test section of one lane width, not to exceed 322 meters (1050 feet) in length, to demonstrate that compaction to between 5 and 9 percent air voids can be obtained. This procedure will continue until a test section with 5 to 9 percent air voids can be produced. Only two (2) test sections per day will be allowed. When a test section producing satisfactory air void content is placed, full production may then resume.

If the percent air voids is determined to be less than 5 percent, immediate adjustments shall be made to the plant production by the Contractor, as approved by the Engineer, within the tolerances as outlined in Subarticle 4.(4), so that an adequate air void level results.

The Contractor is encouraged to perform supplemental Compaction testing for his own information.

Ride Quality

Unless otherwise shown on the plans, ride quality will be required in accordance with Special Specification, "Ride Quality for Pavement Surfaces".

Opening to Traffic

The pavement shall be opened to traffic when directed by the Engineer. The Contractor's attention is directed to the fact that all construction traffic allowed on the pavement open to the public will be subject to the State laws governing traffic on highways.

If the surface ravels, flushes, ruts or deteriorates in any manner prior to final acceptance of the work, it will be the Contractor's responsibility to correct this condition at his expense, to the satisfaction of the Engineer and in conformance with the requirements of this specification.

**Measurement**

The quantity of crumb rubber modified asphaltic concrete will be measured by the composite mass or composite volumetric method.

Composite Mass Method

Crumb rubber modified asphaltic concrete will be measured by the megagrams of the composite "Crumb Rubber Modified Asphaltic Concrete" of the type actually used in the completed and accepted work in accordance with the plans and specifications for the project. The composite asphaltic concrete mixture is hereby defined as the asphalt-rubber, aggregate and additives as noted on the plans and/or approved by the Engineer.

If mixing is done by a drum-mix plant, measurement will be made on scales as specified herein.

If mixing is done by a weigh-batch plant or modified weigh-batch plant, measurement will be determined on the batch scales unless surge-storage is used. Records of the number of batches, batch design and the mass of the composite "Crumb Rubber Modified Asphaltic Concrete" shall be kept. Where surge-storage is used, measurement of the material taken from the surge storage bin will be made on truck scales or suspended hopper scales.

Composite Volumetric Method

The crumb rubber modified asphaltic concrete will be measured by the cubic yard of compacted "Crumb Rubber Modified Asphaltic Concrete" of the type actually used in the completed and accepted work in accordance with the plans and specifications for the project. The composite crumb rubber modified asphaltic concrete mixture is hereby defined as the asphalt-rubber, aggregate and additives as noted on the plans and/or approved by the Engineer. The volume of the composite crumb rubber modified asphaltic concrete mixture shall be calculated by the following formula:

$$V = W / 1000 * Ga$$

Where: V = Cubic meters of compacted "Crumb Rubber Modified Asphaltic Concrete"
W = Total mass of crumb rubber modified asphaltic concrete in kilograms
Ga = Average actual specific gravity of three molded specimens as prepared by Test Method Tex-206-F and determined in accordance with Test Method Tex-207-F.

If mixing is done by a drum-mix plant, the Mass "W" will be determined by scales as specified herein. If mixing is done by a weigh-batch plant or modified weigh-batch plant, and surge-storage is not used, mass will be determined by batch scales and records of the number of batches, batch designs and mass of asphalt rubber and aggregate shall be kept. Where surge storage is used, measurement of the material taken from the surge-storage bin will be made on truck scales or suspended hopper scales.

Ride Quality

Ride quality will be measured as described in Special Specification, "Ride Quality for Pavement Surfaces".

**Payment**

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit price bid for the "Crumb Rubber Modified(CRM) Asphaltic Concrete" of the aggregate gradation type specified.

| Measurement Method | Bid Item | Unit of Measure |
|---|---|---|
| Composite Mass | CRM-Asphaltic Concrete | Megagram |
| Composite Volumetric | CRM-Asphaltic Concrete | Meter |

The payment based on the unit bid price shall be full compensation for quarrying, furnishing all materials, additives, freight involved, for all heating, mixing, hauling, cleaning the existing base course or pavement, tack coat, placing, rolling and finishing crumb rubber modified asphaltic concrete mixture, and for all manipulations, labor, tools, equipment and incidentals necessary to complete the work.

When Surface Test Type-B, as specified in Special Specification, "Ride Quality for Pavement Surfaces", is used, a bonus or deduction for each 0.1609 kilometer (0.1 mile) section of each travel lane will be calculated in dollars and cents. A running total of this will be determined for each day's production. The bonus or deduction for ride quality will be paid for separately from the payment for the material placed.

All templates, straightedges, core drilling equipment, scales and other weighing and measuring devices necessary for the proper construction, measuring and checking of the work shall be furnished, operated and maintained by the Contractor at his expense.

**El Paso Contacts**

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| David Head | TxDOT, El Paso District | Phone: (915) 774-4300 |
| | UTEP | |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

**Odessa Contacts**

| Name(s) | Organization | Telephone Number/Fax/E-mail |
|---|---|---|
| Stephen G. Smith, P.E. | TxDOT, Odessa District, TX-79761 | Phone: (915) 498-4716<br>Fax: (915) 498-4689 |
| Kathryn C. Evans | TxDOT, Odessa District, TX-79761 | Phone: (915) 498-4684<br>Fax: (915) 498-4689 |
| Sidney Cox | Cox Paving Company, P.O. Box 519, Blanco, TX-78606 | Phone: (830) 833-4547<br>Fax: (830) 833-4136 |
| Randy Battenfield | Gibson Recycling, P.O. Box 1208, Atlanta, TX-75551 | Phone: (903) 796-8640<br>Fax: (903) 796-0115 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |

## CHAPTER 10: ECONOMIC ANALYSIS

### Introduction

In this section of the report, a benefit-cost analysis framework has been developed and illustrated using data collected from the Abilene Test Project where glass cullet was used in flexible base. This test project was constructed by the Texas Department of Transportation and the City of Abilene is responsible for it's maintenance. Therefore, information used in the economic analysis were collected from these agencies.

### Identification of Benefits and Costs

Any project will result in a number of effects (benefits & costs) that can usefully be broken down into two main categories: direct effects and secondary effects. Direct effects are the effects that result from the goods and services that are directly produced by the project while secondary effects are the changes in the value of production (both increases and decreases) generated indirectly by the project (Anderson et. al., 1977). Both direct and secondary effects can be broken down into two categories: tangible effects and intangible effects. Tangible effects are relatively easy to value in dollar terms whereas intangible effects are not susceptible to being valued in dollar terms.

### Estimation of Benefits & Costs

The general equations used for estimating the present value of benefits and costs are as follows:

Present Value of all benefits, $B = \sum (B_i / (1 + r)^i)$

Present Value of all costs, $C = \sum (Ci / (1 + r)^i)$

Where, $B_i$ = Total benefits accrued in the ith year
$C_i$ = Total costs accrued in the ith year
$r$ = Discount rate

Two criteria will be used for accepting or rejecting this hypothetical commitment. These alternative criteria, and their associated decision rules are presented in Table 10.1 (Anderson et. al., 1977).

**Table 10.1.** Criteria and Associated Decision Rules

| Criteria | Decision Rule |
|---|---|
| Benefit-Cost Ratio, B/C (the ratio of the present value of benefits and costs) | Accept if B/C > 1; reject if B/C < 1 If B/C =1, Policymakers will make decision based on Intangible and Secondary benefits and costs |
| Net Present Value, B-C (the difference between the present value of benefits and present value of costs) | Accept if B-C > 0; reject if B-C < 0 If B-C =0, Policymakers will make decision based on Intangible and Secondary benefits and costs |

A sensitivity analysis will be performed for both benefit-cost ratio (B/C) & net present values (B-C).

**Illustration of Benefit-Cost Analysis with a Case Study**

In this analysis, it is assumed that the Texas Department of Transportation (TxDOT) makes a commitment to use, in their road base construction projects for the next 10 years, all of the glass cullet collected by the City of Abilene's refuse collection division each year. The City of Abilene will collect glass throughout the year, crush it and sell it to TxDOT so that it can be used at the end of each year. The City of Abilene's Refuse Collection Division currently produces 300 cubic yards (CY) of glass cullet each year, and they have the capacity to produce 1,200 cubic yards (Brock, 1999). The objective of this analysis is to estimate the benefits and costs to society resulting from the use of this material in road construction within a guaranteed 10-year demand for full capacity production.

In the analysis, it is assumed that, at the end of each year, one road-section will be constructed using the total amount of glass supplied by the City of Abilene in that year. In this manner, as many as 10 road-sections will be completed at the end of the 10- year period. It is also assumed that each section has a design life of 20 years. Therefore, all the possible benefits and costs resulting from these 10 road-sections throughout their design lives will be considered in the analysis.

Possible Benefits and Costs

The benefits and costs associated with glass cullet use are as follows.

*Direct and Tangible Benefits* Savings in landfill space: It has been estimated that it would require three cubic yards of glass bottles destined for landfill placement to produce one cubic yard of crushed glass for roadbase construction purposes. Therefore, use of one CY of glass cullet will save three cubic yards of landfill space on the average (Brock, 1999). Given that average disposal cost in landfill is $5 / CY (Condry, 1999), one cubic yard of crushed glass used in the road construction will save three cubic yards worth of landfill volume and save $15 in the waste disposal costs.

Savings in natural resources: Use of one cubic yard of glass cullet will replace one cubic yard of the natural resource which would otherwise be used in road construction. Therefore, the replaced natural resource is saved for future use. In Abilene, the replaced natural resource is limestone which has a cost of $16 / CY (Haynie, 1998).

*Secondary and Tangible Benefits* Increased employment: full use of glass cullet would require two additional City of Abilene employees to increase glass output, an Equipment Operator 1, and a collector at $24,000 and $16,000 annual salaries respectively (Brock, 1999). This secondary benefit will not be considered in the economic analysis. Given that the unemployment rate in Abilene is 3.7% in July of 1999 (Texas Workforce Commission Web Site, 1999) the two employees of the glass cullet operation will likely move from existing positions of employment. Therefore, the long term employment benefits would be an impact to the employment in the area, and is outside the scope of the study.

*Direct and Intangible Benefits* Less pollution, as a result of a decreased amount of mining of natural resources (i.e. limestone), is one of the benefits under this category. Furthermore, people may reduce littering with glass bottles as the value of glass increases. The value of these benefits are not estimated in this analysis.

*Direct and Tangible Costs* Cost of glass cullet: "We will sell glass cullet at a price of $9 / CY if we can find a permanent buyer" (Brock, 1999).

Increased cost of construction due to incorporation of glass in base construction: $1 / CY, based on the information from the project.

Increased maintenance/rehabilitation cost due to incorporation of glass in base construction: No significant change, based on the information for the project.

Increase in transportation cost: No change

Calculation of Benefits

Steps in estimating the benefits are as follows.

$B = B_1 + B_2 + \ldots\ldots\ldots + B_{10}$ ........

Where: $B$ = Total present value of social benefit received out of TxDOT's commitment
$B_1$ = Total Present Value of Benefits gained from 1st construction project
$B_2$ = Total Present Value of Benefits gained from 2nd construction project
$B_{10}$ = Total Present Value of Benefits gained from 10th construction project

Again,

$B_1 = B_{1,1} / (1 + r) + B_{1,2} / (1+r)^2 + \ldots\ldots\ldots + B_{1,20} / (1+r)^{20}$

Similarly, for the 2nd construction project,

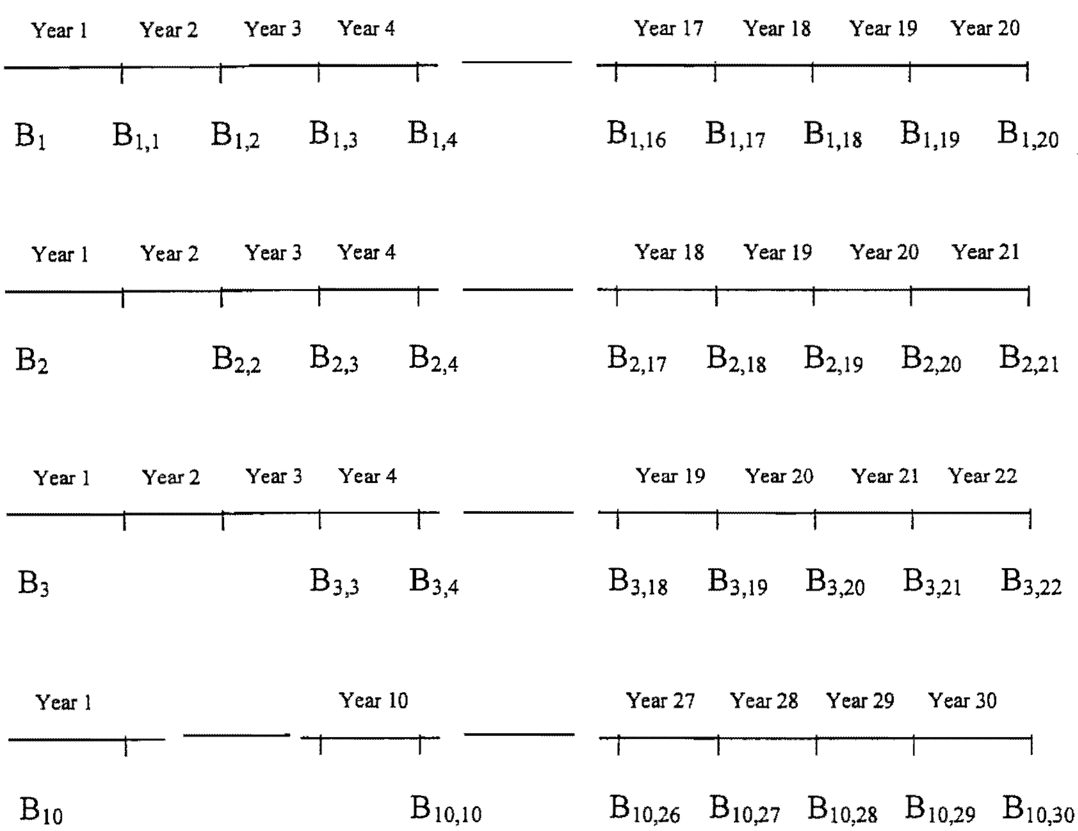
$B_2 = B_{2,2} / (1 + r)^2 + B_{2,3} / (1+ r)^3 + \dots\dots + B_{2,21} / (1+ r)^{21}$

For the 10th construction project,

$B_{10} = B_{10,10} / (1 + r)^{10} + B_{10,11} / (1 + r)^{11} + \dots\dots + B_{10,30} / (1 + r)^{30}$

Where: $B_{1,1}$ = Total benefits gained from 1st construction project at the end of 1st year
$B_{1,2}$ = Total benefits gained from 1st construction project at the end of 2nd year
$B_{2,21}$ = Total benefits gained from 2nd construction project at the end of 21st year
$B_{10,30}$ = Total benefits gained from 10th construction project at the end of 30th year

The following timeline explains how society is benefited at different time from 10 projects.




Now, total social benefits from a project in the first year of construction

= (\$16 + \$15) / CY* 1,200 CY = \$ 31 / CY * 1,200 CY = \$ 37,200

At 3% discount rate,

$B_1 = 37200 / (1 + .03) + 0 / (1 + .03)^2 + \dots\dots\dots\dots + 0 / (1 + .03)^{20}$
$= 36{,}116$ (No benefits in the subsequent years of construction)

Similarly,

$B_2 = 37200 / (1 + .03)^2 + 0 / (1 + .03)^3 + \dots\dots\dots\dots + 0 / (1 + .03)^{21}$
$= 35{,}064$

$B_{10} = 37200 / (1 + .03)^{10} + 0 / (1 + .03)^{11} + \dots\dots\dots\dots + 0 / (1 + .03)^{30}$
$= 27{,}680$

So, $B = 36116 + 35064 + \dots\dots\dots\dots\dots\dots\dots\dots\dots + 27680$
$= 317{,}316$

<u>Calculation of Costs</u>

Steps in estimating the benefits are as follows.

$C = C_1 + C_2 + \dots\dots\dots\dots\dots\dots\dots\dots + C_{10}$ ........ (1)

Where:
$C$ = Total present value of social costs out of TxDOT's commitment
$C_1$ = Total present value of costs gained from 1st construction project
$C_2$ = Total present value of costs gained from 2nd construction project
$C_{10}$ = Total Present Value of Costs gained in year 10 from 10th construction project

Again,

$C_1 = C_{1,1} / (1 + r) + C_{1,2} / (1+r)^2 + \dots\dots\dots\dots\dots\dots\dots\dots\dots + C_{1,20} / (1+r)^{20}$

Similarly, for the 2nd construction project,

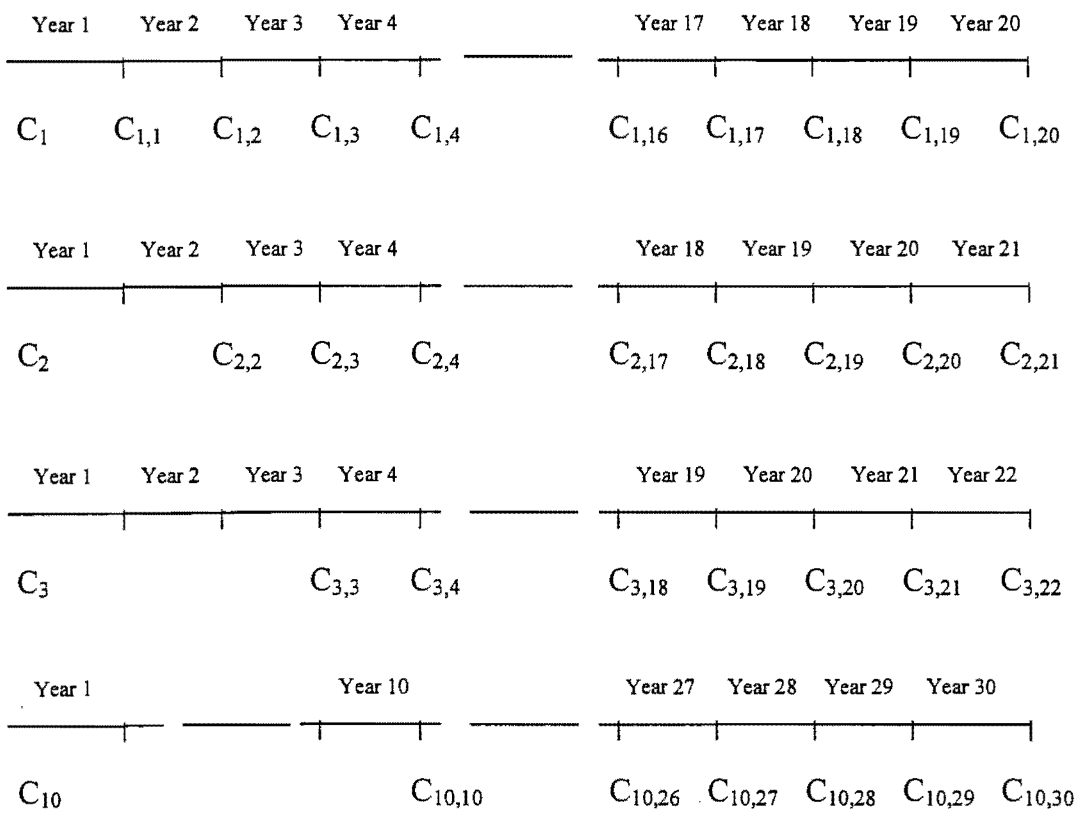
$C_2 = C_{2,2} / (1 + r)^2 + C_{2,3} / (1+r)^3 + \dots\dots\dots\dots\dots\dots\dots\dots\dots + C_{2,21} / (1+r)^{21}$

For the 10th construction project,

$C_{10} = C_{10,10} / (1 + r)^{10} + C_{10,11} / (1+r)^{11} + \dots\dots\dots\dots\dots\dots\dots + C_{10,30} / (1+r)^{30}$

Where:
$C_{1,1}$ = Total costs gained from 1st construction project at the end of 1st year
$C_{1,2}$ = Total costs gained from 1st construction project at the end of 2nd year
$C_{2,21}$ = Total costs gained from 2nd construction project at the end of 21st year
$C_{10,30}$ = Total costs gained from 10th construction project at the end of 30th year

The following timeline explains how society bears costs at different time for the 10 projects




Now, total social costs in the first year of construction from a project.

$= (\$ 9 + \$1) / CY * 1,200\ CY = \$10 / CY * 1,200\ CY = \$ 12,000$

At 3% discount rate,

$C_1 = 12000 / (1 + .03) + 0 / (1 + .03)^2 + \dots\dots\dots\dots + 0 / (1 + .03)^{20}$
$= 11,650$

( No additional maintenance costs in the subsequent years due to glass incorporation )

Similarly,

$C_2 = 12000 / (1 + .03)^2 + 0 / (1 + .03)^3 + \dots\dots\dots\dots + 0 / (1 + .03)^{21}$
$= 11,311$

$C_{10} = 12000 / (1 + .03)^{10} + 0 / (1 + .03)^{11} + \dots\dots\dots\dots + 0 / (1 + .03)^{30}$
$= 8,929$

So, $C = 11650 + 11311 + \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots + 8929$
$= 102,360$

Check for the Criteria

B/C @ 3% discount rate = 317,316 / 102,360 = 3.1

Net Present Value ((@ 3% discount rate) = 214,960 – 102,360 = 112,600

Sensitivity Analysis

The next step is to make a sensitivity analysis to check the extent of variation in B / C ratio with decreasing the total benefits and increasing total costs. Variation of net present value (B-C) will also be checked with the variation of discount rate.

**Discussion**

The reason for looking at different B/C ratios by increasing total costs, decreasing total benefits and varying discount rates is to provide policy makers more statistics of the B/C values in different potential situations. Table 10.2 presents the decreasing trend in B/C ratios with increasing total costs and decreasing total benefits. However, for the expected situations covered in the sensitivity analysis, the B/C ratio was always greater than 1. Table 10.3 presents the decreasing trend in net present value with increasing discount rates. Considering secondary benefits, intangible costs and benefits, TxDOT's hypothetical commitment appears to be beneficial to society.

**Table 10.2:** Sensitivity Analysis (B/C Ratios)

| | **Discount Rate = 3%** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **No Change** | **Cost Increase (%)** | | | | | **Benefit Decrease (%)** | | | | |
| | | **5** | **10** | **15** | **20** | **25** | **5** | **10** | **15** | **20** | **25** |
| B / C Ratio | 3.10 | 2.95 | 2.82 | 2.69 | 2.58 | 2.48 | 2.94 | 2.79 | 2.63 | 2.48 | 2.32 |

**Table 10.3:** Change in Net Present Value with the change of Discount Rate

| | Discount Rate (%) | | | | | |
|---|---|---|---|---|---|---|
| | 3 | 5 | 7 | 9 | 11 | 13 |
| Net Present Value | 214,956 | 194,544 | 176,904 | 161,784 | 148,428 | 136,836 |

In this analysis, based on the benefits and costs derived for two years from the Antilley Road project, it has been assumed that there are no additional costs or benefits (e.g. increase or decrease in maintenance costs) attributed to glass incorporation in roadbase for any of the 10 projects in their subsequent years of construction within their design lives. However, this assumption may not hold true in reality. Therefore, given this additional information, costs and benefits should be recalculated to estimate the B/C ratios and Net Present Values. Having said this, it is believed that the ultimate results will not change (i.e. $B/C \geq 1$ and $NPV \geq 0$).

## CHAPTER 11: CONCLUSION

Non-hazardous recycled materials (NRMs) were demonstrated in a variety of roadway construction applications. The eight materials selected were: bottom ash, compost, crushed concrete, glass cullet, roofing shingles, shredded brush, spent blasting sand, and tires. Each material was proven successful in previous research projects and specifications, guidelines or field notes were available for material applications. This Priority Technology Program (PTP) collected and documented material cost and application information for each material and gathered field evaluation data for several of the materials. A method was prepared for performing economic analyses of NRMs in construction applications.

Bottom ash was used as fine aggregate in hot mix asphalt in two sections of a demonstration project near Mt. Vernon, Texas, with different designs. Both sections proved satisfactory in visual distress surveys, falling weight deflectometer testing, skid resistance testing and surface roughness testing.

Compost (Dillo Dirt™) was applied to a nine-acre area in Austin, Texas historically resistant to vegetation growth. Within a short period of time, grass began growing and provided protection against soil erosion.

In some districts, crushed concrete has been a commonly used base material for several years,. A demonstration project in the Houston district was selected to document application designs and monitor performance. Section design characteristics were documented. Based upon experience, TxDOT engineers note no differences between the performance of crushed concrete and limestone base.

Glass cullet was used in three demonstration projects. A sub-base for flexible asphalt pavement was constructed in Devine, Texas using a blend of glass cullet and crushed limestone. The sub-base performed satisfactorily for design loadings. However, closure of a nearby roadway significantly increased heavy truck traffic on the demonstration section and some rutting and fatigue cracking were observed. In a second demonstration project, glass cullet was mixed with limestone and used as a flexible base for a roadway section in Abilene, Texas. No distress occurred in the Abilene roadway section. The third glass-cullet demonstration project used the cullet as a pipe bedding material near Beaumont, Texas. No problems with the pipe-bedding application have been reported.

Findings from previous uses of recycled plastics are reported within this report. No project was conducted to demonstrate the use of recycled plastics.

Both post-consumer and post-industrial roofing shingles were successfully demonstrated as additives to hot mix asphaltic concrete pavements in a project located in Corsicana, Texas. Construction techniques, mix designs and performance evaluations are presented. Performances of the demonstration project test sections are comparable to conventional mixes.

Shredded brush achieved erosion prevention in an area near Lufkin, Texas where other erosion prevention measures had proven unsuccessful. Although the shredded brush was able to prevent erosion, heavy application reduces the amount of sunlight reaching the soil and it is suggested that shredded brush be considered a temporary soil erosion measure if vegetation is desired on the protected section.

Spent blasting sand was used as fine aggregate in base material for a demonstration project in Houston, Texas. Application of the spent blasting sand was considered routine by the project engineers and no significant problems have been noted in subsequent performance observations.

Scrap tires were used in two separate demonstration projects. Tire chips resulting from shredding used tires were enclosed in a geotextile wrap and covered with compacted soil and incorporated into a bridge embankment in El Paso, Texas. Long-term monitoring of the embankment settlement has shown no significant problems. A hot rubber underseal was used with a crumb rubber modified asphaltic concrete overlay in the Odessa District. No major maintenance of the overlay has been required in the two years since its construction.

Using the guidelines and specifications provided within this report, non-hazardous recycled materials (NRMs) can be used in roadway construction with a high degree of confidence. In many cases, NRMs are now considered commonly used materials.

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## APPENDIX A: RECYCLED PLASTIC

Plastics constitute over 7 percent by weight of the municipal solid waste (MSW) stream or approximately 12 to 20 percent of the volume (Bloomquist et al., 1993). Each year 20.1 megagrams (22.8 million tons) of plastic waste is generated from which 5.9 megagrams (6.5 million tons) constitute packaging wastes (Bligh, 1995). The types of resins and plastic products in MSW stream include polyethylene terephthalate (PET), polyethylene (PE), low-density polyethylene (LDPE), high-density polyethylene (HDPE), polystyrene (PS), polyvinyl chloride (PVC) and polypropylene (PP) (Bloomquist, et al., 1993). Plastics can be recycled to manufacture products for highway construction and applications. Some of these products include, but not limited to, traffic control barricades, fence posts, guard rail posts, speed bumps, drain pipe, roadway signs, park benches and even as modifiers for hot-mix asphalt pavements.

Texas Transportation Institute (TTI) researchers have crash tested two Type III barricades comprised of recycled plastics (Bligh, 1995). The first design utilized hollow-core sections for the vertical support members and horizontal panels. In the second design, barricade constructed entirely of solid HDPE was evaluated. Testing of the first design was successful, but the second was unsuccessful due to the windshield penetration of the test vehicle.

As part of the literature review, vendors of recycled plastic barricades were contacted. In February 1998, Bob Patterson from Distribution Inc., one of the TxDOT approved vendors, provided the following observations related to Type I and Type II recycled plastic barricades they produce.

- HDPE is used to produce barricades. These barricades contain 50% - 80% post consumer plastic. They buy plastic with ultraviolet (UV) additives in it because UV additive protects the barricade from deterioration when exposed to sunlight.

- They manufacture the entire barricade and do not make components of barricade hollow. They think that hollow components filled with sand or water break easily.

- Only 3-4% of all barricades used in US are made of plastic. People use plastic barricades less because they are more expensive (about twice the cost of wood barricades) and get stolen due to their long durability.

- Plastic barricades perform better than other barricades. The plastic barricades installed in 1991 are still in use and have neither posed any problems nor required maintenance.

- Some tests on barricades were conducted when they started business in 1991. Barricades were subjected to temperatures of -40°C (-40°F) and then 49°C (120°F) for several weeks. Impact tests were performed to check whether barricades break or get softened. Since the barricades passed the tests at that time and the supplier for recycled plastic remained unchanged, they have not conducted any test in recent years.

- One of their clients is Impact Recovery in San Antonio.

In July of 1999, Bob Williams from Recycled Plastic Products, Inc., of Englewood, Colorado provided some useful information related to Type III Barricade.

- HDPE is used as a material for recycled plastic barricade. UV inhibitor is used to resist colorfastness, antioxidants to stabilize the product and colorant. They do not use any virgin plastic.

- They also produce fencing products using recycled plastic.

- They mentioned that their products are safe, results in less handling injuries and causes less serious injuries in crashes. All Crash testing related to this product was done by Texas Transportation Institute (TTI) and products were found to be safe.

- One of the clients of Recycled Plastic Products, Inc. is Highway Safety Service in Austin, Texas. They were contacted for information related to field application. They mentioned that the barricades are performing well but it is too early to comment on their long-term durability.

Contact Persons

| **Name(s)** | **Organization** | **Telephone Number/Fax/E-mail** |
|---|---|---|
| Bob Williams | Recycled Plastic Products, Inc., Englewood, CO-80110 | Phone: (303) 975-0033<br>Fax: (303) 975-0050 |
| Bob Patterson | Distribution Inc, - Enviro-cade | Phone: (920) 468-8280 |
| Billy Wehring | Highway Safety Service | Phone: (512) 990-9525<br>Fax: (512) 252-9345 |
| Phillip T. Nash, P. E. | Texas Tech University | Phone: (806) 742-2783 Ext. 231<br>Fax: (806) 742-3488 |