Southwest Region University Transportation Center

Implementation of the Waste and Reclaimed Materials Evaluation System

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16. Abstract

Large quantities of waste materials are generated in the United States every year. Due to societal and environmental concerns many states have enacted legislation to promote their use in highway construction projects. The standard approach to characterize these materials has been to evaluate them in technical laboratory studies which is not appropriate because these materials do not match natural aggregate in technical quality and may still have a high societal, environmental and economic value. A Waste and Reclaimed Materials (WRM) evaluation process has already been developed which takes into account such factors.

This WRM Evaluation process is carried out before detailed technical and economic studies are done to develop specifications for their use. The determination of their utilization potential is based on technical, economic, societal and environmental aspects. An initial screening process is also incorporated which is used to discard WRMs which clearly displays a low utilization potential. The Analytic Hierarchy Process (AHP) from decision analysis theory is used to assign weights to the four evaluation sub-systems and the respective attributes based on their relative importance.

Implementation of this system was carried out after the system was verified by detailed laboratory studies and economic analysis. All the available WRMs were subjected to this evaluation method and were ranked from the highest utilization potential to the lowest. The selected top three WRMs, reclaimed asphalt, Portland cement concrete pavement, and electric arc furnace slag, were subjected to detailed laboratory and economic analyses to determine their viability and to develop specifications for their use in roadbase construction. The WRM evaluation process, laboratory studies, and the implementation package are presented in the report.

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IMPLEMENTATION OF THE WASTE AND RECLAIMED MATERIALS EVALUATION SYSTEM

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Research Report SWUTC/96/467310-1

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ABSTRACT

Large quantities of waste materials are generated in the United States every year. Due to societal and environmental concerns many states have enacted legislation to promote their use in highway construction projects. The standard approach to characterize these materials has been to evaluate them in technical laboratory studies which is not appropriate because these materials do not match natural aggregate in technical quality but may still have a high societal, environmental and economic value. A Waste and Reclaimed Materials (WRM) evaluation process has already been developed, under a grant from the Texas Department of Transportation (TxDOT) and the Texas Natural Resource Conservation Commission (TNRCC), which takes into account such factors.

This WRM Evaluation process is carried out before detailed technical and economic studies are done to develop specifications for their use. The determination of their utilization potential is based on 1) technical, 2) economic, 3) societal, and 4) environmental aspects. An initial screening process is also incorporated which is used to discard WRMs which clearly display a low utilization potential. The Analytic Hierarchy Process (AHP) from decision analysis theory is used to assign weights to the four evaluation sub-systems and the respective attributes based on their relative importance.

Under this research project this system was implemented in Texas. Before its implementation could be carried out the system was varified by conducting detailed laboratory studies and economic analyses. All the available WRMs were subjected to this evaluation method and were ranked from the highest utilization potential to the lowest. The selected top three WRMs: reclaimed asphalt and Portland cement concrete pavement and electric arc furnace slag, were then subjected to detailed laboratory and economic analyses to determine their viability and to develop specifications for their use in roadbase construction. The WRM evaluation process, laboratory studies, and the implementation package are presented in this report.

EXECUTIVE SUMMARY

The purpose of this study was to implement the Waste and Reclaimed Material (WRM) Evaluation System developed under a grant from the Texas Department of Transportation (TxDOT) and the Texas Natural Resource Conservation Commission (TNRCC). The developed WRM evaluation system bases the estimation of utilization potential on technical, economic, societal and environmental aspects of their use in roadbase, after an initial screening process which is used to discard WRMs with low utilization potential. Before the evaluation system could be implemented it had to be verified by conducting appropriate laboratory tests and economic studies. Specifically, this study verified the WRM evaluation process, developed trial specifications for the use of available WRMs in roadbase construction and prepared a field implementation package.

Data had already been collected on the types, quantities, and location of WRMs available in Texas under the TxDOT/TNRCC research project. The WRM evaluation process was then used to rank the available WRMs from lowest potential to highest potential for roadbase application based on technical, economic, societal and environmental aspects. Based on objective data, three WRMs were recommended by the evaluation method for detailed laboratory testing in order to verify the method and develop specifications for their use in roadbase construction. These materials were reclaimed asphalt concrete (RAP), reclaimed Portland cement concrete (RPCP) and electric arc furnace slag (EAFS). These materials were subjected to seven standard laboratory tests to characterize them properly and to determine their strength characteristics. Laboratory test results supplemented by the conducted economic analyses concluded that the use of WRMs is an feasible alternative, hence verifying the WRM evaluation process.

After the WRM evaluation process had been verified, the results were then used to develop to the field implementation package. The implementation package consists of: 1) trial specifications for using RAP, RPCP and EAFS (Appendices B, C, D), 2) a presentation describing the WRM evaluation process (appendix E), and 3) this research report which also serves as the main implementation aid.

The results of this study could not be implemented on a large scale in Texas, as envisioned in the beginning of the research project, due to unforeseen delays in laboratory testing and method verification. Nonetheless, a recycling project in Wichita Falls District of TxDOT was selected for implementation purposes. The results of this case study showed a number of societal and environmental benefits besides economic savings of $442,239 on a 2-lane four mile

long road construction project. The main savings were due to the elimination of the required natural aggregate material and associated earthwork for base construction. Also, the project was expedited by about five month due to elimination of the time intensive tasks of roadbase construction, thus saving user costs too.

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CHAPTER 1. INTRODUCTION

Enormous quantities of waste materials are generated in Texas and other parts of the United States every year. It has become clear that using these waste materials in necessary to preserve the country's natural resources. Recent history has shown policy makers that using waste materials can reduce the consumption of virgin materials and avoid the environmental cost of extracting and processing new materials. Also, using waste and reclaimed materials (WRMs) effectively can address public concerns expressed about the vast quantities of useful materials being discarded and wasted (TGLO 93).

BACKGROUND

In the past, the basic approach for using waste and reclaimed materials (WRMs) has been to investigate them in the laboratory and compare them to standard specifications for virgin materials. This is not an appropriate method because these materials may have societal and environmental value though they do not equal virgin material in technical quality. The feasibility of using WRMs depends upon a number of interrelated factors. In order to make meaningful recommendations these factors need to be evaluated quickly and objectively.

Keeping this in mind, a WRM evaluation method has already been developed under a \$200,000 grant from the Texas Natural Resource Conservation Commission (TNRCC) and the Texas Department of Transportation (TxDOT). The evaluation is based on 1) technical, 2) economic, 3) societal, and 4) environmental aspects after an initial screening which is used to discard WRMs with low utilization potential for use. Currently the system is set up to evaluate any potential WRM for use as roadbase and has the capability of being modified to evaluate WRMs for other transportation applications. Based on the evaluation, the overall potential of a particular WRM may be assessed and only those with high potential forwarded to more detailed technical studies to determine final specifications (Saeed 95, Saeed 96).

It is vital that this WRM evaluation system be integrated and implemented in the field to realize real benefits after laboratory verifications. Laboratory verification and field implementation are the objectives of this research effort and are explained in the following section.

STUDY OBJECTIVES

Data has already been collected on the types, quantities, and location of WRMs available in Texas under a TxDOT and TNRCC research project (Saeed 95). The WRM evaluation process developed under the same study will be used to rank the available materials from lowest potential to highest potential for roadbase application. The three top ranked materials will then be subjected to detailed laboratory testing to validate the results of the evaluation system and to develop trial specifications for field implementation. More specifically the study will address:

- application of the WRM evaluation method to rank the available WRMs, as reported by Saeed et. al. [Saeed 96], based on their utilization potential in roadbase construction,
- select three top tanked materials for laboratory testing and verification of the evaluation method,
- develop trial specification for roadbase construction using the results of the laboratory testing, and
- field implementation of the methodology and preparation of supporting implementation aids.

REPORT ORGANIZATION

This report is divided into 5 chapters. Chapter 2 describes the WRM evaluation method. Application of the evaluation methodology to available WRMs and laboratory testing of three top ranked WRM for method verification is described in Chapter 3. Chapter 4 describes the implementation of results in Wichita Falls District of TxDOT and developed implementation aids. Finally, Chapter 5 of this report describes the conclusions and recommendations of the study.

CHAPTER 2. WASTE AND RECLAIMED MATERIALS EVALUATION SYSTEM

EVALUATION OF WASTE AND RECLAIMED MATERIALS

When the utilization of WRMs is examined, it is desired to achieve a host of technical, economic, societal, and environment related objectives. The developed WRM evaluation system considers technical, economic, societal, and environmental aspects of WRM utilization besides an initial screening used to discard WRMs with low utilization potential early on.

The following sections describe different components of this methodology, shown conceptually in Figure 2.1, in detail. The evaluation criteria discussed are geared towards evaluating WRMs for potential utilization in road base, though the same can be used for asphalt concrete and other applications with minor modifications.

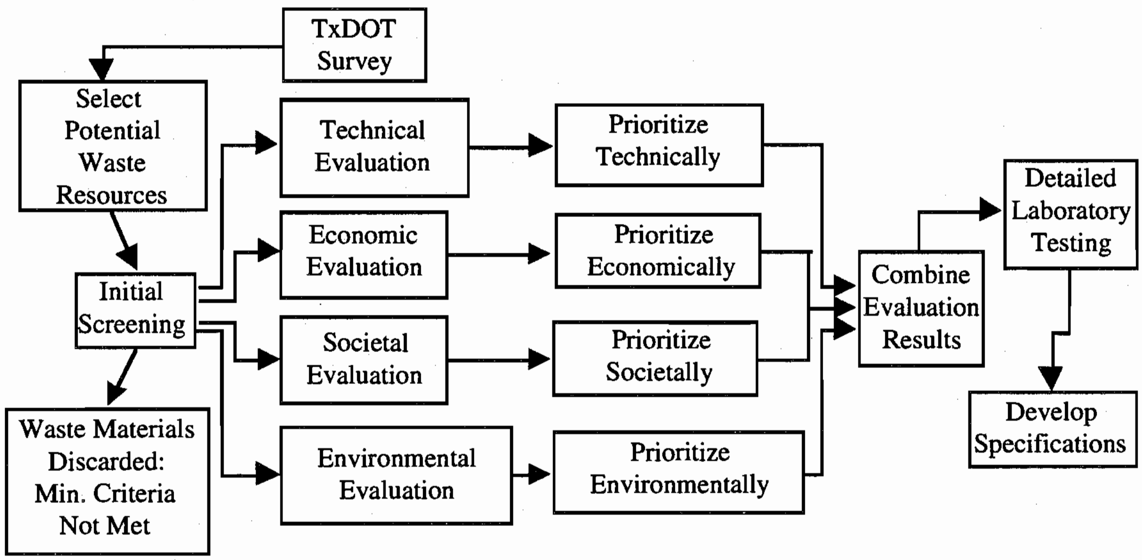


Figure 2.1. Waste and Reclaimed Materials Evaluation System

Initial Screening

Initial screening is utilized to screen out materials with low potential for road base construction before evaluating them using the four criteria previously mentioned. The factors which serve to determine the minimum acceptability of WRMs belong to technical, economic and environmental aspects. These factors are: 1) available quantity, 2) material location, 3) material toxicity, 4) material durability, and 5) water solubility. Societal factors are not included as it is assumed that it is always societally acceptable to reduce the amount of waste materials being generated and discarded to landfills and politically correct to maximize the use of WRMs.

Accumulated or Annually Produced Quantity. It was estimated that fifty thousand tons could be considered to be the minimum amount of material capable of fulfilling the roadbase aggregate requirement for a construction project based on experience on a four-mile long pilot recycling project in Texas. Accumulated quantities should be at least ten times this quantity or five hundred thousand tons. Otherwise, WRMs will not be able to be used often enough to justify expensive evaluations.

Material Location. This factor signifies the location of WRMs with respect to the site where they are potentially going to be used, and is also dependent on the transportation mode available. WRMs must be located within a reasonable distance from the place of potential use or the transportation costs will be very high and may ultimately make their use prohibitive. Distances of fifty miles for truck transport and hundred miles for rail transport are considered to be the maximum economical hauling distance. It must however be noted that transportation costs will vary with the region of the nation, so judgment may need to be made (NCHRP 76).

Material Toxicity. Processing WRMs to produce aggregate for roadbase construction must not make them toxic to the flora and fauna and the permitted levels of suspended solids and leachates must not exceed the permitted limits set by the Environmental Protection Agency (EPA).

Water Solubility. Roadbase is the primary load carrying element of an asphalt pavement in case of thin surfaced pavements. Some WRMs may lose their ability to carry loads when they come in contact with water. This criteria eliminates WRMs based on their inability to carry loads in the presence of water.

Material Durability. Aggregate produced from WRMs should be durable and capable of withstanding the effects of hauling, spreading, and compacting without degradation productive of deleterious fines, as required by ASTM specifications D-2940 (ASTM 92).

The WRM is not considered for further evaluation if it does not meet the requirements of the discussed initial screening. The WRM is subjected to technical, economic, social, and environmental evaluations only when it fulfills are the requirements of the initial screening process.

Technical Evaluation Sub-System

WRMs must posses adequate physical, mechanical and thermal properties required of a material to be used in asphalt pavements. The National Stone Association recommends that aggregate properties be determined by their end-use application (NSA 91). For roadbase application the included properties are coefficient of uniformity, material loss during LA degradation test, particle shape and texture and hardness.

Particle Size Analysis and Distribution. The slope of the grain size distribution curve, which is expressed as the *coefficient of uniformity, Cu,* is used to evaluate the WRMs for permeability and mass stability. A high score for C_u indicates a well graded, dense mix and is scored high in the technical evaluation sub-system. C_u is defined as:

$$C_u = D_{60} \; / \; D_{10},$$

Where: C_u = Coefficient of uniformity

D_{60} = Sieve opening size (mm) through which 60% of the aggregate passes

D_{10} = Sieve opening size (mm) through which 10% of the aggregate passes

Los Angeles Degradation Test. The quality of material called toughness is its ability to resist fracture under impact. The Los Angeles Degradation test determines the material loss due to impact and surface abrasion. A high material loss is scored low in the evaluation process.

WRM Hardness. The resistance to scratching or abrasion offered by a smooth surface is known as hardness and is a measure of the strength of the bonding forces holding the constituents together in a structure. Material hardness is evaluated using the Moh's hardness scale. The judged WRM hardness is assigned score linearly based on the scale where diamond is the hardest and talc is the softest (Berry 83).

Particle Shape and Texture. Particle shape and texture are important in providing a stable base course. Angular, nearly equidimensional particles having a rough surface texture are preferred over round, smooth particles. ASTM D 3398 provides an index of particle shape and texture using the following formula:

$$I_a = 1.25 \, V_{10} - 0.25 \, V_{50} - 32.0$$

Where: Ia = Particle Index

V_{10} = Voids in the aggregate when compacted using 10 blows per layer

V_{50} = Voids in the aggregate when compacted using 50 blows per layer

Technical Evaluation Sub-system Summary. This sub-system assesses the technical utilization potential of WRMs based on the coefficient of uniformity, the particle index, Moh's hardness and percent material loss from the LA degradation test. Table 2.1 indicates the specific test specifications and the objective laboratory data that are used to determine the technical evaluation score on a five point scale.

TABLE 2.1. ESTIMATION OF TECHNICAL EVALUATION SCORE USING LABORATORY TESTS

Evaluation Attribute	Test Designation	Technical Attribute Score					
		0	1	2	3	4	5
Gradation	Tex-110-E, C_u	0	2	4	6	8	10
Particle Shape and Texture	ASTM D 3397-93 Particle Index	0	4	8	12	16	20
Moh's Hardness	Moh's Hardness Scale	0	2	4	6	8	10
Resistance to Applied Load Degradation	ASTM C 131-89 % Material Loss	50	40	30	20	10	0

Economic Evaluation Sub-System

The main purpose of economic evaluation is to identify those WRM resources that are most feasible for utilization as aggregate in road base construction in terms of economics. The same five point scale evaluation process was utilized as described earlier in the technical evaluation section. The five attributes evaluated on a five point scale for economic evaluation are: 1) disposal cost, 2) processing cost of use, 3) transportation cost, 4) accumulated or annually produced quantity, and 5) cost of modifiers/stabilizers or additional material.

Disposal Cost. The disposal cost of WRMs is an important factor in determining its economic feasibility for use. Landfills usually accept material in terms of volume it will occupy and quote a rate in terms of cubic yards. Two rates are usually quoted, one each for compact and uncompact material. WRMs fall under the compact materials category and the quoted rates range from $1.2 - 4.5 per ton, excluding transportation costs to the landfill. Disposal cost is the dollar savings that would be realized if the material is used in roadbase construction so are termed as benefits as far as the economic evaluation sub-system is concerned. The higher the disposal cost, the more we should try to use the material and hence, higher the score (Saeed 96).

Transportation Costs. Several alternatives are available for the transport of waste materials. The most feasible of these are truck, rail as discussed earlier.

Cost figures of transporting WRMs are subject to wide variations. Texas Sand and Gravel Carriers Association uses a published rate list to quote prices to transport aggregate a certain number of miles on a per ton basis. These costs range from a high of $20.00 per ton, for transport of material for two hundred miles, to a minimum of $1.00, for transporting WRMs within ten miles (TSGCA 95). The lower the transportation cost to the intended place of use, higher is the WRM scored, as it will be much cheaper to use. Keeping this in mind, transportation cost of $0.00 is assigned a score of 5 and a cost of $10.00 or more, a score of zero.

Accumulated or Annually Produced Quantity. This factor takes into account the quantity of WRM available or produced annually. Obviously, the more is the available quantity of a particular WRM, the higher the assigned score. A survey of Texas Department of Transportation (TxDOT) districts was conducted by Saeed et. al. (Saeed 96) to determine the types, quantities and locations of available WRMs. The maximum available quantity 355,000 tons of RAP is assigned the maximum possible score of five, whereas the minimum available quantity is assigned a score of zero. WRMs having intermediate quantities are assigned scores linearly between the two extreme quantities.

Cost of Stabilizers/Modifiers or Additional Materials. There may be certain WRMs which may require the addition of natural aggregate or some stabilization agent to use them in roadbase construction. This cost is the dollar amount spent to produce a ton of the final mix. For the purposes of the WRM evaluation method, the more the cost of additional material the less the assigned score. A WRM which requires no additional additive/stabilizer or natural aggregate material is assigned a score of five and a WRM which requires about $6.00 per ton of the final produced mix is assigned a score of zero to indicate our preference for a material which requires no additive at all.

Summary of Economic Evaluation Sub-system. Table 2.2 shows the estimation of economic evaluation scores based on the disposal cost, processing cost of use, transportation cost, cost of stabilizer/modifiers or additional material required and the accumulated or annually produced quantity.

TABLE 2.2. ESTIMATION OF ECONOMIC EVALUATION SCORE USING ACTUAL DOLLAR VALUES

Evaluation Attributes	Societal Attribute Score					
	0	1	2	3	4	5
Accumulated/Annually Produced Quantity, 10^3 tons	0	71	142	213	284	355
Disposal Cost, $/ton	0.00	1.00	2.00	3.00	4.00	5.00
Transportation Cost, $/ton	10.00	8.00	6.00	4.00	2.00	0.00
Processing Cost of Use, $/ton	2.50	2.00	1.50	1.00	0.50	0.00
Cost of Stabilizers/Modifiers/Additional Material, $/ton	6.00	4.80	3.60	2.40	1.20	0.00

Societal Evaluation Sub-System

Many WRMs due to their volume, location, or associated disposal problems present a threat to wildlife and flora and fauna and arose the interest of groups involved in such issues. There is societal as well as political pressure to find means to stabilize, remove, or use these wastes. The impetus to use WRMs, hence, comes from both the society and the government. It is difficult, if not impossible, to measure societal and environmental implications in actual dollar terms, nevertheless, the societal evaluation sub-system evaluates the following three societal attributes on a scale of zero to five. These are: 1) storage site aesthetics, 2) safety/health hazard, and 3) government/special group interest (Saeed 96).

Storage Site Aesthetics. WRMs, as stated above, generate a lot of public desire to be used if they are more visible. A material which is more visible by being close to a main highway, will generate a lot of public pressure compared to a material which is hidden behind a hill or is not visible at all due to thick vegetative growth. A highly visible material is assigned a score of five, to indicate our preference for its use, and a hidden material is assigned a score of zero.

Health/Safety Risk. This factor takes into account of the damaging potential of WRMs, *in their current condition*, to the general public. A WRM which possesses no risk to the general public must be rated low compared to a WRM which possesses the highest possible risk, which must be rated high. Fire hazard is the greatest damage that can be imparted to the general public, so is assigned a score between four and five on this evaluation scale. This is followed by disease risk which is assigned a score between three and four, and so on as shown in Table 2.3.

Government/Special Group Interest. The interest of the general public in using WRMs is often supplemented by the presence of environmental preservation groups, which generate a lot of public pressure. The legislature can propose, and pass laws to control these environmental and ecological problems. The proposed evaluation scale considers this propagation of actions and assigns scores accordingly. The highest score of five is assigned to WRMs which have some legislation making their use mandatory and so on. It is also assumed that any WRM for which legislation exists banning its use would not be a candidate and would have been rejected in the initial screening process.

Societal Evaluation Sub-system Summary. Table 2.3 demonstrates the estimation of societal attribute scores based on storage site aesthetics, safety/health hazard and government/special group interest. Due care has been taken to be as objective as possible in this process.

TABLE 2.3. ESTIMATION OF SOCIETAL EVALUATION SCORE

Evaluation Attribute	**Societal Attribute Score**					
	0	**1**	**2**	**3**	**4**	**5**
Storage Site Aesthetics	Hidden	Partially Hidden		Visible in Dist.		Highly Visible
			Land	scaped		
Safety/Health Hazard	Risk to Handling Personnel				Fire Hazard	
	Protective Gear Required					
	None	Gloves	Masks	Full Disease Risk		
Government/Special Group Interest	Legislation					
	None	Being Prepared		Future Implementation		In Effect
			Being	Considered		

Environmental Evaluation Sub-System

A great deal of concern is expressed about the environmental issues with regard to the utilization of WRMs in highways by the general public, as well as by DOTs, legislatures, lawyers and academia. From a technical point of view, the potential environmental impact of a WRM should be evaluated before actual field use. The environmental effects associated with processing and use of WRMs in roadbase are considered in the following three ways (Saeed 96):

- Benefits of using WRMs,
- Effects of processing WRMs, and
- Effect on environment of WRM use.

Benefits of Using WRMs. This factor attempts to quantify the benefits that might be derived from altering the present method of waste material disposal or of removing existing stockpiles by using them in roadbase. Conservation of natural aggregate material is an important benefit of WRM use. If we are able to conserve natural aggregate by using a particular WRM, it should be assigned a high score in the evaluation system. On the other hand, if a WRM requires a lot of natural aggregate to make its use possible, then it should be scored at the lower end. A hundred percent conservation of natural aggregate material qualifies for a score of five and zero percent conservation of natural aggregate results in a score of zero for this attribute.

Effects of Processing WRMs. This factor takes into account the effects of processing a specific waste resource as part of the recycling system. Noise and dust pollution from the recycling facility are a major concern with respect to the populated areas.

A material which produces a high noise level when processed must be rated low compared to a material which produces next to no noise at all. A noise level of 150dB, which is painfully loud, is assigned a score of zero. On the other hand, no noise at all, in case of a WRM which requires no processing at all , hence no noise generation, is assigned a score of five (NSA 91).

Dust in the air is a function of distance from the plant, although most of it has settled after about a mile. The best score of five is assigned when there is no dust produced at all, or the population is about a mile away from the processing plant. A score of zero is assigned when hypothetically, atmosphere dust measurements are taken at the plant, with the plant at full production and no dust control in operation.

Effect on Environment of WRM Use. The hazard potential of a WRM can be accounted for if one considers the effect of using it on ground and surface water. If a particular WRM is going to have a lot of heavy metal leachates during its service life, it would be unwise to use that particular WRM. On the other hand a WRM having a low leaching potential is recommended for use even if it contains undesirable materials because it will not release those metals.

The Extraction Process Toxicity test is used for the purpose of evaluating WRMs on this attribute. In the evaluation process, the leachates from the waste material are analyzed for the concentration of various metal as required by the EPT test and then they are scored on the basis of the national drinking water standard (NDWS). Metal concentrations at or below NDWS are scored five in the evaluation process and metal concentration of 100 times or more are given a score of zero.

Environmental Evaluation Sub-system Summary. Table 3.4 demonstrates the estimation of environmental attribute scores based on objective data.

TABLE 2.4. ESTIMATION OF ENVIRONMENTAL EVALUATION SCORE

Evaluation Attribute	Environmental Attribute Score					
	0	**1**	**2**	**3**	**4**	**5**
Benefits of using WRMs (% natural aggregate conserved)	0	20	40	60	80	100
Noise Pollution (dB)	150	120	90	60	30	0
Dust Pollution (distance to population, miles)	0	0.2	0.4	0.6	0.8	1.0
Extraction Process Toxicity Test (x NDWS, mg/l)	100	80	60	40	20	0.00

Final Estimation Of WRM Utilization Potential

As already described the evaluation of WRMs must be based on technical, economic, societal and environmental aspects but these objectives conflict within the framework of the final comprehensive evaluation to be made. The four evaluations simply do not permit high achievement in all aspects at once. A relatively simple approach to this problem is to create a model that is additive. This implies that a score will be estimated for each objective and scores will then be added, weighting them appropriately according to the relative importance of the various objectives.

Once a particular WRM has been subjected to the four evaluation sub-systems, the individual scores from each attribute within each evaluation sub-system need to be combined to determine the final utilization potential (WRMUP). An additive model is used for this purpose, as shown, and the final score is represented on a scale of zero to five. On this scale, five represents the maximum utilization potential of a particular WRM in roadbase construction, whereas a score of zero represents no utilization potential at all.

$$\text{WRMUP} = W_T \Sigma\, w_{T,J}\, S_{T,J} + W_E \Sigma\, w_{E,J}\, S_{E,J} + W_S \Sigma\, w_{S,J}\, S_{S,J} + W_{En} \Sigma\, w_{En,J}\, S_{En,J}$$

Where:

$W_{T,E,S,En}$ = Weights for the various evaluation sub-systems

$w_{J;T,E,S,En}$ = Weights for the technical, economic, societal and environmental attributes

$S_{J;T,E,S,En}$ = Scores for the technical, economic, societal and environmental attributes

Selection of weights for the attributes and the evaluation sub-systems is based on their importance in the overall scheme of things, and may vary from location to location according to the prevailing local conditions, especially political and societal. One might argue that the selection of weights introduces subjectivity into the evaluation process. But, by breaking the evaluation process into smaller units and by using the Analytic Hierarchy Process (AHP) developed by Saaty in 1980s (Saaty 82), the whole process is made objective and the concern about non-quantitative factors is addressed effectively in a systematic manner. Advantages of using AHP for weight selection, and the determination of various weights themselves is the subject matter of the next section.

ANALYTIC HIERARCHY PROCESS

The AHP revolves around the proper assessment of importance of each factor under consideration in order to make tradeoffs among them and to develop a system of weights based on priorities to choose the best solution. It provides a flexible model which enables people to refine their problem definition, and to reflect the natural tendency of the mind to sort the elements of a system into different levels and to group like elements into each level. AHP can deal with the independence of elements in a system and does not insist on consensus but tracks the logical consistency of judgment used in determining importance (Saaty 80).

Determination of weights using the AHP can be summarized as the following:

1. Develop a hierarchical structure of factors and sub-factors contributing to the final goal or objective (accomplished in the previous section, using systems methodology.)

2. Rank these factors in order and put them as headings of both rows and columns in the comparison matrix.

3. Compare the factors relatively on a scale of 1 to 9. The scale represents a ratio comparison of the two factors.

4. Put the reciprocal of each cell to the symmetric cell of the lower half of the matrix.

5. Calculate $\sum$ cell value $_i$ / column sum $_i$ to reach a combined weight for each factor.

6. Normalize the combined weight to generate a priority vector. The coefficient of the priority vector implies the weight of each factor.

Assessment of Weights

In order to keep matters simple, all the factors were compared relatively on a scale of 1 to 5. The 1 to 5 scale represents a ratio comparison of two factors with respect to:

1. two factors contribute equally,
2. one factor is slightly favorable than the other,
3. one factor is moderately favorable over the other,
4. one factor is strongly favorable over the other, and
5. one factor dominates the other.

Description of the mathematical manipulations carried out to determine the weights are beyond the scope of this report but these can easily can be accomplished by anyone using the 6 listed steps. Table 2.5 lists the weights which were determined using the AHP. It must however be remembered that these weights are for reference purposes only and the reader is advised to develop weights keeping the local conditions in view. Another advantage of AHP is its ability to check for consistency. People tend to be inconsistent when they are comparing a number of actors using pair-wise comparisons. The comparison scale is of no value if the inconsistency is high enough to ruin the comparison logic. The eigenvalue approach is used to check for consistency. The maximum eigenvalue, l_{max}, is the size of the comparison matrix. Because people are unlikely to be totally consistent while making the several pair-wise comparisons, then for a reciprocal matrix, the value l_{max} will always be greater than N, the size of the matrix. So l_{max} - N provides a measure of the inconsistency. This is normalized using the matrix size and is termed as the comparison index, CI.

$$CI = (l_{max} - N) / (N-1)$$

Consistency ratio, CR, is defined as the ratio between the CI and random consistency, RC, obtained using 500 different size random matrices. The CR should be less than 10% to be acceptable (Saaty 82 a, Saaty 82 b). The CR was calculated using the above approach for the five comparison matrices and was determined to be less than 10% for all of them.

CHAPTER SUMMARY

This chapter presented a brief description of the WRM evaluation system and AHP used to determine the weights of the evaluation sub-systems as well as the attributes within each sub-system. The determined weights should be used for demonstration purposes and the user is encouraged to develop his own weights as it is expected that they will change with the local conditions especially political and societal.

Under this study WRMs determined to be available in Texas were subjected to the evaluation system to rank them from the lowest potential to the highest potential for highway application. Three top ranked materials were then tested in the laboratory to validate the results of the system. Next chapter of this document is devoted to the discussion of the results of the laboratory test results and implementation efforts.

TABLE 2.5. ESTIMATED WEIGHTS FOR THE EVALUATION FACTORS BASED ON AHP

Evaluation Attribute	Mean Weight
Technical Evaluation Sub-system	**0.4826**
Gradation	0.2646
Particle Shape and Texture	0.0784
Particle Hardness	0.1356
Resistance to Applied Load	0.5214
Economic Evaluation Sub-system	**0.2867**
Acc./Annually Produced Quantity	0.4587
Transportation Cost	0.1471
Disposal Cost	0.2482
Stab./Mod. or Add. Material Cost	0.0580
Processing Cost of Use	0.0880
Societal Evaluation Sub-system	**0.0873**
Govt./Sp. Group Interest	0.2311
Health/Safety Risk	0.6652
Storage Site Aesthetics	0.1037
Environmental Evaluation Sub-system	**0.1434**
Benefits of Recycling	0.2854
Noise Pollution	0.0882
Dust Pollution	0.0882
Leaching Potential	0.5382

CHAPTER 3. METHODOLOGY APPLICATION AND LABORATORY TESTING

WRM LOCATION AND AVAILABILITY SURVEY

Before governing bodies in Texas can make maximum use of WRMs in transportation projects, they must know, among other things, the types, quantities, sources and properties of available WRMs. A survey was conducted to answer these questions and is detailed in research report 1348-1 by Saeed et al [Saeed 95]. A brief description of the results is presented here.

Research Methodology

Data collection methods for the survey included 1) mail questionnaires, 2) telephone interviews, and 3) limited site visits. At the first level of sampling 84%, 21 of the 25, TxDOT district offices responded. Questions were designed to collect information about the types of WRMs available, stockpile locations, material quantity, material performance and the availability of any scientific/engineering test data.

Survey Results

A total of 21 out of 25 TxDOT districts responded to the survey. A large number of these, 19 districts reported having stockpiles of reclaimed asphalt concrete (RAP), followed by reclaimed Portland cement concrete (RPCP) which was reported to be stockpiled in 9 districts. RAP was estimated to be present in excess of 355 thousand tons followed by about 19 thousand tons of RPCP. Only four TxDOT districts reported any stockpiles of coal combustion by products - fly ash (FA), bottom ash (BA) and pond ash (PA). Other WRMs from commercial producers included steel slag (SS), tire chips (TC), and ceramics. Table 3.1 shows the available WRMs and their estimated quantities.

TABLE 3.1. ESTIMATED QUANTITIES OF WRMS STOCKPILED AT VARIOUS TXDOT LOCATIONS

Waste and Reclaimed Materials	Est. Quantity (tons)
Reclaimed Asphalt Concrete	355,000
Reclaimed Portland Cement Concrete	190,000
Fly Ash	22,500
Bottom Ash	20,000
Pond Ash	20,000
Tire Chips	10,500
Ceramic Waste	10,000
Blast Furnace Slag	500

EVALUATION OF AVAILABLE WRMS

The available WRMs were subjected to separate technical, economic, societal and environmental evaluations as outlined in the WRM evaluation methodology described in Chapter 2. Detailed calculation of the individual attribute scores is shown in Appendix A of this document. Table 3.2 summarizes the results of the WRM evaluation process. Evaluated WRMs were assigned to the categories as shown in Table 3.3. Based on the results of the WRM evaluation process, the three top ranked WRMs, RAP, EAFS, and RPCP, were selected for detailed laboratory testing and to verify the method and develop specifications for field use.

LABORATORY TESTING OF SELECTED WRMS

Based on the results of the WRM evaluation method, the top three materials: reclaimed asphalt and Portland cement concrete (RAP and RPCP) and electric arc furnace slag (EAFS), were selected for detailed laboratory testing to develop specifications for their use in roadbase construction.

The laboratory testing program was conducted in two parts (Saeed 96). The first part investigated the physical properties of the WRM. Conducted tests included particle size and distribution analysis, LA abrasion, particle shape and texture, hardness, specific gravity, etc. RAP, RPCP, and EAFS samples were obtained in accordance with Test Method Tex-100-E, "Surveying and Sampling Soils for Highways" [Tex-100-E 95], and were prepared according to test method Tex-101-E, "Preparation of Soil and Flexible Base Materials for Testing" [Tex-101-E 95].

TABLE 3.2 RESULTS OF THE WRM EVALUATION PROCESS

Waste & Reclaimed Materials	**Evaluation Score**				
	Technical	**Econo.**	**Societal**	**Environ.**	**Total, %**
Reclaimed Asphalt Concrete	1.16	1.38	0.23	0.66	68.60
Reclaimed PCCP	1.14	0.60	0.15	0.61	50.20
Electric Arc Furnace Slag	1.54	0.83	0.13	0.52	60.40
Fly Ash	1.43	0.32	0.18	0.32	45.20
Bottom Ash	1.43	0.32	0.19	0.32	45.20
Pond Ash	1.43	0.32	0.18	0.32	45.00
Natural Crushed Limestone	1.43	1.01	0.03	0.47	58.85

TABLE 3.3. CATEGORIZATION OF WRMS AS ROADBASE CONSTRUCTION AGGREGATE MATERIAL

Waste & Reclaimed Materials	Total, %	Category	Remarks
Reclaimed Asphalt Concrete	68.60	I	Best material
Reclaimed PCCP	50.20	III	Marginal material
Electric Arc Furnace Slag	60.40	II	Second best material
Fly Ash	45.20	IV	Unsuitable as agg. in roadbase
Bottom Ash	45.20	IV	Unsuitable as agg. in roadbase
Pond Ash	45.00	IV	Unsuitable as agg. in roadbase
Natural Crushed Limestone	58.85	N/A	For comparison purposes only

Based on experience, it was decided that the all the WRMs will be made to conform to the specification of ASTM D 2940 before being further tested. ASTM 2940 D states that if a material falls within a certain gradation envelop, it can expected to provide a stable base for highways and airports.

In the second part of laboratory testing it was decided to determine the strength characteristics of the selected WRMs using the Texas Triaxial Test as it is widely used to characterize base materials. This approach proved to be full of problems. Most of WRMs are cohesionless in nature and a freestanding test specimen could not be prepared. As the objective was to determine the relative strength characteristics of various WRMs, the California Bearing Ratio (CBR) test was selected. The CBR test method does not require the test specimen to be extruded from the compaction mold and was well suited for the purposes of this research. Table 3.4 provides the laboratory test data.

TABLE 3.4 LABORATORY TEST RESULTS

Test Method / Evaluated WRMs	RAP	EAFS	RPCP
Gradation, C_u, ASTM C136 / Tex-200-F	2.5	6.8	4.7
Specific Gravity, ASTM C 128 / Tex-201-F	2.2	3.4	2.4
LA Abrasion, % loss, ASTM C131	26.0	22.0	30.0
Hardness	7.0	8.0	7.0
Part. Shape & Texture, ASTM D 3398	14.2	15.0	13.0
Material Added, %	30.0	0.0	50.0
CBR, %, ASTM D 698	97.1	135.0	90.0

SPECIFICATION DEVELOPMENT

The laboratory testing described in the previous sections formed the first step to verify the method and most importantly to develop trial specifications for field implementation. Detailed laboratory testing demonstrated the applicability of the method and its success in prescreening materials for detailed laboratory testing. Only those WRMs which passed the evaluation method and were feasible on an overall technical, economic, societal and environmental basis were forwarded to the next step. This approach saved on both financial and human resources, as only those WRMs were subjected to detailed laboratory testing which showed high utilization potential in roadbase construction.

Appendices B, C, and D describe the trial specifications that were developed using the results of the detailed laboratory testing. These specification, for RAP, RPCP, and EAFS respectively, are ready for field implementation. RAP specifications were implemented in the Wichita Falls District of TxDOT and are described in Chapter 4 of this document.

CHAPTER 4. TECHNOLOGY TRANSFER AND FILED IMPLEMENTATION OF THE WRM EVALUATION SYSTEM

Implementation of the WRM evaluation method is one of the main objectives of this research project. At the time of proposal writing it was envisioned that the research team would be able to implement the WRM evaluation system for a number of projects at the TxDOT as well as city/county level. This could not be accomplished due to unexpected delays and problems encountered during the laboratory testing phase of the research effort. Since, TxDOT personnel from the Wichita Falls district were already involved with the project and a good candidate project also existed, the Wichita Falls district of TxDOT was selected for assisted implementation of the evaluation method.

This chapter describes the recycling project in Wichita Falls district of TxDOT and the implementation aids prepared to facilitate the use of WRMs in roadbase construction projects.

TxDOT RECYCLING PROJECT IN WICHITA FALLS

RAP from the Wichita Falls district of TxDOT was selected as a case study for the use of WRMs on a portion of FM 369 in Wichita county and for evaluation using the evaluation process. The reconstructed portion linked a newly constructed corrections facility with US 287 outside Wichita Falls city limits. RAP from this project was evaluated using the WRM evaluation process and was determined to have a utilization potential of about 70% as detailed in the previous chapter.

The primary contractor on this project, Zack Burkett and Co., submitted a Value Engineering Change Proposal (VECP) requesting authorization to use RAP in base course in place of the original TxDOT design which required a crushed limestone base. The original pavement design called for scarifying the original pavement, incorporating the old pavement into the subgrade, adding lime in slurry form, compacting and shaping this into new subgrade. A new crushed limestone base and a hot mix asphalt concrete (HMAC) riding surface was then to be added on top of the so prepared subgrade. Under the VECP, the existing pavement was left undisturbed and RAP used as a base course directly on top of the existing pavement. A HMAC riding surface was then provided (Burkett 95).

Economic Benefits

The largest economic benefit of the VECP was that 17,100 cubic yards of required flexible base material was replaced with 14,700 cubic yards of RAP material which was available to the department at no cost. Though, for the purposes of economic analysis, RAP was valued at \$ 28.37/m^3. Converting to a RAP base course also saved on the quantities of lime treatment as well as the required excavation because the existing pavement was left undisturbed under the VECP. Table 4.1 lists the items for both the original design as well as the modified design under the VECP and the projected savings. By agreeing to the VECP, the department saved a total amount of \$442,397, exclusive of the overhead and profit. The contractor was entitled to half of this amount, or \$221,198 as shown in Table 4.1. Also shown are the required quantity changes and the corresponding unit prices.

Other Benefits

Besides economic savings, the department also benefited from improved public relations and earned public good will by using RAP. Use of RAP base material also expedited the project by about 7 months due to the elimination of time-intensive work items such as the preparation of the subgrade and the flexible base course. Also, RAP base course could be opened to the public much sooner than the proposed limestone base course, thus saving users' costs. By using RAP base course the overall project was expedited, hence shortening the time local residents were inconvenienced. A much cleaner project also resulted by eliminating the flexible limestone base course and the lime slurry treatment of the subgrade. Dust pollution was eliminated by avoiding lime treatment of base, hence improving the overall project safety. Eliminating of the latter enhanced traffic handling through the project and the chances for lime slurry damage to vehicles travelling through the project was avoided.

FIELD IMPLEMENTATION AND TECHNOLOGY TRANSFER

Field implementation of the WRM evaluation method and technology transfer is achieved using the described implementation package. The implementation package consists of 1) presentation, 2) developed specifications, and 3) this report, which also serves as the main implementation package for this research.

Presentation

Appendix E of this document outlines a presentation which describes the WRM evaluation system, its background and objective, the evaluation process itself, laboratory testing and implementation of the results. This presentation can be made to the participants of a meeting/seminar to familiarize them with the WRM evaluation process. This report would serve as the main reference for any additional questions that might arise.

TABLE 4.1. ECONOMIC ANALYSIS OF ROADBASE CONSTRUCTION ALTERNATIVES IN WICHITA FALLS

Item Description	Units	Estimated Quantity		Cost	Difference
		Original	VECP	$	$
Excavation	CY	30,259	27,859	2.65	- 6,360
Embankment	CY	10,819	8,820	2.64	-5,297
Flexible Base Material	CY	17,082	0	25.50	-435,591
Reworking Base Material	Sta	90.50	0	265	-23,982
Lime Treatment Subgrade	SY	66,070	0	1.10	-72,677
Lime Type A	T	1,090	0	82.00	-89,412
Haul, RAP Stockpile	CY	1,272	0	5.00	-6,360
Asphalt Emulsion (AE-P)	G	13,702	0	1.90	-26,033
Aggregate (Ty B, Gr 3)	CY	525	0	30.5	-16,012
Asphalt Emulsion (CRS-2)	G	22,840	0	1.12	-25,580
Barricades. Traffic Control	M	12	5	2350	-16,450
Construct Detours	Sta	86	0	235	-20,210
Reflective Pav. Marking	LF	48,045	13,645	0.15	-5,160
RAP Base Material	CY	0	14,675	21.7	319,181
Total TxDOT Savings Due to VECP					-442,397
Contractor's Bonus					221,198
Total TxDOT Savings					-221,198

Specifications for Use of WRMs

As detailed in chapter 3 of this document RAP, RPCP, and EAFS were selected for detailed technical study based on the results of the evaluation process. Results of laboratory testing done during the technical evaluation sub-system and subsequently for method verification were used to develop specifications for the use of these materials in road base construction. These trial specifications are describes in appendices B, C, and D for RAP, RPCP, and EAFS respectively and are ready for field use on an experimental basis and should be updated based on experience with field use.

Research Report

This research report serves as the main implementation package for the whole project. Not only does it describe the WRM evaluation process, but also documents a presentation - outlining the whole process, and trial specifications for the use of WRMs in roadbase construction. Information documented in this report can be supplemented using information provided in Center for Transportation Research reports 1348-1 and 1348-2F by Saeed et. al. [Saeed 95, Saeed 96].

CHAPTER SUMMARY

This chapter described the implementation and technology transfer efforts of this research project. Main technology transfer is achieved by means of this report which includes four appendices to make this whole implementation process an easy one. Additionally, a case study describing the RAP recycling project in Wichita Falls district of TxDOT is also reported. The strength properties of RAP used in that construction project were demonstrated to be adequate, and comparable to standard TxDOT asphalt stabilized base material. Also, the economic viability of recycling was demonstrated by using a better paving material at a lower cost.

CHAPTER 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to implement the Waste and Reclaimed Material (WRM) evaluation system developed under a grant from the Texas Department of Transportation (TxDOT) and the Texas Natural Resource Conservation Commission (TNRCC). Before the evaluation system could be implemented it had to be verified by conducting appropriate laboratory tests and economic studies. More specifically, this study verified the WRM evaluation process, developed trial specifications for the use of available WRMs in roadbase construction and prepared a field implementation package.

SUMMARY

Data had already been collected on the types, quantities, and location of WRMs available in Texas under the TxDOT/TNRCC research project. The WRM evaluation process developed under the same study was used to rank the available WRMs from lowest potential to highest potential for roadbase application based on technical, economic, societal and environmental aspects of their use. Based on objective data, three WRMs passed the evaluation method and were recommended for detailed laboratory testing in order to verify the method and develop specifications for their use in roadbase construction. These materials were reclaimed asphalt concrete (RAP), reclaimed Portland cement concrete (RPCP), and electric arc furnace slag (EAFS). These materials were then subjected to seven standard laboratory tests to characterize them properly and to determine their strength characteristics. Laboratory test results supplemented by the conducted economic analysis proved the use of WRMs to be a feasible one, hence verifying the WRM evaluation process.

After the WRM evaluation process had been verified, the results were then used to develop to field implementation package. The implementation package consists of: 1) a presentation describing the WRM evaluation process (Appendix E), 2) trial specifications for using RAP, RPCP and EAFS (Appendices B, C, D), and 3) this research report which serves as the main implementation package.

The results of this study could not be implemented on a large scale in Texas, as envisioned in the beginning of the projected, due to unforeseen delays in laboratory testing and method verification. Nonetheless, a recycling project in Wichita Falls District of TxDOT was selected for implementation purposes. The results of this case study showed a number of societal and environmental benefits besides economic savings of $442,239.

CONCLUSIONS

The findings of this study are listed below:

1) WRMs often do not equal natural aggregate materials in technical quality but may still have a high societal, environmental and/or economic value which provide the impetus for their use.

2) Based on the recommendations of an expert review panel the technical evaluation sub-system was weighed more heavily in the overall evaluation system followed by the economic, environmental and societal evaluation sub-systems. These weights are for demonstration purposes only and tend to change with prevailing societal trends.

3) RAP demonstrated the maximum utilization potential 70% for use after evaluation using the WRM evaluation process. RAP was followed by EAFS, RPCP and coal combustion by-products with utilization potentials of 60%, 50% and 40% respectively.

4) The WRM evaluation system was verified when the results of detailed laboratory testing and the economic analyses concurred with its recommendations.

5) Results of the implementation case study showed that the use of WRMs in roadbase is a viable alternative. This approach results in safer, cleaner and expedited construction projects which also cost less.

6) The developed trial specifications provide ahead start in the right direction, though field testing remains to be done to develop performance based specification.

7) The results of the WRM evaluation system are sensitive to prevailing local conditions. Every effort should be made to properly implement the evaluation system using the developed implement package and to account for local societal and political factors.

RECOMMENDATIONS

The results of this study point to several recommendations for future research and to facilitate the facilitate the maximum use of WRM in transportation projects by implementing the WRM evaluation process. These recommendations are as follows:

1) It is recommended that the WRM process be modified to rationally and objectively evaluate WRMs for other engineering applications besides in roadbase construction projects. This could be accomplished by making adjustments to the evaluating attributes for each appropriate evaluation sub-system.

2) A comprehensive analytical, laboratory and field study should be conducted to estimate the performance of the top ranked WRMs. The trial specifications could be modified in light of the results of the study.

3) A comprehensive field experiment should be undertaken on all the tested WRMs. This work could be accomplished by implementing the WRM evaluation system in a number of locations and constructing test sections using the developed specifications. Using this approach inventory and monitoring data can be collected to assess long-term field performance of WRMs.

4) The developed trial specifications should be implemented and further studied in pilot experiments. These should be made less restrictive, if possible, based on the field performance of WRMs.

5) Research should be undertaken to determine the feasibility of computerizing the WRM evaluation system with a user friendly interface. This would result in better and easier implementation of the evaluation process.

6) A survey should be conducted to assess the recycling efforts at the county and city level. The WRM evaluation process can be described to interested parties at a seminar and assistance given as per need basis to implement the systems in their locales.

APPENDIX A

ESTIMATION OF WRM UTILIZATION POTENTIAL USING THE DEVELOPED WRM EVALUATION SYSTEM

TABLE A.1. ESTIMATION OF UTILIZATION POTENTIAL OF RPCC

Factor	Score	Remarks
Initial Screening		
Acc / Ann Produced Quantity	OK	19 thousand tons
Material Location	OK	Various locations, accessible
Material Toxicity	OK	Non toxic
Water Solubility	OK	Non soluble
Material Durability	OK	Proven durability
Technical Evaluation		
Gradation	2.34	Cu = 4.68
Particle Shape and Texture	3.25	Angular
Hardness	3.50	= 7.00
Resistance to Applied Load	1.95	= 30%
Economic Evaluation		
Quantity	0.26	19 thousand tons
Transportation Cost	1.50	Distances > 96 km
Disposal Cost	5.00	Maximum savings
Stab / Mod / Add Material Cost	2.50	50% natural material required
Processing Cost of Reuse	4.00	Site mixed, minimal
Societal Evaluation		
Govt./Sp. Group Interest	3.00	No statutes
Health / Safety Risk	1.00	None / minimal
Storage Site Aesthetics	4.00	Highly visible, less locations
Environmental Evaluation		
Benefit of Recycling	2.50	50 % saving of virgin aggregate
Noise Pollution	5.00	No processing required
Dust Pollution	5.00	No processing required
Leaching Potential	5.00	None
WRMUP = 50.20%		

TABLEA.2. ESTIMATION OF UTILIZATION POTENTIAL OF FLY ASH

Factor	Score	Remarks
Initial Screening		
Acc / Ann Produced Quantity	OK	2 thousand tons
Material Location	OK	Various locations, accessible
Material Toxicity	OK	Non toxic
Water Solubility	OK	Soluble, but not applicable
Material Durability	OK	Not applicable
Technical Evaluation		
Gradation	5.00	Material obtainable as desired
Particle Shape and Texture	3.91	Angular
Hardness	3.00	= 6.00
Resistance to Applied Load	1.77	= 32.33%
Economic Evaluation		
Quantity	0.03	2 thousand tons
Transportation Cost	0.75	Power plant locations
Disposal Cost	3.00	Considerable savings
Stab / Mod / Add Material Cost	1.50	100 % natural material required
Processing Cost of Reuse	2.00	Site mixed, minimal
Societal Evaluation		
Govt./Sp. Group Interest	2.50	No statutes
Health / Safety Risk	2.00	Hazardous
Storage Site Aesthetics	2.00	Hidden plant locations
Environmental Evaluation		
Benefit of Recycling	0.00	No saving of natural aggregate
Noise Pollution	5.00	No processing required
Dust Pollution	5.00	No processing required
Leaching Potential	2.50	None

WRMUP = 45.20 %

TABLE A.3. ESTIMATION OF UTILIZATION POTENTIAL OF BOTTOM ASH

Factor	Score	Remarks
Initial Screening		
Acc / Ann Produced Quantity	OK	2 thousand tons
Material Location	OK	Various locations, accessible
Material Toxicity	OK	Non toxic
Water Solubility	OK	Soluble, but not applicable
Material Durability	OK	Not applicable
Technical Evaluation		
Gradation	5.00	Material obtainable as desired
Particle Shape and Texture	3.91	Angular
Hardness	3.00	= 6.00
Resistance to Applied Load	1.77	=32.33%
Economic Evaluation		
Quantity	0.02	2 thousand tons
Transportation Cost	0.75	Power plant locations
Disposal Cost	3.00	Maximum savings
Stab / Mod / Add Material Cost	1.50	100 % natural material required
Processing Cost of Reuse	2.00	Site mixed, minimal
Societal Evaluation		
Govt./Sp. Group Interest	3.00	No statutes
Health / Safety Risk	2.00	Hazardous
Storage Site Aesthetics	2.00	Hidden plant locations
Environmental Evaluation		
Benefit of Recycling	0.00	No saving of natural aggregate
Noise Pollution	5.00	No processing required
Dust Pollution	5.00	No processing required
Leaching Potential	2.50	None

WRMUP = 45.20 %

TABLE A.4. ESTIMATION OF UTILIZATION POTENTIAL OF POND ASH

Factor	Score	Remarks
Initial Screening		
Acc / Ann Produced Quantity	OK	2 thousand tons
Material Location	OK	Various locations, accessible
Material Toxicity	OK	Non toxic
Water Solubility	OK	Soluble, but not applicable
Material Durability	OK	Not applicable
Technical Evaluation		
Gradation	5.00	Material obtainable as desired
Particle Shape and Texture	3.91	Angular
Hardness	3.00	= 6.00
Resistance to Applied Load	1.77	= 32.33%
Economic Evaluation		
Quantity	0.02	2 thousand tons
Transportation Cost	0.75	Power plant locations
Disposal Cost	3.00	Maximum savings
Stab / Mod / Add Material Cost	1.50	100 % natural material required
Processing Cost of Reuse	2.00	Site mixed, minimal
Societal Evaluation		
Govt./Sp. Group Interest	2.50	No statutes
Health / Safety Risk	2.00	Hazardous
Storage Site Aesthetics	2.00	Hidden plant locations
Environmental Evaluation		
Benefit of Recycling	0.00	No saving of natural aggregate
Noise Pollution	5.00	No processing required
Dust Pollution	5.00	No processing required
Leaching Potential	2.50	None

WRMUP = 45.00 %

TABLE A.5. ESTIMATION OF UTILIZATION POTENTIAL OF ELECTRIC ARC FURNACE SLAG

Factor	Score	Remarks
Initial Screening		
Acc / Ann Produced Quantity	OK	130 thousand tons
Material Location	OK	Various locations, accessible
Material Toxicity	OK	Non toxic
Water Solubility	OK	Non soluble
Material Durability	OK	Proven durability
Technical Evaluation		
Gradation	3.41	Cu = 6.82
Particle Shape and Texture	3.75	Angular
Hardness	4.00	= 8.00
Resistance to Applied Load	2.80	= 22%
Economic Evaluation		
Quantity	1.83	130 thousand tons
Transportation Cost	0.50	Steel plant location
Disposal Cost	5.00	Maximum savings
Stab / Mod / Add Material Cost	5.00	None required
Processing Cost of Reuse	5.00	None required
Societal Evaluation		
Govt./Sp. Group Interest	2.50	No statutes
Health / Safety Risk	1.00	None / minimal
Storage Site Aesthetics	2.50	Hidden, less locations
Environmental Evaluation		
Benefit of Recycling	5.00	100 % saving of virgin aggregate
Noise Pollution	5.00	No processing required
Dust Pollution	5.00	No processing required
Leaching Potential	2.50	Under Consideration

WRMUP = 60.40%

TABLE A.6. ESTIMATION OF UTILIZATION POTENTIAL OF NATURAL CRUSHED LIMESTONE

Factor	Score	Remarks
Initial Screening		
Acc / Ann Produced Quantity	OK	Freely available
Material Location	OK	Various locations, accessible
Material Toxicity	OK	Non toxic
Water Solubility	OK	Non soluble
Material Durability	OK	Proven durability
Technical Evaluation		
Gradation	5.00	Available in any combination
Particle Shape and Texture	3.91	PI = 15.60
Hardness	3.00	= 6.00
Resistance to Applied Load	1.77	= 32.33%
Economic Evaluation		
Quantity	5.00	Freely available
Transportation Cost	5.00	No fixed destination
Disposal Cost	0.00	Maximum savings
Stab / Mod / Add Material Cost	1.00	Cost : $ 5.00 per ton
Processing Cost of Reuse	5.00	None required
Societal Evaluation		
Govt./Sp. Group Interest	0.00	No statutes
Health / Safety Risk	0.00	None / minimal
Storage Site Aesthetics	3.00	Hidden, quarry locations
Environmental Evaluation		
Benefit of Recycling	0.00	No saving of SNA
Noise Pollution	3.00	Crusher at quarry
Dust Pollution	4.00	Crusher at quarry
Leaching Potential	5.00	None

WRMUP = 58.85%

APPENDIX B

TRIAL SPECIFICATIONS FOR FLEXIBLE BASE USING RAP

DESCRIPTION

This work shall consist of construction of a base course using either previously reclaimed and stockpiled asphaltic concrete or pulverizing the existing asphaltic concrete pavement, hereinafter called RAP. If RAP has to be transported in, it shall be done so from TxDOT approved stock piles and in case of pulverization, portions of underlying base material may also be included to the depth and width shown on the plans, without damaging the underlying layers. Water will then be incorporated into the RAP. This reclaimed material will then be spread and compacted in accordance with the plans and specifications and as directed by the engineer.

MATERIALS

RAP shall meet the following gradation requirements prior to the addition of the natural aggregate material for gradation adjustment:

Sieve Size	% Passing
50.80 mm	100
31.75 mm	95

The top size of RAP shall not exceed 1/2 the depth of the base layers. No additional natural aggregate material shall be added unless dictated by the job mix requirements or if required to increase the thickness of the base course, and shall meet the requirements as shown in Table B.1.

The natural aggregate material shall be used with the approval of the project engineer and shall meet the requirements of Item 247, "Flexible Base", as outlined in "Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges." An overall effort shall be made to maximize the use of RAP within the limits of the jobmix formula.

TABLE B.1. GRADING REQUIREMENTS FOR FINAL BASE MIXTURES (AFTER ASTM D 2940)

Square Sieve Size (mm)	Percentage Passing by Weight	Job Mix Tolerances
50.00	100	- 2
37.50	95 - 100	± 5
19.00	70 - 92	± 8
9.50	50 - 70	± 8
4.75	35 - 55	± 8
0.60	12 - 25	± 5
0.075	0 - 8	± 3

CONSTRUCTION METHOD

Prior to the delivery of the base material, the subgrade or existing roadbed shall be shaped to conform to the typical sections, shown on the plans or established by the Engineer.

RAP and any required natural material, when specified on plans, shall be mixed in a manner which does not disturb the underlying material in the existing roadway. Furthermore, base construction operations shall not be performed when the weather is foggy, rainy, or when the weather conditions are such that in the judgment of the engineer, proper mixing, spreading, and compacting cannot be accomplished.

The required in place density will be 95% of the laboratory molded density and will be determined using Test Method Tex-113-E, "Determination of Moisture-Density Relations of Soils and Base Materials." After each section of flexible base is completed, tests as necessary will be made by the Engineer in accordance with Test Method Tex-115-E, "Field Method for Determination of In-Place Density of Soils and Base Materials". The selected rolling pattern shall be followed unless change in the mixture or placement conditions occur which affect compaction which would require a new rolling pattern to be established. Water used for compaction shall conform to the requirements of Item 204, "Sprinkling", as outlined in "Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges".

After placing and compaction of the waste material it shall be allowed to cure for a period of at least two hours before any traffic, including contractors equipment, is allowed on the completed RAP base course. It may then be open to traffic and allowed to cure till the moisture content drops to below 2% by weight of the mix before the placement of any hot mix asphaltic concrete material.

EQUIPMENT

The contractor shall furnish a self propelled machine capable of pulverization in-situ materials, if so required, to the depth shown on the plans. The contractor shall furnish equipment capable of mixing RAP and the required amount of water to a homogenous mixture and placing the mixture in a windrow or directly into the hopper of a paver. Said machine shall be capable of screening and crushing capabilities to reduce all the oversized particles to size prior to mixing. The method of placing the mixed material shall be such that segregation does not occur. The mixing equipment shall be capable of registering the rate of flow and total delivery of the water introduced into the mixture. The mixed RAP base shall be spread in one continuous pass, without segregation, to the lines and grades established by the engineer.

Rolling shall be considered subsidiary to this Item and all rollers shall meet the requirements specified in the Item 210, "Rolling (flat wheel)", and Item 213, "Rolling (pneumatic tire)" as outlined in "Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges". The number, weight, and type of rollers shall be sufficient to obtain the required compaction while the mixture is in a workable condition. Any type of rolling that results in cracking, movement, or other type of pavement distress shall be discontinued until such time as the problem can be resolved. Discontinuation and commencement of rolling operation shall be at the discretion of the project engineer.

MEASUREMENT

Work as prescribed for this item will be measured by the square meter of the completed sections for the depth specified. The asphalt emulsion shall be measured by the liter. Water used in this operation will not be paid for directly but will be considered subsidiary to this bid item.

PAYMENT

The work performed and materials furnished, as prescribed by this item, and measured as provided under "measurements", will be paid for at the unit prices bid for this item and "asphalt emulsion" and such prices shall be full compensation for the removal, and processing of the existing pavement, for furnishing, preparing, hauling, and placing all materials, including RAP from other sources; for all freight involved; for all manipulations, including rolling and broming and for all labor, tools, equipment, and incidentals necessary to complete this work.

APPENDIX C

TRIAL SPECIFICATIONS FOR FLEXIBLE BASE USING RPCP

DESCRIPTION

This work shall consist of construction of a base course, using either previously reclaimed and stockpiled Portland cement concrete or pulverizing the existing Portland cement concrete pavement, hereinafter called RPCP. If RPCP has to be transported in, it shall be done so from TxDOT approved stock piles and in case of pulverization, portions of underlying base material may also be included to the depth and width shown on the plans. Any natural aggregate material and water, if required, will then be incorporated in this mixture. This properly mixed material will then be spread and compacted in accordance with the plans and specifications and as directed by the project engineer.

MATERIALS

The constructed base course shall consist at most 50% RPCP by weight of the final mixed material, and the remaining material shall be at least Group 4A conforming to the ASTM soil classification. The natural material added must conform to the specifications of Item 247, "Flexible Base" as outlined in "Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges". RPCP shall be substantially free of all foreign matter and the final base mixture shall meet the gradation requirements, as shown in Table C.1. The top size of RPCP shall not exceed 1/2 the depth of the recycled mat.

CONSTRUCTION METHOD

Prior to the delivery of the base material, the subgrade or existing roadbed shall be shaped to conform to the typical sections, shown on the plans or established by the Engineer. Recycling operations shall not be performed when the weather is foggy, rainy, or when the weather conditions are such that in the judgment of the engineer, proper mixing, spreading, and compacting cannot be accomplished.

TABLE C.1. GRADING REQUIREMENTS FOR FINAL BASE MIXTURES (AFTER ASTM D 2940)

Square Sieve Size (mm)	Percentage Passing by Weight	Job Mix Tolerances
50.00	100	-2
37.50	95 - 100	± 5
19.00	70 - 92	± 8
9.50	50 - 70	± 8
4.75	35 - 55	± 8
0.60	12 - 25	± 5
0.075	0 - 8	± 3

The contractor may add water to RPCP, when approved by the engineer, to facilitate uniform mixing and compaction. The water may be added to the material before the addition of the binder or may be added concurrently with the binder. The moisture content after addition of water to the mixture shall not exceed 5% of the dry weight of RPCP.

Rolling patterns shall be established as outlined in test method Tex-207-F, Part III, to achieve the maximum compaction. The selected rolling pattern shall be followed unless change in the mixture or placement conditions occur which affect compaction which would require a new rolling pattern to be established.

After placing and compaction of the recycled material it shall be allowed to cure for a period of at least two hours before any traffic is allowed on the completed recycled Portland cement concrete base. It may then be open to traffic and allowed to cure till the moisture content drops to below 2% by weight of the mix before the placement of any hot mix asphaltic concrete material.

EQUIPMENT

The contractor shall furnish a self propelled machine capable of pulverizing in-situ materials, if required, to the depth shown on the plans. The contractor shall furnish equipment capable of mixing RPCP and the natural aggregate material to a homogenous mixture and placing the mixture in a windrow or directly into the hopper of a paver. Said machine shall be capable of screening and have crushing capabilities to reduce all the oversized particles to size prior to mixing. The method of disposing the mixed material shall be such that segregation does not occur.

Placing of the recycled Portland cement concrete base course shall be accomplished by means of a self-propelled paver. The recycled material shall be spread in one continuous pass, without segregation, to the lines and grades established by the engineer.

Rolling shall be considered subsidiary to this item and all rollers shall meet the requirements specified in Item 210, "Rolling (flat wheel)", and Item 213, "Rolling (pneumatic tire)." The number, weight, and type of rollers shall be sufficient to obtain the required compaction while the mixture is in a workable condition. Any type of rolling that results in cracking, movement, or other type of pavement distress shall be discontinued until such time as the problem can be resolved. Discontinuation and commencement of rolling operation shall be at the discretion of the project engineer.

MEASUREMENT

Work as prescribed for this item will be measured by the square meter of the completed sections for the depth specified. The cementing agent shall be measured by the gallon. Water used in this operation will not be paid for directly but will be considered subsidiary to this bid item.

PAYMENT

The work performed and materials furnished, as prescribed by this item, and measured as provided under "measurements", will be paid for at the unit prices bid for "recycling of Portland cement concrete material" and "Portland cement", and such prices shall be full compensation for the removal and processing of the existing pavement, for furnishing, preparing, hauling, and placing all materials, including RPCP from TxDOT approved sources; for all freight involved; for all manipulations, including rolling and brooming and for all labor, tools, equipment, and incidentals necessary to complete this work.

APPENDIX D

TRIAL SPECIFICATIONS FOR FLEXIBLE BASE USING EAFS

DESCRIPTION

This work shall consist of construction of a base course, using previously reclaimed and stockpiled Electric Arc Furnace Slag, hereinafter called EAFS. EAFS shall be transported in from TxDOT approved stock piles. Any water, if required, will then be incorporated in this mixture. This properly mixed material will then be spread and compacted in accordance with the plans and specifications and as directed by the project engineer.

MATERIALS

The maximum amount of EAFS shall be incorporated in the base course within the limits of the jobmix formula. EAFS shall be substantially free of all foreign matter and shall meet the gradation requirements, as shown in Table D.1. The top size of EAFS shall not exceed 1/2 the depth of the recycled mat. No additional natural aggregate material shall be added unless dictated by the job mix requirements or if required to increase the thickness of the base course. The natural aggregate material shall be used with the approval of the project engineer and shall meet the requirements of Item 247, "Flexible Base", as outlined in "Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges".

CONSTRUCTION METHOD

Prior to the delivery of the base material, the subgrade or existing roadbed shall be shaped to conform to the typical sections, shown on the plans or established by the Engineer.

Recycling operations shall not be performed when the weather is foggy, rainy, or when the weather conditions are such that in the judgment of the engineer, proper mixing, spreading, and compacting cannot be accomplished.

TABLE D.1. GRADING REQUIREMENTS FOR FINAL BASE MIXTURES (AFTER ASTM D 2290)

Square Sieve Size (mm)	Percentage Passing by Weight	Job Mix Tolerances
50.00	100	-2
37.50	95 - 100	± 5
19.00	70 - 92	± 8
9.50	50 - 70	± 8
4.75	35 - 55	± 8
0.60	12 - 25	± 5
0.075	0 - 8	± 3

The contractor may add water to EAFS, when approved by the engineer, to facilitate uniform mixing and compaction. The required in place density will be 95% of the laboratory molded density and will be determined using Test Method Tex-113-E, "Determination of Moisture-Density Relations of Soils and Base Materials". After each section of flexible base is completed, tests as necessary will be made by the Engineer in accordance with Test Method Tex-115-E, "Field Method for Determination of In-Place Density of Soils and Base Materials". The selected rolling pattern shall be followed unless change in the mixture or placement conditions occur which affect compaction which would require a new rolling pattern to be established. Water used for compaction shall conform to the requirements of Item 204, "Sprinkling", as outlined in "Texas Department of Transportation Standard Specifications for Construction of Highways, Streets and Bridges". Rolling patterns shall be established as outlined in test method Tex-207-F, part III, to achieve the maximum compaction. The selected rolling pattern shall be followed unless change in the mixture or placement conditions occur which affect compaction which would require a new rolling pattern to be established.

After placing and compaction of the recycled material it shall be allowed to cure for a period of at least two hours before any traffic is allowed on the completed recycled EAFS base. It may then be open to traffic and allowed to cure till the moisture content drops to below 2% by weight of the mix before the placement of any hot mix asphaltic concrete material.

EQUIPMENT

Placing of the EAFS base course shall be accomplished by means of a self-propelled paver. The recycled material shall be spread in one continuous pass, without segregation, to the lines and grades established by the engineer.

Rolling shall be considered subsidiary to this item and all rollers shall meet the requirements specified in Item 210, "Rolling (flat wheel)", and Item 213, "Rolling (pneumatic tire)." The number, weight, and type of rollers shall be sufficient to obtain the required compaction while the mixture is in a workable condition. Any type of rolling that results in cracking, movement, or other type of pavement distress shall be discontinued until such time as the problem can be resolved. Discontinuation and commencement of rolling operation shall be at the discretion of the project engineer.

MEASUREMENT

Work as prescribed for this item will be measured by the square meter of the completed sections for the depth specified. The cementing agent shall be measured by the gallon. Water used in this operation will not be paid for directly but will be considered subsidiary to this bid item.

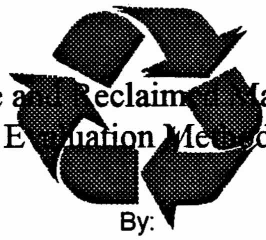
PAYMENT

The work performed and materials furnished, as prescribed by this item, and measured as provided under "measurements", will be paid for at the unit prices bid for "recycling of electric arc furnace slag material" and such prices shall be full compensation for the removal and processing of the existing pavement, for furnishing, preparing, hauling, and placing all materials, including RPCP from TxDOT approved sources; for all freight involved; for all manipulations, including rolling and brooming and for all labor, tools, equipment, and incidentals necessary to complete this work.

APPENDIX E

PRESENTATION DESCRIBING THE WRM EVALUATION SYSTEM

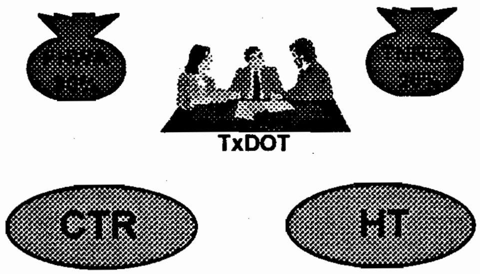
Waste and Reclaimed Materials in Roadbase



Waste and Reclaimed Materials Evaluation Method

By:
Athar Saeed

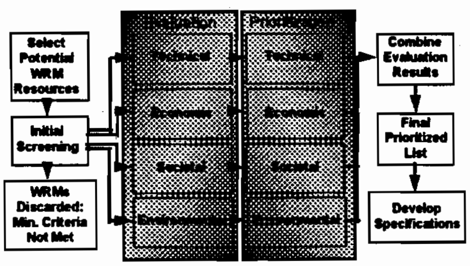
Background



Objective

Develop a method to evaluate Waste and Reclaimed Materials (WRMs), encompassing all facets of their utilization, without undertaking expensive and time consuming technical studies

Material Evaluation Flowchart



Initial Screening

- Used to Eliminate Materials with Low Potential
- Factors for Minimum Acceptability
  - Accumulated/Annually Produced Quantity
  - Material Location
  - Material Toxicity
  - Material Durability

Technical Evaluation

- Gradation
- Particle Shape and Texture
- Particle Hardness
- Resistance to Applied Load Degradation

Technical Eval. Sub-System

Attributes \ Score	0	2	4	6	8	10
Gradation, Cu	0	2	4	6	8	10
WRM Hardness	0	2	4	6	8	10
Particle Shape & Texture	0	4	8	12	16	20
LA Degradation	50	40	30	20	10	0

Economic Evaluation

- Accumulated/Annually Produced Quantity
- Cost of Processing WRMs
- Cost of Additional Materials
- Transportation Cost

Societal Evaluation

- Storage Site Aesthetics
- Safety/Health Hazard
- Government/Special Group Interest

Environmental Evaluation

- Benefits of Recycling
- Environmental Effects of Processing
  - Noise Pollution
  - Dust Pollution
- Effect of Material Use on Environment

Combined Evaluation

$$CE = W_T TE + W_E EE + W_S SE + W_{En} EnE$$

CE = Combined Evaluation
TE = Technical Evaluation
EE = Economic Evaluation
SE = Social Evaluation
EnE = Environmental Evaluation
W_i = Respective Weight

Selection of Weights

- Based on AHP
- Estimated Weights
  - Technical : 48%
  - Economic : 28%
  - Societal : 8%
  - Environ. : 14%

Prioritized List of WRMs

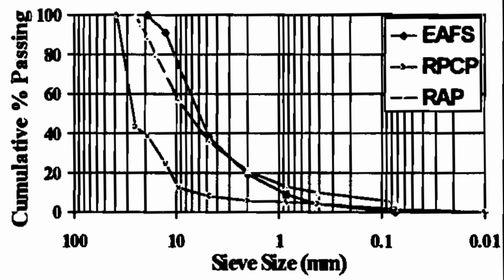
- Reclaimed Asphalt Concrete: 68%
- Electric Arc Furnace Slag: 60%
- TxDOT Standard Roadbase: 58%*
- Reclaimed PCC: 50%
- Powerplant Ash: 45%

* For Comparison Only

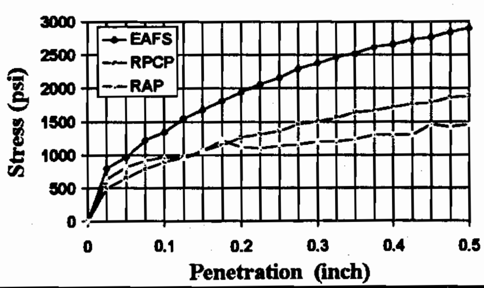
Laboratory Testing Program

- Characterization Tests
  - Grain Size Distribution
  - Hardness
  - Specific Gravity
  - Particle Shape and Texture
- Aggregate Tests
  - Los Angeles Abrasion Test
  - California Bearing Ratio

Grain Size Distribution



California Bearing Ratio



Contributions

- Waste and Reclaimed Materials Evaluation System
- Types and Quantities of WRMs Available in Texas
- Specifications for Roadbase Construction Using WRMs
- State of the Practice of WRM Use

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