USE OF QUARRY FINES FOR ENGINEERING AND ENVIRONMENTAL APPLICATIONS

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SPECIAL RESEARCH REPORT FOR THE
NATIONAL STONE ASSOCIATION

OCTOBER 1992

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

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October 1992

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CHAPTER 1

INTRODUCTION

BACKGROUND AND PROBLEM STATEMENT

An estimated 1.2 billion tons of construction aggregates are produced in the United States annually. The production of crushed stone aggregates generates, as a by-product, quarry fines. Quarry fines are products that are produced as a result of the crushing operation, containing a large amount of fine material that passes the No. 200 sieve. Quarry fines may be dry screenings collected from below the last screen deck in a dry or semi dry state or pond screenings, obtained from washing aggregates, collected from settling ponds. The amount of fines generated varies from one crushing plant to another and may include up to 20% of the production depending on quarry nature, type of rock crushed, and type and size of aggregates produced. Most of the specifications for construction use of aggregates do not accept any material with more than 10% passing No. 200 sieve. Currently these fine grained material are used on a limited basis and their proper disposal is a growing concern of the stone industry.

To solve this problem it is important that the industry continue to seek alternative uses and markets for quarry fines. Identifying new applications could 1) minimize or eliminate costs related to storage and disposal of these materials, 2) serve as a convincing demonstration of environmental awareness of the crushed stone industry, and 3) generate additional revenue from the sale of these stockpiled fine materials.

This report has attempted to define the magnitude of the fines problem in the industry, and find additional potential uses of quarry fines for engineering and environmental applications. This chapter discusses the scope and the methodology used in the study.

SCOPE OF THE STUDY

This study includes finding potential uses of quarry fines and identifying the most promising economic applications. Quarry fines are difficult to market because they contain at least 15% or more of minus No. 200 sieve material in it, which in many case is considered clayey materials. In this case most or part of the fines passing No.200 sieve could be just pulverized rock which is an inert material that would not react with bonding agents. We have attempted to quantify the magnitude of the problem within the stone industry. We have attempted to classify the fines based on the type of parent rock and the gradation. Most of the present uses of the fines are documented herein to summarize the usage of the fines. Some additional promising uses are suggested and two of those uses are studied in detail. The scope of this project was limited due to the limited resources.

METHODOLOGY

The methodology used to approach this problem was subdivided into two stages.

STAGE I

Stage I of the project dealt with the study of several samples of quarry fines. The material properties and characteristics were thoroughly examined. The industry production volumes and the fines production were studied in detail. Four basic tasks were accomplished to complete stage I.

1. Literature review.

2. Industry survey.

3. Visit to quarries.

4. Testing of quarry fines samples.

Literature Review: Published data served as the best source of information to start. An extensive literature review was conducted and focussed on :

1. The types of quarry fines that are found in the industry and relative quantities and percentages of fines that are found among various crushed stone sources.

2. Previous uses of fines in highway, building or environmental applications.

3. Research into possible usage of fines in combination with other materials.

The literature review and the conclusions of the review are discussed in next chapter in detail.

Industry Survey: A questionnaire was designed and sent to 101 companies/quarries all over the country. Questionnaires were sent to all the National Stone Association member quarries (32) in Texas and selected NSA member companies (69) in other states. The survey was conducted, primarily, to determine the magnitude of the problem associated with quarry fines in the crushed stone industry, and to characterize the fines produced. The methodology and the results of the industry survey are discussed in detail in chapter III of this report.

Quarry Visit: A Visit was made to a major crushed stone quarry in Texas. The quarry visit was very helpful in understanding the production processes of fines. Information was gathered during the visit regarding general characteristics of quarry fines, settling ponds, etc. The production of crushed stone quarry fines are discussed in Chapter III of this report.

Testing: Tests were conducted to determine suitability of the material for the applications studied. Following tests were done for some of the samples received:

1. Grain size analysis.

2. Moisture Content.

3. Tests to determine whether quarry fines could be used in a cement stabilized subbase layer. The tests were conducted to determine:

   a. Indirect tensile strength,

   b. Unconfined compressive strength,

   c. Poisson's ratio, and

   d. Static Modulus of Elasticity.

4. Tests to determine the strength characteristics of flowable fill using quarry fines.

Testing procedures and the results are discussed in Chapters III and VI of this report.

STAGE II

Stage II of the project was a continuation and summary phase of Stage I. The information from Stage I was analyzed and synthesized to come to conclusions regarding potential uses. Necessary tests were conducted to determine suitability of the material for a particular use. Stage II can be broken down into two tasks which are themselves self explanatory.

1. Assessment of potential uses.

2. Report of findings.

The assessment of potential uses can themselves be broken into two tasks, namely, the present uses of quarry fines and the most promising uses of quarry fines. Two of the most promising uses of quarry fines were selected for further detailed study. A brief report of findings and recommendations of the study is herein produced.

CHAPTER 2

LITERATURE REVIEW

SCOPE

The literature review focussed on studying: 1) Types of quarry fines that are found in the industry, 2) relative quantities and percentages of fines that are found among various crushed stone sources, 3) previous uses of fines in highway, building or environmental applications, and 4) new possible uses of fines in combination with other materials.

Quarry fines, especially pond screenings, have inherently high moisture content. The fineness of the material and the high moisture content cause problems in handling and sale of the material. Also, though the cost of quarry fines is very low at the quarry site, the transportation costs discourage the sale of quarry fines beyond a radius of 50-100 miles away from the quarry. These limitations account for lack of work done on identifying engineering uses for quarry fines. Due to rising environmental concerns it is a necessity that the by-products of the crushed stone industry be utilized to the fullest extent possible.

A literature search was done using the following literature databases:

1. Transportation & Road Research laboratories,
2. Highway Research Information Systems,
3. Texas Department of Transportation, and
4. The University of Texas at Austin.

PREVIOUS RESEARCH

Considerable thought has been given to usage of waste materials as potential replacements for highway aggregates. R.D. Walker (Ref. 1) et. al., R.H. Miller et. al. (Ref. 2), and Charles R. Marek et. al.(Ref. 3), have all done research, in a way inter-related, addressing the problems of aggregate shortage and potential replacements of natural aggregate. Specifically, they address the problems and magnitude of:

1. Aggregate production in various regions of the country.
2. Shortage of conventional aggregates faced in some regions of the country.
3. Classification, quantities, and description of several waste materials and their potential to be used as a highway material.

These authors discuss and consider several types of domestic wastes, industrial wastes and mineral wastes. Industrial wastes like fly ash are discussed in more detail than others with regard to potential as highway material. There are no specific detailed discussions about quarry fines being put into specific engineering uses. However, R.H. Miller et. al., reports that mineral wastes obtained as tailings from mining/quarrying can be considered as potential replacements for highway aggregates.

CONCRETE INCORPORATING LIMESTONE FINES

Ahmed et. al., (Ref. 15), investigated the influence of very fine sand (finer than 75 micron or passing No. 200 sieve), from natural and crushed stone sources, on the performance of fresh and hardened concrete. Tests were conducted on two series of concrete mixture. One series (Series A) consisted of mixes having a constant slump of 100 $\pm$ 15 mm and the other series (Series B) contained mixes with a water-cement ratio of 0.70. Very fine sand passing No. 200 sieve present, if any, in the natural and manufactured sand was removed by sieving over a No. 200 sieve. Natural and crushed stone fines were then added in increasing percentages from 0 to 20% of the sand content replacing an equal amount of sand. The results of the tests on series A and Series B are as shown below:

1. Water demand increases rapidly when the very fine sand replacement is more than 15% in concrete using crushed stone sand.
2. Water bleeding data indicated a definite beneficial effect from the incorporation of more fines in the fine aggregate.
3. Series A (constant slump) tests showed that the compressive strength of constant-slump concrete decreases linearly with increasing percentage of fines. The flexural and bond strength's were also affected similarly.
4. Series B tests (concrete with constant water-cement ratio) showed that incorporation of fines in concrete resulted in significant reduction in slump.
5. The compressive strength of crushed stone sand concrete indicated an increase in strength by the incorporation of fines. However, the compressive strength of concrete using natural sand was not affected significantly by the incorporation of fines.

Malhotra et. al., (Ref. 33), also studied the problem of incorporation of limestone dust as partial replacement for sand in concrete. The results of the tests, conducted by the authors, were almost the same as given by Ahmed et. al. (Ref. 15). The results indicated that at water-cement ratio's of 0.53 and 0.70, compressive strength of concrete incorporating 15% and 20% limestone dust were higher than that of the concrete with no fines. Authors suggest two reasons for the increase in strength, although no experiments were performed to confirm these observations.

1. Due to the filler effect of the dust, air content of the concrete mix was reduced, thus increasing the density of the mix and the strength.

2. Factors such as the accelerated hydration of cement paste and the formation of carboaluminates contribute to an increase in strength.

The effect of incorporation of limestone fines in concrete can be summed up as follows (Ref. 15, 33):

1 The incorporation of up to 15% limestone fines as a partial replacement for fine aggregate in concrete does not significantly affect the properties of fresh & hardened concrete.

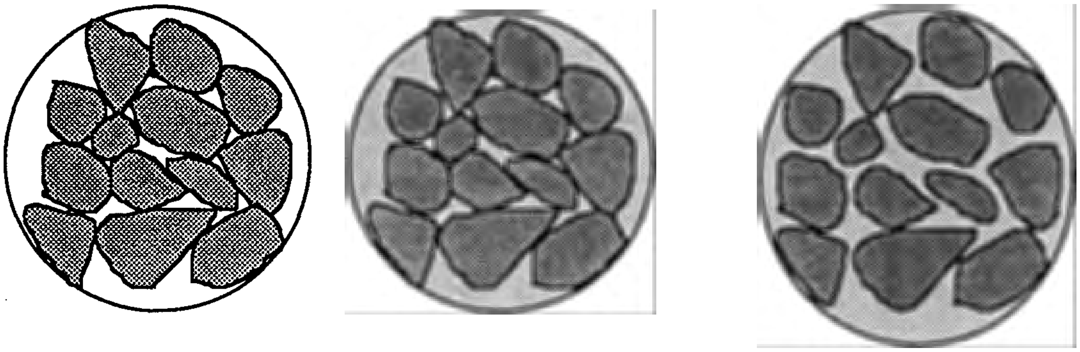
2 The use of limestone fines imparts more cohesiveness to fresh concrete giving it a decided advantage in super plasticized concrete.

3. Concrete incorporating more than 10 percent stone dust as a partial replacement for fine aggregate regardless of the water-cement ratio, shows a considerable loss in entrained-air content and slump.

4. Concrete, with a water-cement ratio of 0.70, incorporating more than 10 percent limestone dust shows significant increase in shrinkage as compared to concrete with no fines in it. Shrinkage increases with increase in fines content, but increase in shrinkage is comparatively lower in concrete (incorporating limestone dust) with water-cement ratio of 0.53 than in concrete with water-cement ratio of 0.70.

FINES CHARACTERISTICS.

Non-stabilized base courses are used under flexible pavements to increase the load carrying capacity of the pavement by distributing the load through a finite thickness of pavement. Faiz (Ref. 40) discussed the effect of fines on the stability of soil-aggregate mix, used in a base course and summarizes that the quantity of fines in a soil-aggregate mix has a major influence on maximum density, strength, frost resistance, and drainage. Faiz discussed three idealized physical states of soil-aggregate mixes as stated by Yoder (Faiz: Ref. 40). They are shown in Fig. 2.1.



(a)	(b)	(c)
a. Aggregate with no fines	b. Aggregate with sufficient fines for maximum density	c. Aggregate with great amount of fines
Grain-to-grain contact	Grain-to-grain contact with increased resistance against deformation	Grain-to-grain contact destroyed, aggregate floating in fines
Variable density	Increased density	Decreased density
Pervious	Low permeability	Low permeability
Nonfrost susceptible	Frost susceptible	Frost susceptible
High stability if confined, low if unconfined	Relatively high stability if confined or unconfined	Low stability
Not affected by adverse water condition	Not greatly affected by adverse water condition	Greatly affected by adverse water condition
Difficult to compact	Moderately difficult to compact	Not difficult to compact

Fig. 2.1. Physical states of soil-aggregate mixtures. After Ref. 40

Faiz noted the following in his literature review:

1. For a given soil-aggregate mix there is an optimum fines content at which maximum densities are attained.

2. Optimum fines content decreases as compactive effort increases.

3. From the standpoint of density and strength, a small amount of fines are desirable as additives to base-coarse aggregates, but larger quantities are detrimental.

Faiz on his discussion on the effect of crushed material noted that relatively higher strength values (CBR tests) are obtained for crushed stone than for gravel mixes, for the same compactive effort and proportion of fines in the soil-aggregate mix. However, he also noted that lower values of density may be obtained for crushed stone as compared to gravel.

Vinson et. al. (Ref. 11), developed a three test procedure to determine the quantity of fines produced during crushing, handling, and placement of aggregates used as base course in roadway construction. The nature and quantity of the fines, created by laboratory tests simulating natural conditions, are analyzed in order to determine their contribution to frost action susceptibility of a representative base course aggregate. A comparison of the laboratory and field tests is done and they conclude that the fines produced in the laboratory overestimates the quantity of fines that is likely to be produced for a given crushing, handling, and placement history. Also it is quoted that the fines produced during the operations should not render the base course aggregate frost susceptible, but fines present before crushing in combination with those produced in processing may prove to be detrimental to roadway pavement structure performance.

Thornton et. al. (Ref. 10), analyzed the rapid shear strength characteristics of fine grained materials. Rapid shear strength is a test which approximates a "failure" traffic condition. The authors conclude that the rapid shear strength of granular base material decreases with increases in the amount of fines passing No. 200 sieve. The authors state that decreasing the water content from very wet (near saturation) to optimum water content significantly increases the strength. The authors also state that crushed stone gravel is stronger than bank (natural, uncrushed) gravel.

In summary it can be said that in any soil aggregate mixture there is an optimum fines content at which maximum densities exist. There are some fines produced during crushing, handling, and placement of aggregates used as base course, but they do not themselves render the base course frost susceptible. In general, crushed stone gravel is stronger than natural uncrushed gravel.

FILLER EFFECT ON STRENGTH OF CEMENT MORTAR

Sorokka et. al. (Ref. 42) discussed the effect of three fillers (ground limestone, dolomite, and basalt) on the strength of cement mortars. The cement mortar mix used in the study was 1:2.75 (cement to sand) having a water-cement ratio of 0.70. Cement used was ordinary portland cement and naturally-occurring siliceous sand having a fineness modulus of 1.04 and an apparent specific gravity of 2.63 g per cu. cm. The fillers were obtained by fine grinding of limestone, dolomite and basalt. The filler content used to study the effect on the strength of cement mortar were 10, 20, 30, and 40% of the cement weight replacing a corresponding volume of sand. The results of the tests confirmed that fillers improve the strength of portland cement mortars and that this improvement is mainly due to accelerated hydration. The basalt filler possessed some pozzolonic properties. Hence the improvement in strength, increasing with filler content and fineness, reached a maximum of 56% for basalt fillers (at the age of 28 days, 40% filler content). The improvement in strength for the other two non-pozzolonic fillers, also increasing with filler content and fineness, reached 39% and 48% at the age of 28 days. The authors suggest that the improvement in strength may also be attributed to increased mix density (i.e. a lower air content) associated with the use of fillers, accounting for strength differences up to 10%. The authors dismiss the formation of monocalcium carboaluminate in the case of the finest limestone filler (specific surface of 10,300 g.cm per g) as irrelevant to the strength aspects.

MISCELLANEOUS USES

The aggregate handbook published by the National Stone Association (Ref. 21) and a paper presented at the fifty-first annual meeting of the ASTM (Ref. 9) detail the usage of very fine aggregates in non - construction uses. Some of those uses are briefly mentioned here and are later discussed elsewhere in a separate chapter.

Asphalt filler is one of the most common uses for fines. Asphalt filler is finely pulverized material, (limestone, dolomite or slag) which when incorporated with asphalts, hardens the product, increases its stability or strength under deforming load, and renders it less affected by temperature. The fineness specified is generally about 80% passing the No. 200 sieve. To summarize the work reported on mineral fillers :

1. Mineral fillers stiffen asphalt, and the degree of stiffening varies significantly between different fillers.

2. For a given filler source, the finer the filler the greater the stiffening effect.

3. Performance varies for different fillers and there are no tests that can adequately predict their performance.

Quarry fines are also used as fertilizer fillers. The main function of a fertilizer filler is to dilute the commercial fertilizers, aid in distribution of the fertilizer, prevent caking of the fertilizers, and to furnish a soil conditioning-effect. A rather granular lime stone or dolomite material of No. 20 to No. 80 sieves is used to make the fertilizer flow freely as through a grain drill.

Since pulverized limestone provides readily available calcium in quantity, it is used as a mineral supplement in poultry and animal feeding. The material desired should be with a fineness of at least 95% passing the No. 100 sieve.

The use of finely crushed limestone and dolomite for effecting soil improvement as an agricultural lime product cannot be overemphasized. The fineness depends on the products available and the product sizes range between passing No. 8 to No. 200 sieve.

Combustible coal dust in air and settled on objects in a coal mine creates a dangerous risk of explosion in the mine. Mine dusting of coal mines is done to reduce the danger of explosions by diluting the combustible dust in the mine with a non-combustible dust. The fineness desired for the non combustible dust is 100% passing No. 20 sieve and at least 50% passing No. 200 sieve.

MISCELLANEOUS CONSTRUCTION

Menacci (Ref. 43) on his article about Charles F. Myers Jr., mentions some of the applications developed by Myers. He reports that Myers helped develop a blasting grit plant. The grit was used instead of sand to clean paint and rust off the bottom of ships and was made of wet bottom boiler slag from a gas and electric company's coal fired generating operations. Myers had developed a topsoil mix for the Baltimore Zoo using fines and a cushion course for horse race tracks using fine aggregates. Myers had also helped to develop a thermal back fill for placement of high tension electrical wires in the ground. The back fill mixture was developed to dissipate the heat generated from the electrical wires using a very dense fines product that sets quickly. When the need arises to replace the lines, the back fill mix could be taken out of the trench and refilled again after the new lines have been laid.

USES OF POND SCREENINGS

Stokowski, (Ref. 35), stated there are at least 85 potential uses for pond screenings, the fines washed from an aggregate. These uses range from additives to non-specification aggregate, to applications as fill or daily cover for landfills, to industrial mineral feed stocks, to specialty products such as soil amendments, sand/lime products, or acid neutralizers for strip-mine, chemical plant, or other wastes. The author states that there are about 1 billion tons of pond screenings, industry wide, that could be recovered from settling ponds. Additionally, the author states that where large quantities of consistent material are available, pond screenings can readily yield salable products. To date, this recent paper by the author seems to be the major effort to summarize the potential uses of pond screenings. Most of the uses for the pond screenings would also apply to the dry screenings. Some of the potential uses as described by the author are given in Table 2.1. Comments of the author are also included where necessary. (Comments in brackets indicate references pertaining to this report).

Table 2.1. POTENTIAL PRODUCTS THAT COULD UTILIZE POND SCREENINGS

SOURCE: Stokowski, Jr., 1992, Ref. 35.

AGRICULTURAL PRODUCTS	
USES	**TECHNICAL COMMENTS**
1. Livestock	
a. Animal Shelter Absorbent	Material needs to be dry, substances which self-agglomerate are preferred. Added value in dairy barns because of anti-skid properties. Possible value from calcite or dolomite content if wastes are subsequently used as fertilizer.
b. Feed Additive	Limestone and Dolomite fines have some nutritive value. (Discussed in chapter 4).
c. Horse Tracks	Light-colored, fine materials have value because they do not clog hooves or discolor fetlocks. (Mentioned earlier, ref. 43).
d. Poultry Grit	Needed for proper digestion. (Discussed in chapter 4).
2. Manufactured Topsoil	Product can be made from most pond screenings. An organic source, such as sewage sludge or compost is incorporated with the pond screenings, along with any necessary admixtures for pH or nutrient control. Sales are usually to state highway departments, contractors, and railroads.
3. Pesticide/ Fertilizer Prodn.	(Discussed in chapter 4)
a. Bulking Agents/Carriers	Material must be dry and of a uniform, consistent gradation. Value may be added if soil amendment properties can be shown.
4. Soil Amendments	
a. Aglime	(Discussed in chapter 4)

Table 2.1. Potential Products That Could Utilize Pond Screenings - Continued...

b. Trace Minerals	the pond screenings from blast furnace slag, granite and trap rocks have the greatest potential to provide. The fine gradation is a definite plus.
c. Lawn & Agr. Sand	The sandier sizes could be utilized to improve the drainage and raise the elevation of poorly-drained soils. Greatest potential in areas of heavy clay soils. (Discussed in chapter 4 under Aglime).
CONSTRUCTION PRODUCTS	
USES	**TECHNICAL COMMENTS**
1. Asphalt Blotter	A well-known but low-volume use for fine sand. Most pond screenings could fill the same function if they were reasonably dry. (Discussed in chapter 4 under mineral fillers)
2. Crusher-Run Additive	Material can be added in the plant or in the pit. successful, long-term utilization is difficult to attain without strict control of addition rates and proper blending. Several plants are currently adding the pond screening fines to their products.
3. Electrical Cable Back fill	Essentially a dense-graded base; The maximum density product has a high thermal and a low electrical conductivity. Low iron or limestone pond screenings could be successfully used.
4. Floor Hardeners	The coarser size fractions of the screenings are sprinkled (dry shake) onto concrete floors to impart wear resistance. Slag and trap-rock fines have reportedly been sold for this purpose. Granite fines are also suitable.
5. Fill	
a. Flowable Fill	Most pond screenings could fill this market after natural dewatering and addition of low quantities of cement.(Detailed Discussion in chapters 5 & 6)

Table 2.1. Potential Products That Could Utilize Pond Screenings - Continued...

b. Granular and under-slab	Useful after natural dewatering. Some mica rich materials may be unsuitable because mica prevents proper consolidation and dewatering. Sales reported in southeastern states.
c. Reinforced Earth	The pH and electrical resistivity of the material must be within specifications.
6. Grouts, pumped	
a. Ground Stabilization	Pond screenings, especially those from carbonate rocks because of their acid neutralizing property, could be used as major component in a stabilization grout for abandoned coal mines. May also have some use in a compaction grout or for mud-jacking concrete slabs.
b. Oil Well	Specialty additives for fractured formations.
7. Crushed Stone Base Additive	-- See discussions on crusher-run additive--
8. Mineral Filler	
a. Asphaltic Concrete	A well-known use for mineral fines that is already met from other sources. (Discussed in chapter 4)
b. Slurry Seal	(Discussed in chapter 4)
c. Masonry Cement	A well known use for mineral fines that is often supplied from bag-house dust collectors. The moisture content and agglomeration tendency of many pond screenings upon drying are major drawbacks.
d. PCC Blocks	Possibilities as a solid admixture. Would require drying, and probably additional grinding or sizing. Value may be added from products with pozzolonic tendencies.
e. Concrete	See discussion under blocks. Value as a sand in Cellular concrete, High strength concrete, and precast concrete.
f. Cement Mortar and Grout	Value as a sand
g. Sewer Pipe	Fine calcareous aggregate provides resistance to acid attack.

Table 2.1. Potential Products That Could Utilize Pond Screenings - Continued...

9. Pyro-processed products	
a. Manufactured Aggregate	Would require briquetting or pelletizing.
b. Brick	Additive to improve the properties of some clay rich minerals.
c. Lightweight Aggregate	pro-additive to improve the properties of some clay rich minerals.
d. Glass Foam	Would require briquetting. Also can be used as additive for mineral and rock wool products.
d. Tile and Pipe	Additive to improve the properties of some clay rich minerals
10. Sand applications	
a. Masonry, Plastering	Must be free from clay, and consistently colored, in addition to grading requirements.
b. Road Grit for Ice and Snow	Must be coarse enough to provide traction, and dry enough to distribute.
11. Sand Blasting Grit	Potential specialty by-products from reprocessing the screenings. These might include silica-free heavy minerals for sand-blasting, or even fine ballast or similar low-quartz rock fragments.
12. Shingle Components	
a. Granules, Roofing	Requires a specific grading, ability to receive a variety of sodium silicate based colors, and opacity to ultra violet light.
b. Granules, Headlap	Requires a specific grading. Sales in northeastern and southeastern United states.
c. Shingle Backing	Requires a specific grading. A high mica content is desirable. Sales in Southeastern United States.

Table 2.1. Potential Products That Could Utilize Pond Screenings - Continued...

d. Asphalt Stabilizer, Filler (Building paper)	Requires a specific, very fine grading.
13. Soil Stabilizer	Utilized to decrease the plasticity index of soils. (See also aglime)
14. Tracks and Play Areas	Running tracks, Bicycle pathways, Hiking paths, Horse race tracks, playgrounds.
POLLUTION CONTROL PRODUCTS	
USES	**TECHNICAL COMMENTS**
1. Acid Neutralization	
a. Acid-Mine Drainage	In deep mines, coal preparation plant wastes and strip mines treatment. (Discussed in chapter 4)
b. Acidic Waste	Carbonate rock pond screenings can be an economical method of neutralizing acidic waste streams from chemical plant wastes, dye-plant waste, landfill-leachate etc.
Watersheds	treatment of acidified lakes can be done by using finely ground limestone or dolomite.(Discussed in chapter 4)
2. Daily Cover - Landfills	Most pond screenings could be used for this application but it is not a promising market for existing landfills. these landfills usually have sufficient material available on their own property. Special circumstances where they would need to purchase outside material are: 1) if the useful life of the landfill can or was extended past the availability of local fill, or 2) if acids in the landfill are a problem that can be solved by neutralization with carbonate-rock pond screenings.
3. Flue gas Desulfarization.	Fine, wet material desired. Material can be used for Wet Limestone scrubber process only. (Discussed in chapter 4)

Table 2.1. Potential Products That Could Utilize Pond Screenings - Continued...

4. Hazardous-waste Solidifier	Some liquid hazardous wastes can be solidified by nixing with fine powders. This process allows the waste to be handled with less risk. The fine nature of dried, and especially agglomerated, pond screenings may be ideal for this purpose.
5. Pond Liners	Pond screenings with a high clay content can be concentrated to form a low permeability product to meet this use.
6. Pond-liner Separators	Sand is specified to separate the impermeable membranes that line hazardous waste disposal and storage sites. The primary benefit from sand is that its high permeability allows ready detection of leaks. A secondary benefit is that it is easy to spread. Some carbonate rock pond screenings are also highly permeable, easy to spread, and would also neutralize any leaking acids.
7. Sludge-Dewatering aid	Fine sandy materials assist in pressure or vacuum dewatering by increasing the permeability of the sludge. In addition, a fine sand helps in solar-drying of gelatinous sludges.
8. Sludge stabilizer	
a. Municipal septage	Drying required. Particulate admixtures to thixotropic sludges allow them to be handled and shipped with conventional machinery. In addition, they can often be stockpiled instead of lagooned, allowing a more-efficient use of land.
b. Non-Sewage	-- see discussion above-- carbonate minerals in the pond screenings might add value if sludge is acidic.

Table 2.1. Potential Products That Could Utilize Pond Screenings - Continued...

SAFETY PRODUCTS	
USES	**TECHNICAL COMMENTS**
1. Anti-skid Grit	--See discussions under animal shelter absorbents and road grit for ice and snow.--
2. Mine Dust	Low-silica, whitish carbonate rock pond screenings potentially could be dried, and possibly ground finer into mine dust products. Alternatively, damp material with a suitable composition could be fed slowly into the Raymond mill along with traditionally coarser material. The moisture from the damp material would evaporate because of the heat generated during grinding, and help cool the product and the mill.

Table 2.1. POTENTIAL PRODUCTS THAT COULD UTILIZE POND SCREENINGS

SOURCE: Stokowski, Jr., 1992, Ref. 35.

CONCLUSIONS OF LITERATURE REVIEW:

1. There are many regulations by federal and state agencies, which have defined the limiting quantities of fines in aggregate products which can be used for engineering applications. Regulations governing release of stone dust in the atmosphere have also resulted in accumulation of these waste fines. It could be seen from the literature review that some effort is being put forth by industry personnel to find applications for these wastes.

2. The work done by Stokowski (Ref. 35) seems to be the major effort, to date, to summarize the potential uses of fines. The list provides some practical applications for quarry fines.

3. The effect of fines in portland cement concrete and in cement mortar is clearly summarized by available literature.

4. A list of most promising uses for fines was developed after the literature review was done. These promising uses are:

1. Ready mixed flowable fill
2. Sandbags
3. Solid waste landfills
4. Low cost masonry uses
5. Miscellaneous sand applications
6. Cement treated quarry fines subbase
7. Subsurface sewage disposal system

These uses are discussed in detail in the chapter titled, "Possible Engineering Uses of Fines". An evaluation of quarry fines usage in ready mixed flowable fill applications and in cement treated subbase is subsequently done in a later chapter.

CHAPTER 3

CRUSHED STONE PRODUCTION

The production processes and equipment used in a quarry depend upon; size of the operation, shape of the deposit, kind of rock quarried, estimated life of operation of the quarry, and location of the deposit with respect to urban centers. However, the basic production processes, do not vary much among different quarries. Crushed stone production capacity of a plant may vary from as little as 100,000 tons per year up to 10 million tons per year. A typical aggregate operation produces approximately 400 - 500,000 tons each year (Ref. 21).

The production of fines in a quarry site is illustrated in Fig. 3.1. Most stone is mined from open quarries. Mined boulders and blast rock are loaded and hauled to a crusher bin. The quarried rock is fed through primary and secondary crushers for processing and are subsequently screened to produce aggregates of sizes determined by demand.

Primary crushing is often done at or near the pit, usually by jaw or gyratory crushers, but impact and other special types of crushers are also used. In-pit movable crushers are also increasingly being used. Cone crushers and gyratory crushers are the most common types of secondary crushers used. Impact crushers, including hammer mills and roll crushers are also used as secondary crushers (Ref. 12).

Screening is most commonly done by using inclined vibratory screens. For screening large sizes of crushed stone, grizzly bars, rod decks and heavy punched steel or plastic plates are used. For smaller sizes, woven wire, welded wire, cloth, rubber or plastic screens are used. Screened aggregates larger than 3/8" size are used in large quantities in the construction industry.

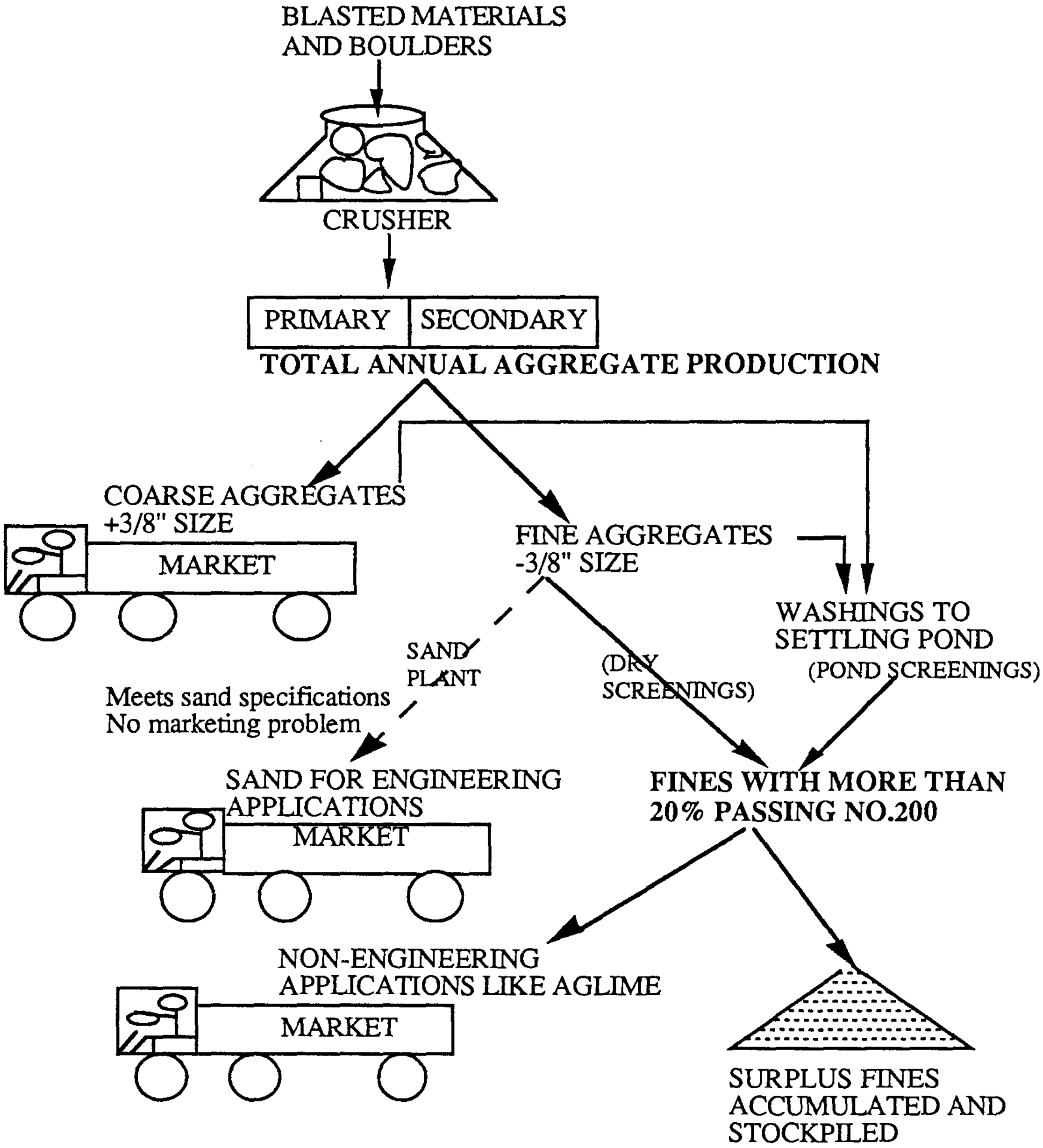


Fig. 3.1 Crushed stone products and production of fines

Fine aggregates from the secondary crusher are processed to manufacture sand. Manufactured sand is produced by the use of a sand screw plant. A typical sand screw plant consists of two large screws which weave through a mixture of sand and water, separating the very fine particles. Manufactured sand is usually produced to meet state specifications for certain uses.

PRODUCTION OF FINES

Aggregates smaller than 3/8" size are found in several classifications based on ASTM D448 ;

1) No. 8 stone (Passing 3/8 sieve and retained on No. 8 sieve)

2) No. 9 stone (No. 4 sieve to No. 16 sieve) and

3) No.10 stone (No. 4 sieve to zero or pan).

No. 10 stone, also called dry screenings, is material collected from below the last screen deck in a dry or semi-dry screening operation. The dry screenings can contain 10 to 30% of material passing No. 100 sieve (ASTM D448).

Much of the large aggregate production in the US is washed to meet specification requirements. Aggregate is washed, primarily, to remove dust and to remove clay and fine sand/silt from coarse and fine aggregates. Waste water from stone washing processes and from the sand plant are discharged to the settling pond, tank, or basin. The fines washed from the aggregates, called pond screenings (pond fines, slimes or tailings), are recovered from the settling ponds and stockpiled on a berm near the pond for several months to allow natural dewatering. After the material is sufficiently dewatered it is incorporated into other aggregate products, moved to a more remote stockpile, or wasted (Ref. 35). Pond screenings contain a high percentage (15% to 98%) of material passing No. 200 sieve and are much finer than dry screenings.

Removal of suspended solids, especially in geographic areas of water rationing or high land values, may also be achieved by utilizing clarifiers, thickeners, and belt presses. However, settling ponds offer the most cost effective means of cleaning water. Flocculants are often added to waste streams to enhance/accelerate settlement of very fine particles.

INDUSTRY SURVEY

To obtain more information on the type of aggregate produced, annual quantity of fines produced, quantity of stockpiled fines over several years, various uses of fines etc., a questionnaire was designed and sent to all National Stone Association member quarries (32) in Texas and selected NSA member companies (69) in other states. A sample questionnaire is provided in the appendix. Also a list of companies that participated in the survey and a summary of their responses are provided in the appendix.

Of the 101 questionnaires sent, 21 responses were received. Eight questionnaires were returned due to change of addresses of NSA members. Only two responses were received from the 32 questionnaires sent to quarries in Texas. Nineteen responses were received from companies located outside Texas. Most companies had given data for more than one crushed stone product or one quarry operation, and hence 171 quarries were represented in the survey by 21 participating companies. (Nation wide there are about 4000 operations involved in crushed stone production.)

ANNUAL AGGREGATE PRODUCTION

Approximately three quarters of crushed stone production reported by the participating companies were limestone and dolomite. In order of volume, they are followed by granite, trap rock, sandstone and quartzite, marble, and other miscellaneous stone. The participating companies reported a production of 167 million tons of crushed stone production in 1989, compared to the national annual production of 1.2 billion tons.

Fine aggregate (less than 3/8" size) production, reported as a percentage of total aggregate production by type of aggregate, varied from 9.10% for dolomite to 23.50% for trap rock. The fine aggregate production of limestone producing quarries was 16.98%. An average of 16.25% of the total annual aggregate production were fine aggregates passing 3/8" sieve. (It was noted that the company responses to question VI, regarding "percentage of dry 3/8 inch or lesser size aggregate production", varied from 0% to 55%. The variation is due to the fact that all but a few companies had omitted the word 'dry' in the question. This was evident from the questionnaire replies and telephone conversations with company representatives. Hence the responses for question VI were interpreted to be the percentage of "3/8 inch or lesser size aggregates produced per year"). Table 3.1 shows annual production of fine aggregates passing 3/8" size , by aggregate type.

1	2	3	4	5	6
NO.	AGGREGATE TYPE	NO. OF QUARRIES REPORTING	TOTAL ANNUAL AGGREGATE PRODUCTION (TONS)	ANNUAL FINE AGGREGATE (PASSING 3/8") PRODUCTION (TONS)	FINE AGG. EXPRESSED AS A % OF TOTAL ANNUAL AGG. PRODUCTION
1	LIMESTONE	75	89 416 667	15 176 417	16.98%
2	DOLOMITE	58	42 875 000	3 902 500	9.10%
3	GRANITE	22	18 500 000	3 792 500	20.50%
4	TRAP ROCK	10	14 500 000	3 407 500	23.50%
5	QUARTZITE	4	3 416 667	831 667	20.98%
6	SANDSTONE	2	2 791 666	522 917	18.73%
7	MARBLE	4	3 000 000	600 000	20.00%
8	OTHER	4	1 550 000	207 500	14.14%
	TOTAL			**28 441 001**	**16.25%**

Table 3.1. Table showing annual production in tons of fine aggregate passing 3/8" sieve by aggregate type.

MARKET OVERVIEW

Information on production and sale of 3/8 inch and smaller sized products was also sought via the questionnaire. Information was also obtained on annual quantities of 3/8" and smaller sized aggregates not marketed (surplus). Not many companies reported that they were able to market all of their 3/8 inch and smaller sized aggregates produced. Some companies stated that the annual quantities of fine aggregates that were not marketed were in a range as low as 1% to as high as 27%, expressed as a percentage of the total annual aggregate production. By type of aggregate, these percentages varied from 2.0% for dolomite to 9.1% for trap rock and are shown in Column 7 of Table 3.2. Fig. 3.2 shows the surplus fine aggregates that are not marketed every year. It can be seen that fine aggregates constitute 16.2% of total aggregate production, out of which 3.7% (of total aggregate production) is a surplus and is not marketed every year.

Information on quantities and sizes of products difficult to market were requested from the survey participants in Question VIII of the questionnaire. Only 50% of the participants responded to this question. One reason the companies failed to respond to this question may be that the companies did not have aggregate size categories as stated in the questionnaire, though an extra line was provided for aggregates of other sizes. Of the companies that responded to this question, one company indicated that they do not have any difficulty marketing their products. In contrast to this, another company reported that they have aggregates in sizes ranging from passing 3/8" sieve to retaining on # 200 sieve, stored at their sites, amounting to about 31.8% of their total annual aggregate production. Other responses to question VIII indicated that the companies find difficult to market, quantities of fine aggregates, ranging from 4.0% to 14.0% of total annual aggregate production. Table 3.3 shows the sizes and quantities of fines the companies found difficult to market. The current markets for aggregates passing 3/8 size, as reported by the survey participants are provided in Table 3.4 .

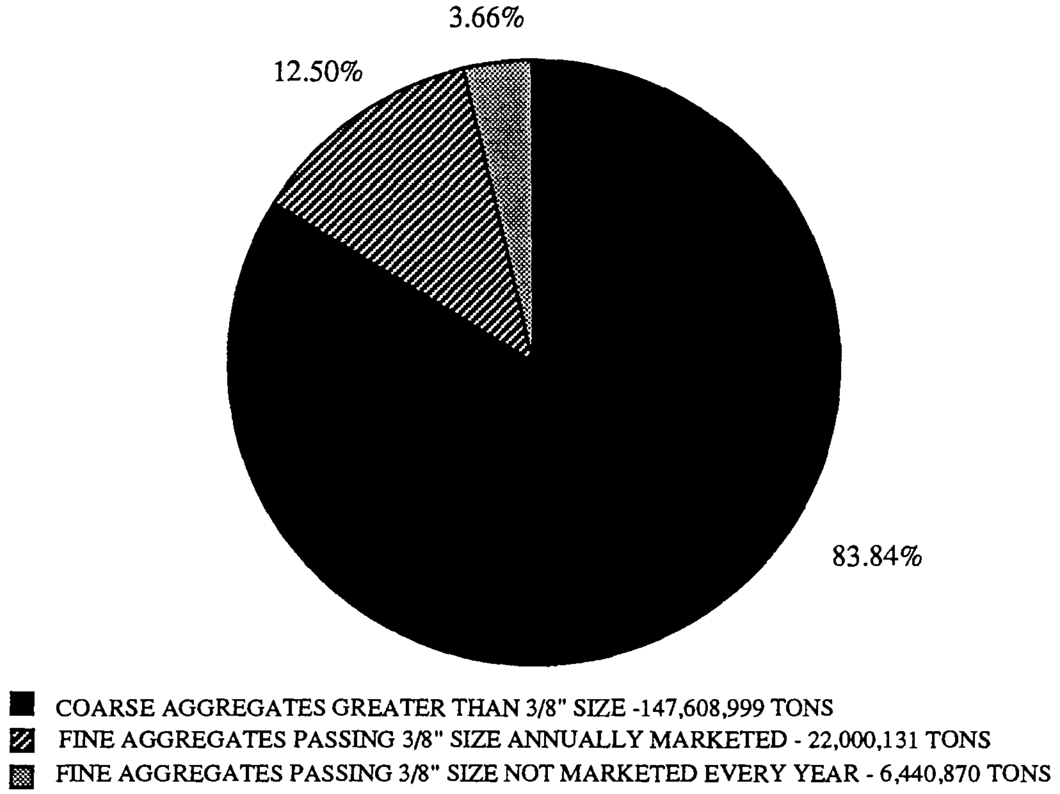


Fig. 3.2 Distribution of crushed stone aggregates expressed as a percentage of the total annual aggregate production.

1	2	3	4	5	6	7
NO.	TYPE OF AGGREGATE	NO.OF QUARRIES REPORTING	FINE AGGREGATE PASSING 3/8" ANNUAL PRODUCTION (TONS)	FINE AGGREGATES PASSING 3/8" ANNUALLY MARKETED (TONS)	FINE AGGREGATES PRODUCED BUT NOT MARKETED PER YEAR (COL.4 - COL.5) (TONS)	UNMARKETED FINE AGG. EXPRESSED AS A PERCENTAGE OF TOTAL ANNUAL AGGREGATE PRODUCTION.
1	LIMESTONE	75	15176417	12321834	2854583	2.19%
2	DOLOMITE	58	3902500	3029000	873500	2.04%
3	GRANITE	22	3792500	2893500	899000	4.86%
4	TRAPROCK	10	3407500	2088129	1319371	9.10%
5	QUARTZITE	4	831667	692134	139533	4.08%
6	SANDSTONE	2	522917	383334	139583	5.00%
7	MARBLE	4	600000	500000	100000	3.33%
8	OTHER	4	207500	92200	115300	7.44%
	TOTAL		**28441001**	**22000131**	**6440870**	**3.68%**

Table 3.2 Table showing the percentage of fine aggregates passing 3/8" sieve not marketed, by questionnaire participants, expressed as a percentage of the total annual aggregate production.

QUANTITIES OF FINE AGGREGATE (IN TONS) REPORTED DIFFICULT TO MARKET												
	FINE AGGREGATE SIZES BY SIEVE NUMBERS											
Company No.	NO. 4		NO. 20		NO.50		NO.100		NO.200		Size Zero	% of Total Annual Production
1										100,000		8.0%
2		←		105,000		→		→		→		14.0%
		30,000		← 390,000		→						
3		←				60,000		→		→		4.0%
4		←				None		→		→		0.0%
5								100,000		100,000		3.8%
6								75,000		125,000		6.7%
7		75,000								25,000		8.0%
8						←		450,000		→		4.5%
9		←				1,510,000		→		→		31.8%
10										2,000,000		6.7%
11		← 500,000 →								700,000		6.7%
12										100,000		13.3%
13										100,000		8.0%

Table 3.3 Sizes and quantities of fine aggregates companies find difficult to market.

CURRENT MARKETS FOR FINE AGGREGATES OF GIVEN SIEVE SIZES			NO. OF COMPANIES REPORTING
NO.4	AGLIME	Size Zero	1
	LIVESTOCK FEED		1
	SINTER STONE FOR STEEL INDUSTRY		1
	DESULFURIZATION		1
	ASPHALT SAND		2
	ADDITIVE- BASE COURSE MATERIAL		1
	CONCRETE SAND		1
NO.4	TOPPING ROCK	NO. 20	1
	HOT MIX AGGREGATE		1
	MASONRY SAND AND FILL		1
	FILL UNDER CONCRETE		2
	CONCRETE PRODUCERS		3
	BLACKTOP PRODUCERS		2
	BACKFILL		2
	ASPHALT SAND		4
	CONCRETE BLOCK		1
	CONCRETE ROOFTILE		1
NO. 20	AGLIME	NO.100	5
	GLASS		1
	ASPHALT SAND		1
NO.100	AGLIME	NO.200	1
	SHINGLE FILLER		1
	WASHED SHOT		1
	ICE CONTROL		1
	ASPHALT MIX		1
	CONCRETE SAND		1
NO.200	AGLIME	Size Zero	3
	BACKFILL		1
	ASPHALT MIX		2
	CONCRETE SAND		1
	FOUNDATION FILL		1
	ASPHALT SAND		1

Table 3.4 Current markets for aggregates passing 3/8" size

STOCKPILED FINES.

The most important information received from the fines market study were the quantity of the fine aggregate products that were stockpiled at quarry sites (accumulated over years). Responses indicated that fines amounting to 12.80% of the total annual aggregate production were stockpiled at quarry sites. Except for two companies with little or no fines stockpiled at their site, most companies indicated that there were abundant fines stockpiled at their sites. Some companies reported that the quantity of recoverable fines from the settling ponds were so high that no reasonable estimate could be provided. Most companies gave conservative figures, e.g. "100,000+ tons". The stockpiled fines, by type of aggregate, varied from 2.7% (of total annual aggregate production) for miscellaneous stone to 29.3% for sandstone. From the study it was found that accumulated stockpiled fines over past years ranged from 0.0% to 96% of total annual aggregate production. On the whole, stockpiled fines amounted to 12.8% of the total annual aggregate production.

It must be noted that in addition to stockpiled fines, abundant quantities of fines can still be recovered from settling ponds. One company, who did not participate in the questionnaire survey, but sent fine aggregate samples for testing, stated "At the mine site there are several large areas that probably contain 17 to 25 million tons of tailings that have not been reprocessed " (Ref. 36). The fines in this case were produced as a result of mining and milling of sphalerite ores. Stokowski (Ref. 35) has stated that one billion tons of pond screenings could be recovered from settlement basins.

Table 3.5 shows the stockpiled quarry fines accumulated over years as a percentage of total annual aggregate production.

1	2	3	4	5	6
NO.	AGGREGATE TYPE	NO. OF QUARRIES REPORTING	TOTAL ANNUAL AGGREGATES PRODUCTION (TONS)	ACCUMULATED STOCKPILED FINES (TONS)	STOCKPILED FINES EXPRESSED AS A % OF TOTAL ANNUAL AGG. PRODUCTION.
1	LIMESTONE	75	89 416 667	11 230 917	12.6%
2	DOLOMITE	58	42 875 000	5 802 267	13.5%
3	GRANITE	22	18 500 000	2 196 400	11.8%
4	TRAP ROCK	10	14 500 000	1 270 400	8.7%
5	QUARTZITE	4	3 416 667	649 995	19.0%
6	SANDSTONE	2	2 791 666	816 667	29.3%
7	MARBLE	4	3 000 000	400 000	13.3%
8	OTHER[1]	2	1 550 000	42 500	2.7%
	TOTAL		**176 050 000**	**22 409 146**	**12.8%**

Table 3.5 Table showing stock piled quarry fines accumulated over years as a percentage of total annual aggregates production.

CONCLUSIONS OF INDUSTRY SURVEY:

1. The survey conducted as a part of this project indicated that quarry fines stockpiled in a company vary from 0 to 96% of the company's total annual aggregate production. Stockpiled fines amounted to an average of 12.80% of the total annual aggregate production of the companies surveyed. Even a conservative figure like 13% of total annual aggregate production, projected industry wide, amounts to about 130 million tons of fines stockpiled industry wide considering that about 1 billion tons of crushed stone aggregate are produced industrywide annually.

2. The reported uses of quarry fines are limited. The Engineering and Environmental related uses are even fewer when quarry fines approach a fineness in the minus 200 sieve size.

3. On an average, about 3.6% of total annual production of aggregates is fine aggregates unsold every year. Individual company amounts varying from 1.0% to 27.4% of total annual production are not marketed every year.

4. Except for one company who reported no marketing problems, companies reported that they face difficulty marketing fine aggregates amounting to 4% to 14% of total annual aggregate production.

5. On an average 16.3% of total aggregate production is fine aggregates less than 3/8" size.

MATERIAL CHARACTERISTICS

GRADING:

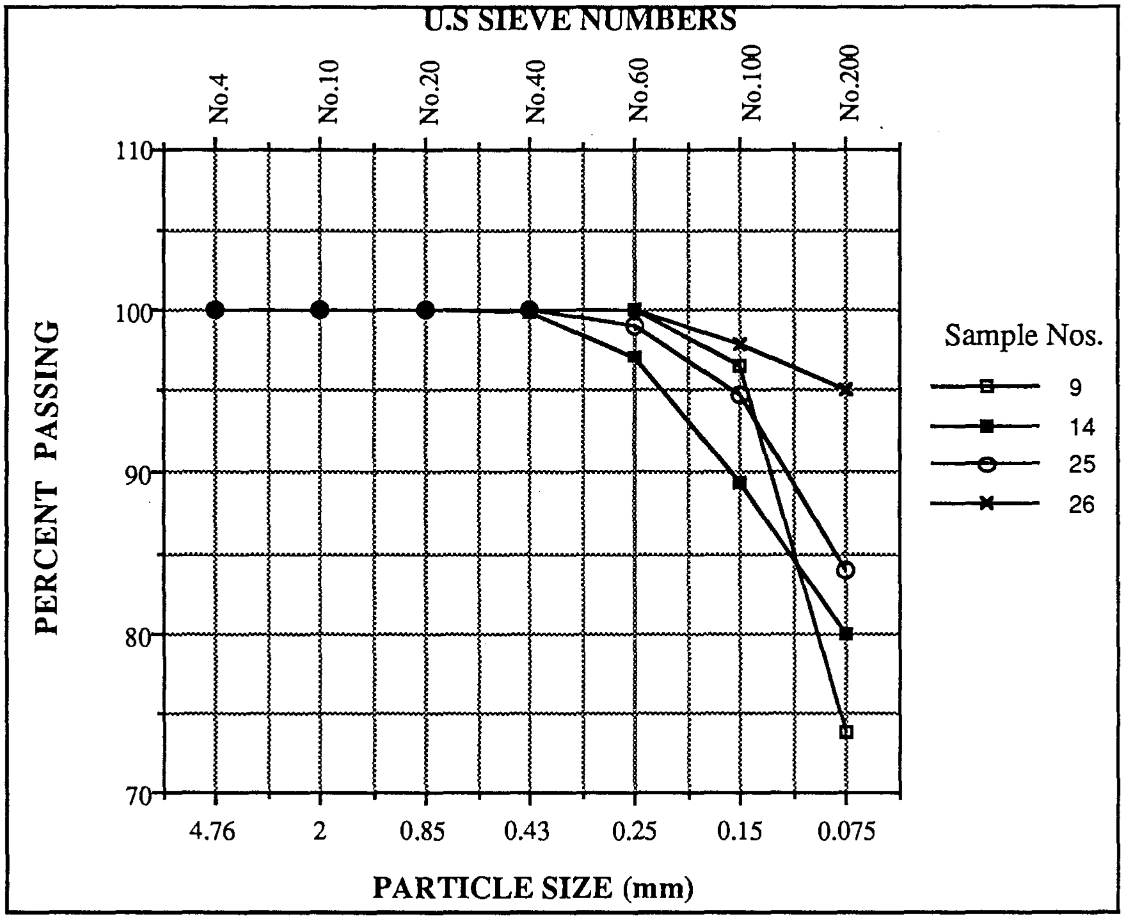
Grading, the most important property of the fines, varies depending on type of rock produced, grain size of the material being washed, and plant design. The No. 10 size aggregates or dry screenings, obtained by a dry or semi-dry screening operation are much coarser than settlement pond screenings. Grading of pond screenings vary within the settlement pond.

Twenty five quarry fines samples from various quarries (Sample Nos. 2 thru 26) were subjected to grain size analysis tests. Texas Department of Transportation testing procedures Tex 111-E, "Determination of the Amount of Minus No. 200 Sieve Material in Soils", and Tex 110-E, "Determination of Particle Size Analysis of Soils" were used for grain size analysis of the samples. No. 4, No. 10, No. 20, No. 40, No. 60, No. 100, and No. 200 sieves were used in the procedure. Most of the samples were dry screenings. Only three samples were pond screenings. There is no information available on locations in the settlement pond from where the pond screenings were sampled. Quarry fines can generally be divided into six categories, based on the percentage passing No. 200, as shown in Table 3.6. The results of grain size analysis are shown in Fig. 3.3 to Fig. 3.8. The potential engineering and environmental uses for quarry fines in each of these categories are also listed in Fig 3.3 to Fig. 3.8. The classification does not imply that quarry fines falling under category I can be used for all construction purposes, it just means that there is a likelihood of the material being used for construction purposes, provided they satisfy other grading requirements. Most of these listed potential uses are discussed elsewhere in this report.

CATEGORY	% PASSING NO.200	COMMENTS
I	0 - 10 %	Generally OK for construction use.
II	10 - 15 %	Does not meet sand specification. but can be used for sand applications.
III	15 - 25 %	Reasonably OK for use as a non-specification aggregate.
IV	25-50 %	Can be used for selected uses only.
V	50-75 %	High percentage of fines. Can be used for selected uses only.
VI	>75 %	High percentage of fines. Can be used for selected uses only.

Table 3.6 Classification of quarry fines

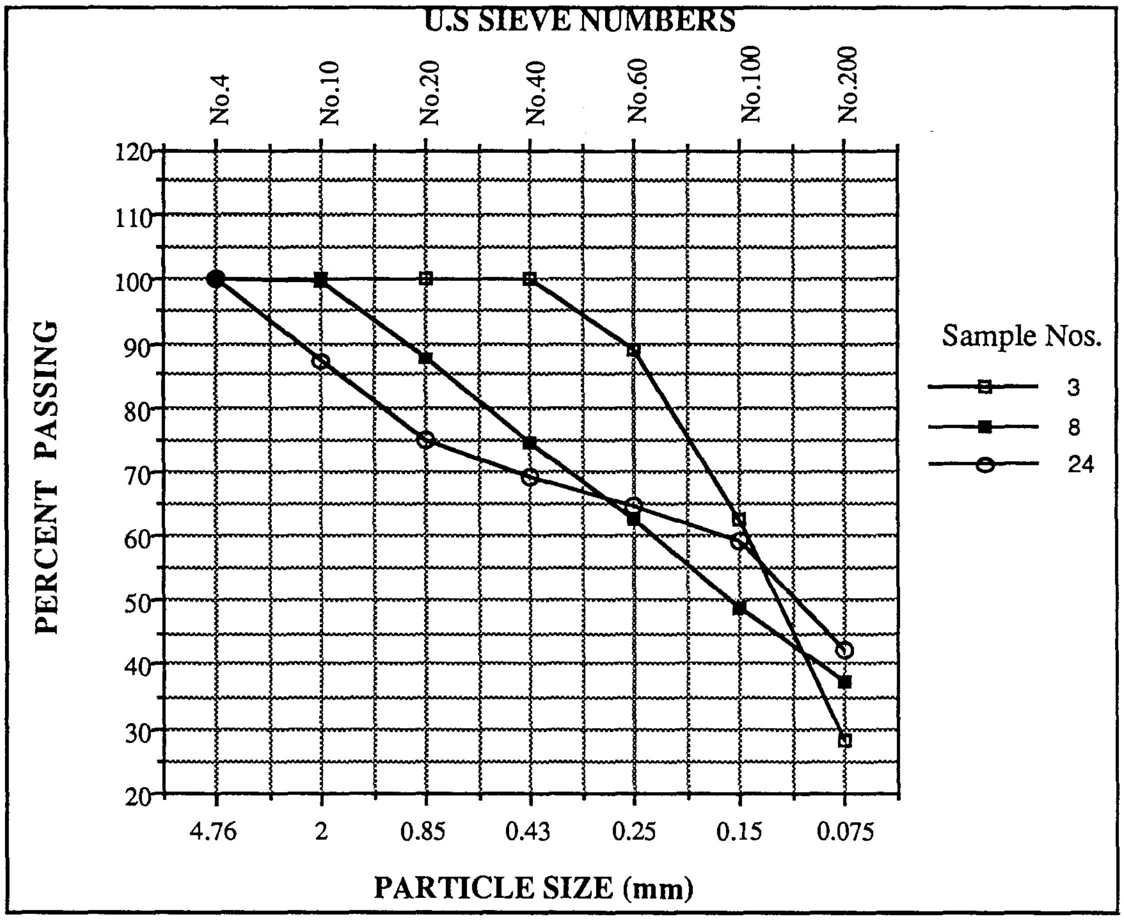
Chemical composition of quarry fines is also an important material characteristic of quarry fines. The chemical composition of dry screenings vary to a certain extent with grain size. The chemical composition of washed pond fines vary with grain size and differ considerably from that of the washed aggregate. The scope of this report does not cover the treatment of chemical composition of quarry fines.



Potential Engineering and Environmental Uses:

1. Underslab granular fill — 2. Flowable fill
3. Cement stabilized grout — 4. Acid mine drainage abatement
5. Pond and watershed liming
6. Neutralizing acidic waste streams from chemical plants, landfill leachate etc.
7. Asphalt filler and Asphalt stabilizer — 8. Roofing granules
9. Flue gas desulfarization

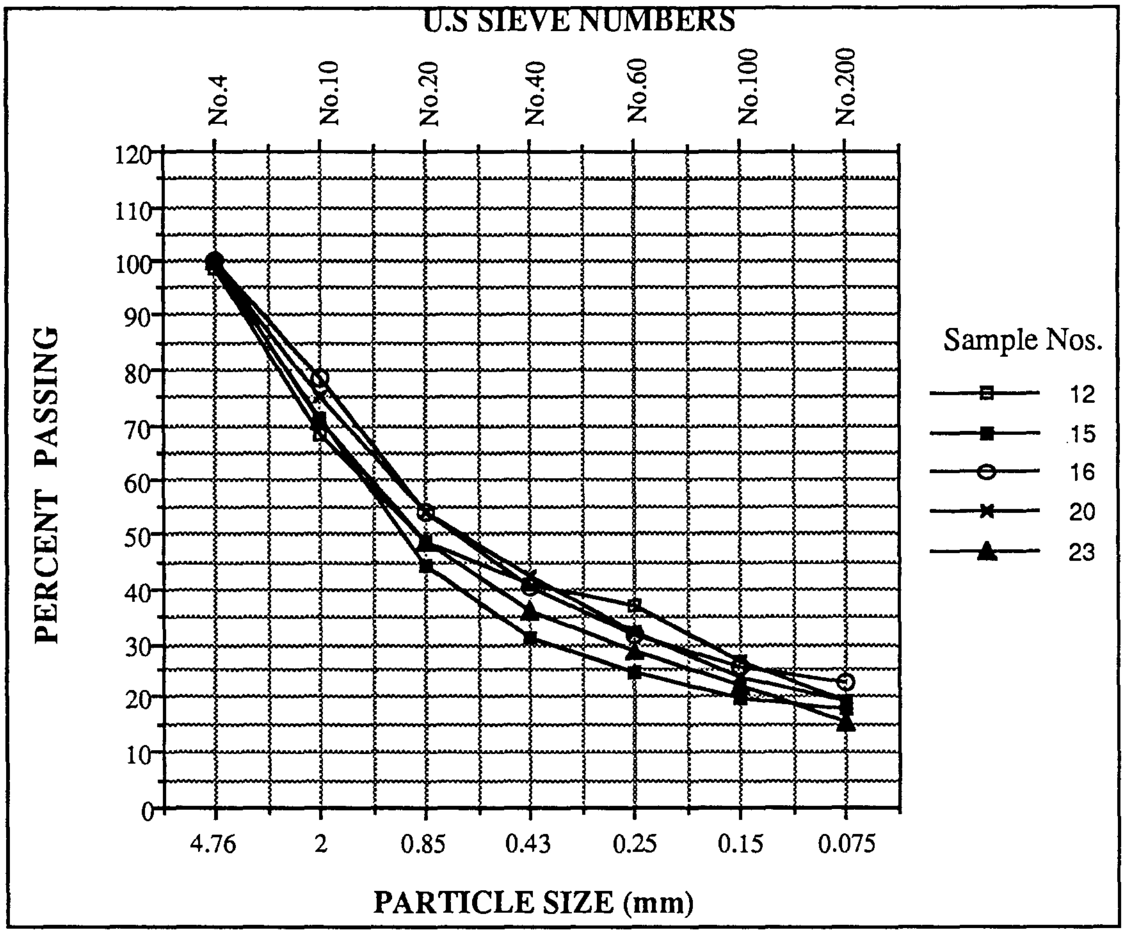
Fig. 3.3 Grain size range of quarry fines samples and potential uses of quarry fines in category VI (>75% passing No. 200)



Potential Engineering and Environmental Uses:

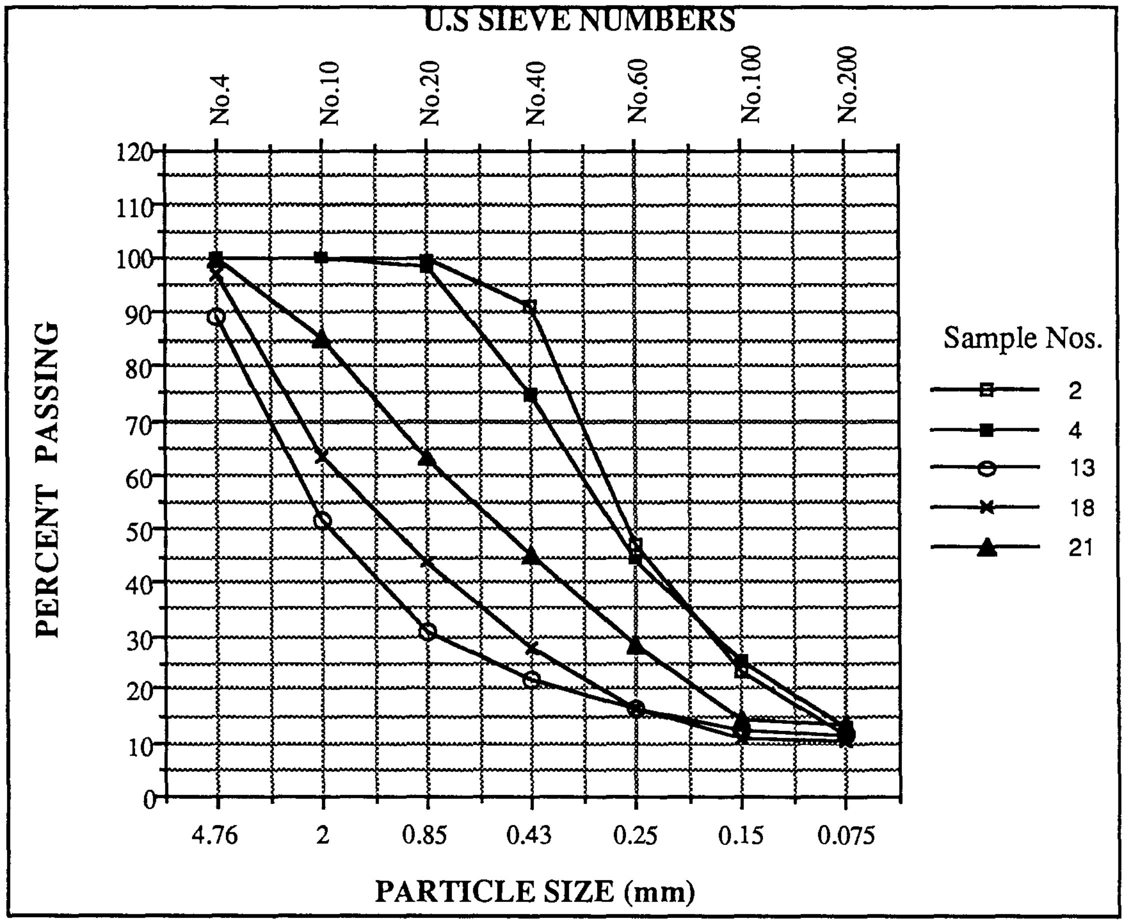
1. Asphalt sand
2. Road grit for ice control
3. Cement mortar and grout
4. Flowable fill
5. Base course material additive
6. Acid mine drainage abatement and mine dusting
7. Flue gas desulfarization

Fig. 3.4 Grain size range of quarry fines samples and potential uses of quarry fines in category IV (25-50% passing No. 200)



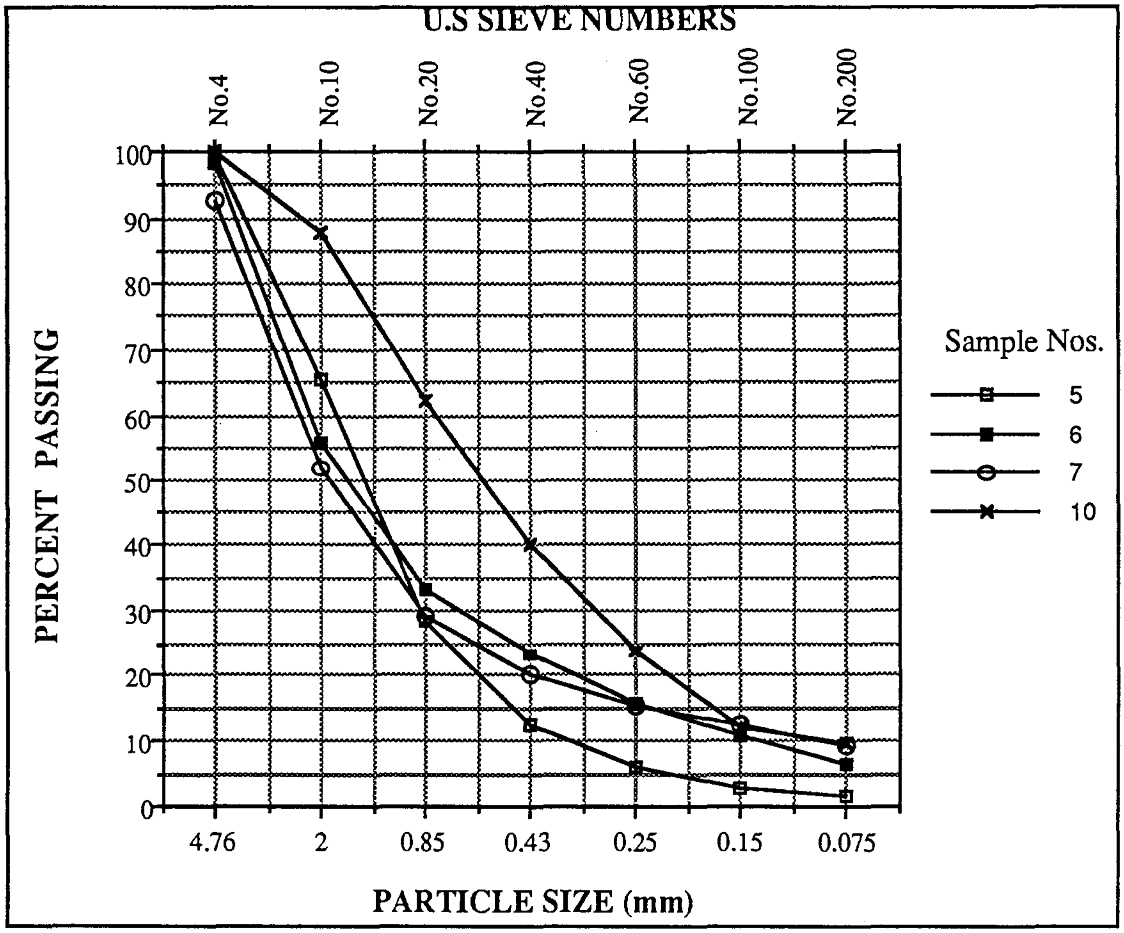
Potential Engineering and Environmental Uses:
1. Topsoil additive
2. Steam cured bricks - products with high silica contents
3. Fill layer - Horse race tracks, play areas, pedestrian pathways etc.
4. Mine dusting - Carbonate quarry fines
5. Hazardous waste pond liner - separators
6. Cement stabilized subbase/base layer

Fig. 3.5 Grain size range of quarry fines samples and potential uses of quarry fines in category III (15 - 25% passing No. 200)



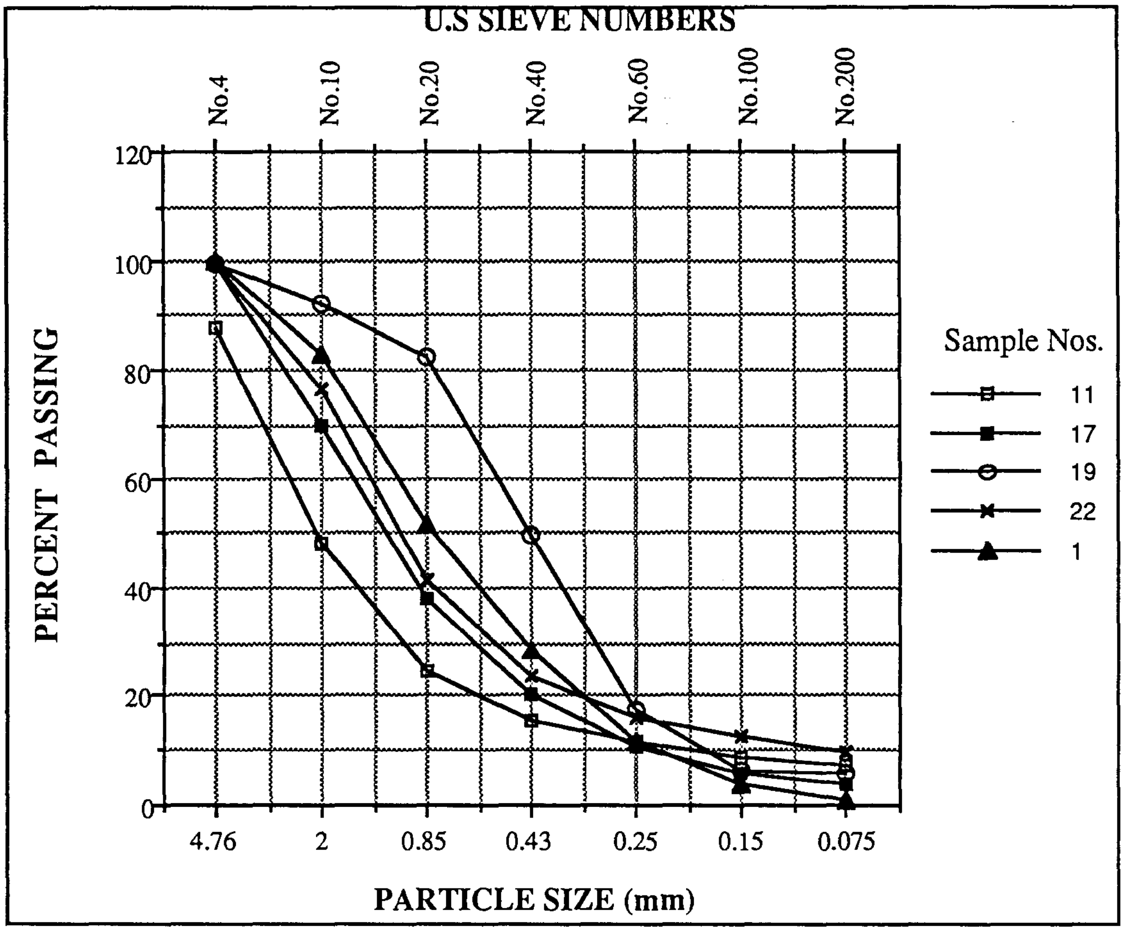
Potential Engineering and Environmental Uses:
1. Masonry sand and fill
2. Mortar and Grout
3. Cement stabilized subbase
4. Flowable fill 5. Sand filling applications
6. Solid waste disposal sites: acid waste neutralizing layer and pond line separators
7. Portland cement concrete blocks, cement floor tiles etc.

Fig. 3.6 Grain size range of quarry fines samples and potential uses of quarry fines in category II (10-15% passing No. 200)



Potential Engineering and Environmental Uses:	
1. Concrete sand	2. Asphalt sand
3. Sand applications such as in portland cement concrete blocks, Plastering sand, etc.	
4. Cement treated Base/subbase	5. Flowable fill
6. Floor hardener (Granite, slag, trap rock fines to impart wear resistance to floors)	
7. Sewer pipe manufacture (Calcareous fine aggregates resist acid attack)	
8. Road grit for ice control	9. Solid waste disposal sites

Fig. 3.7 Grain size range of quarry fines samples and potential uses of quarry fines in category I (0-10% passing No. 200)



Potential Engineering and Environmental Uses: As listed in previous page.

Fig. 3.8 Grain size range of quarry fines samples and potential uses of quarry fines in category I (0-10% passing No. 200)

Figs. 3.7 and 3.8, are shown for fines belonging to category I in order to avoid clustering. No samples were available in category V. The potential uses listed for fines belonging to category VI apply to category V also.

MOISTURE CONTENT

Dry screenings do not contain excessive moisture contents, whereas pond screenings often have high moisture contents. Moisture contents range above 20% when removed from the settlement pond but decrease to 5 - 15 % during stockpiling (Ref. 35). Some of the samples received from quarries were not packed in air-tight containers and hence might have lost moisture during transit. Most of the samples received were dry screenings. One sample of pond screenings along with the tailing waste water and another sample of pond screenings recovered from the pond (drained) were received. The moisture content of the first sample when separated from the waste water was 34.1% and that of the second was 11.5%.

Stokowski (Ref. 35) reported the following regarding moisture content of pond screenings:

1. Pond clays from sand and gravel processing have the highest moisture contents. The associated flume sands have the lowest.

2. Carbonate-rock pond screenings tend to dewater at a slower rate than those from granite, trap rock or slag, possibly because clays are liberated from these sedimentary rocks and become part of the pond screening.

3. Mica-rich pond screenings dewater poorly and often retain nearly their original moisture content.

4. Rotary drying reduces the moisture and content of the pond screenings. Rotary drying is technically and economically feasible.

Thus it can be deduced that handling of mica-rich pond screenings and pond clays from sand and gravel is difficult due to their high moisture contents. They can only be used in situations where their moisture content is an advantage and not for any fill or structural uses.

CONCLUSIONS

From the above discussions, it can be deduced that fine grading and moisture content are two important properties of quarry fines that need to be considered before using them in any applications. Grading of fines is difficult to change but it may be worthwhile to reduce the moisture content of certain types of pond screenings, if there is a potential market that requires dried pond screenings.

A potential use for quarry fines is in situations where the product's fineness and the high water content would both be beneficial. An optimum potential use would take advantage of the fineness while minimizing the disadvantages that come along with the high water content.

CHAPTER 4

PRESENT USES OF FINES

INTRODUCTION

Quarry fines are presently used more in the non-construction industry than in the construction industry. About 20% of the total annual aggregates produced in the United States,mostly quarry fines, are sold for non-construction uses, such as in agriculture, chemical and metallurgical processing industries, and for environmental and miscellaneous applications. Although the objective of this quarry fines project is to find new potential uses for the fines, the present uses of the fines are discussed here to provide comprehensive information about crushed stone fines for interested readers. Present uses are briefly discussed here and the interested reader may consult References 8 and 21, for more detailed discussions. Some of the gradations specified for fine material, under uses mentioned herein, may not contain more than 20% passing No. 200. Fines with some modifications in their gradations can be put into these uses and hence those uses are also included here.

ASPHALT RELATED USES

SLURRY SEAL

Slurry seals are a mixture of asphalt emulsion, well-graded fine aggregate, and mineral filler. The mineral filler is a hydrated lime or cement which combines with water and asphalt to form a high specific gravity liquid medium that supports the larger mineral aggregate. The thickness of the slurry seal is dictated by the maximum size of the aggregate. The slurry seals can fill small cracks in the pavement surface, reduce raveling, protect the existing pavement as well as provide a skid resistant surface (Ref. 21).

The aggregate used in slurry seals should be well graded. A slurry seal aggregate should be clean and predominantly crushed. Since the aggregate is subjected to intense loading at the surface of the pavement, the toughness and durability of the aggregate should be equal to that of a high-quality, hot asphalt mixture. Slurry seal machines - which are truck or trailer mounted portable plants are used for construction. Slurry seal gradations are given in ASTM D 3910 and are shown below in Table 4.1. ASTM type I aggregate is the only aggregate permissible with a large amount of fines and quarry fines could easily fit in that category. More than one aggregate stockpile may need to be blended to achieve the required gradation for a slurry seal. Quarry fines in categories No. I, II and III, as discussed in Chapter III may be used for slurry seals.

	Amount Passing Sieve, weight %		
Sieve size	**Type I**	**Type II**	**Type III**
3/8 in (9.5 mm)	100	100	100
No. 4 (4.75 mm)	100	90 to 100	70 to 90
No. 8 (2.36 mm)	90 to 100	65 to 90	45 to 70
No. 16 (1.18 mm)	65 to 90	45 to 70	28 to 50
No. 30 (600 μm)	40 to 60	30 to 50	19 to 34
No. 50 (300 μm)	25 to 42	18 to 30	12 to 25
No. 100 (150 μm)	15 to 30	10 to 21	7 to 18
No. 200 (75 μm)	10 to 20	5 to 15	5 to 15

Table 4.1 Slurry Seal Type I - Aggregate Specification

ASTM D 3910 specifies tests used to evaluate slurry seal specimens. Residual Asphalt Content, Water and Mineral Filler Content, and Wet Track Abrasion Test are some of the tests described.

Texas Department of Transportation has replaced the asphalt emulsified slurry seal technique for maintaining roads by a microsurfacing technique. Fine aggregates manufactured from crushed sand stone, crushed gravel, and crushed granite are commonly used in microsurfacing. Crushed limestone fine aggregates are not used in this application. Fine aggregates constitute about 90% of the total microsurfacing mix. In 1992 alone, Tx DOT has estimated to use about 200, 000 tons of microsurfacing mix. This suggests that about 180,000 tons of crushed stone fine aggregates would be used in this particular application in Texas.

MINERAL FILLER

Mineral filler is used in asphalt to stiffen the asphalt and increase its volume. It may be hydrated lime, cement, or stone dust. Fine limestone is used as a mineral filler when hydrated lime or cement is not being used. An optimum amount of mineral filler is needed to achieve maximum density in dense asphaltic mixtures. It is important that the quality and quantity of mineral filler be evaluated prior to acceptance and be determined and controlled. Natural, unwashed sands and gravels coated with clay and silt, and crushed stone fines with excessive quantities of mica are undesirable mineral fillers. The maximum allowed P.I. is 4 for mineral filler used in asphalt concrete mixtures and the minimum sand equivalency (ASTM D 2419) for aggregate used in H.M.A.C varies from 45 to 50. It must be noted, however, that the amount of mineral filler is counted as part of the minus No. 200 sieve fraction of the aggregate gradation, thus reducing the amount of No. 200 sieve fraction allowable in the fine aggregate (Ref. 21).

AGRICULTURE RELATED USES

The largest current use (more than 50% of the fines market) of crushed stone fines is in the agriculture sector. The agriculture sector has been a stable customer for crushed stone producers, especially lime stone producers, located within competitive distance to agricultural markets. Major agricultural uses of limestone include its direct application as aglime to correct soil acidity, as a fertilizer filler or conditioner, as an ingredient in mineral livestock feeds, and as poultry grit.

AGLIME

The direct application of crushed stone fines as agricultural limestone is the largest single use of quarry fines. Agricultural limestone helps in effectively neutralizing the acid-soil conditions caused by natural changes in soil pH and maintains the pH at agronomically acceptable levels. The acidity in soil can be attributed to many processes such as leaching, acid precipitation, growing crops such as legumes, nitrogen fertilizers etc. Generally, the natural tendency of many soils, particularly in areas of moderate to heavy rainfall, is to become more acid with time. Due to its application, aglime stimulates soil microbial activity, improves soil tilth or physical condition, supports heavier plant growth, and increases the efficiency of fertilizers.

The quality of agricultural limestone is usually measured by two factors (Ref. 34). The first factor is Neutralizing Value (NV), also called Calcium Carbonate Equivalent (CCE). This measurement is obtained by mixing the limestone with a known amount of acid and then determining how much of the acid has been neutralized by the limestone. The second factor is particle size or particle size distribution.

Generally, the finer the particles, the more efficient or reactive the limestone. Various efficiency ratings have been proposed for liming materials based on particle size distribution. One most often used rating scale is produced in Table 4.2 (Ref. 34).

By taking the percentage passing each sieve and multiplying it by the efficiency factor, a fineness factor for limestone is obtained. Multiplying the fineness efficiency by the neutralizing value, discussed above, gives a number which rates the efficiency of the limestone called Effective Calcium Carbonate Equivalent (ECCE). Pure calcium carbonate (CaCo3) is used as the standard for expressing lime quality and is given a value of 100 or 100%.

Sieve Size (mesh)	**Particle size MM**	**Efficiency factor (%)**
>8	>2.0	0
8 to 20	2.00 to 0.85	20
20 to 60	0.85 to 0.25	60
<60	< 0.25	100

Table 4.2 Limestone efficiency factors based on particle size Source : Ref 34

Terry L. Bell et. al.(Ref. 34) reports that the variation in quality of limestone sold in Texas is due more to particle size than to chemical composition, which further emphasizes how important it is for the Aglime products to be fine. Quarry fines in all VI categories can be used as aglime, but categories VI and V may make better aglime due to their fineness. Apart from limestone sold in the fine powder form, aglime is also sold in pelletized form and fluid lime form (80 to 90% passing No. 200 sieve). Also, apart from the commercial agriculture market, more than 5 million tons of aglime are used annually for the establishment and maintenance of million of acres of turf lawn in public recreation areas and private properties. In addition, orchard trees are limed in

Europe and in many other parts of the world. It is a potentially untapped market in the United States.

About 18,934,000 tons of aglime was sold in United States in 1989 (Ref. 12).

Market study for aglime: A simple marketing strategy is provided here for companies willing to enter or expand their agricultural limestone market:

1. Obtain state and/or county geological survey maps in the areas of interest from your local agricultural department. The county agricultural extension agent may be a good source to start with.
2. Locate the areas with predominantly acidic soils or areas with potential aglime uses and see if they are conveniently located in your marketing area. As an example, the Texas map showing counties with acidic soils is reproduced in Fig. 4.1 (Ref. 34).
3. Calculate the ECCE of the limestone produced at your quarry site, as outlined earlier.
4. Compare the prices of limestone marketed in the area, if any, to that of the limestone marketed by you. Also compare the quality of the limestone marketed in that area, again if any, to that of yours.
5. A vigorous marketing campaign may be worthwhile, to reach untapped markets. such as liming of orchard trees, which is not done in the U.S but is practiced in other parts of the world.
6. In some situations, it may be possible to market higher quality lime (fine particle size) at a somewhat higher price per ton and yet reduce per acre costs of lime (Ref. 34).
7. If research determines a potential market, conduct a marketing campaign by informing potential buyers about the advantages of using your aglime.

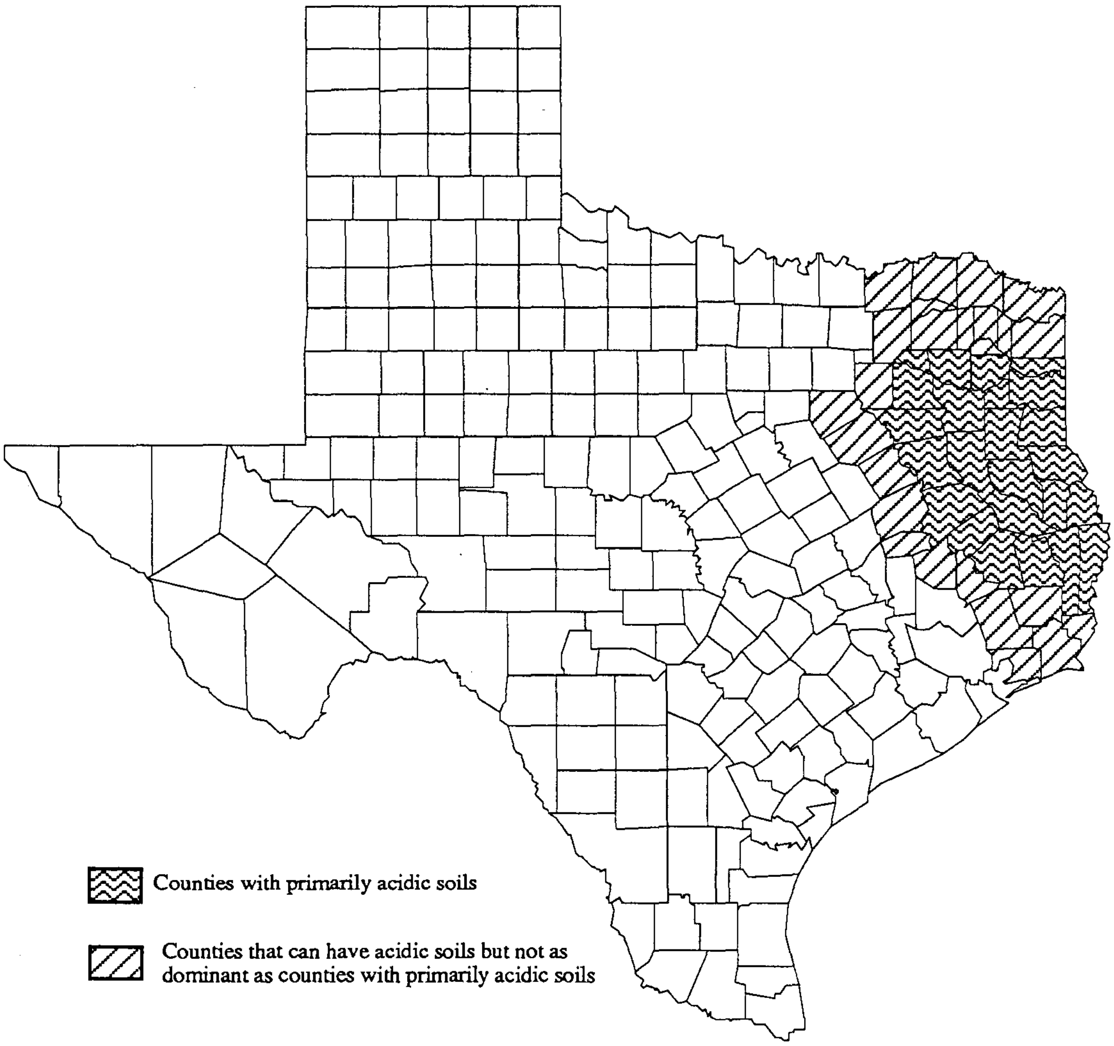


Fig. 4.1 Texas map showing counties with acidic soils. Source: Ref. 34

FERTILIZER FILLER

Dolomitic limestone is used as a fertilizer filler added to fertilizer materials to provide bulk, prevent caking, dilute the mix to the proper analysis, help neutralize the effects of acid forming nitrogen-ingredients, and help prevent bag rot sometimes caused by excess acid in the super phosphate component of fertilizer. At the present time there are no state or federal standards for the filler materials and hence the specifications for filler are established by individual companies involved with formulation of the product. In most situations, however, the industry tries to obtain dolomite or limestone that gives the closest possible match of particle size with the other blending materials in their inventory (Ref. 21).

In most bulk-blending situations, the fertilizer fillers would be required to fall under particle size distributions of NO. 6 to No. 20 sieve and preferably have a size representing the greatest percent by weight of the fertilizer blend. Quarry fines in Categories I and II may be suitable for use as fertilizer fillers. Annually about 3 million tons of crushed stone fines are used in United States as fillers or extenders (Ref. 12).

LIVESTOCK FEED AND POULTRY GRIT

Pulverized high calcium limestone is the primary calcium source for livestock. Calcium and phosphorus are major constituents of bone. Calcium also plays a major role in various body processes. Therefore high calcium limestone is a helpful ingredient in the animal rations. Most states have regulations governing the production, marketing and sale of livestock and feed ingredients. The material generally preferred for use as livestock feed is expected to be high purity limestone having 95% or more calcium carbonate with 95% or more passing the No. 100 sieve (Ref. 21).

Annually about 1.5 million tons of fines are consumed as live stock feed in United States (Ref. 12).

Limestone in granular form is used as poultry grit. Grit, when added to poultry food ration, lodges in the gizzard and enables the poultry to grind and utilize the feed more efficiently. Poultry grit specifications usually provided by the purchaser range from approximately 0.142 to 0.187 inches (Sieve No. 6 and No. 4) and all the way up to 0.375 inches (3/8" sieve). Rounded or spherical granules with a uniform gradation are required for uses as poultry grit. Annually about 500,000 tons of fines are used as poultry grit (Ref. 21).

About 2,365,000 tons were used as mineral feed and poultry grit in U.S. in the year 1989 (Ref. 12).

ENVIRONMENTAL RELATED USES

Environmental applications provide great potential for using quarry fines. Some of these applications in which quarry fines are currently used are provided below.

CONTROL OF SO_2 EMISSIONS

The collective term used to describe the processes involving removal of sulfur dioxide (SO_2) from stack exhausts to avoid releasing them to the atmosphere is called stack gas desulfarization. The coal fired utilities and other private industries that use coal as a primary source of fuel use limestone for stack gas desulfarization. Many approaches are used and depending on the type of approach used, the aggregate gradations vary from No. 6 to No. 200 sieve. For example flue gas desulfarization requires a high calcium carbonate content aggregate (95%) with 100% passing the No. 20 sieve and 80% passing the No. 325 sieve (0.0017 in), with a magnesium content less than 2%. Quarry fines in categories IV, V, and VI could be used for desulfarization.

Approximately about 1,159,000 tons of quarry fines were used for this purpose in United States in 1989 (Ref. 12).

POND AND WATERSHED LIMING

Aglime is used extensively for pond and watershed liming since it reduces the effects of acid rain on ponds and water sheds and increases the pH of the water bed (Ref. 21).

Very fine minus No. 100 sieve size material to No. 60 size material are used for this purpose. Other liming products, e.g. dry and hydrated calcitic lime, are also used for the same purpose and their quality is evaluated as discussed under the aglime uses.

ACID MINE DRAINAGE ABATEMENT (AMDA)

Acid mine drainage is a pollution problem resulting from the oxidation of pyrite (FeS) present in mine wastes. AMDA is primarily associated with mining and cleaning of coal and other sulfide minerals. If the pollution problem is not properly treated, they leachate and the resulting acid discharge kills vegetation and fish, contaminates ground water and in general negatively affects the environment. High purity limestone or a mixture of lime and pulverized limestone are used to neutralize the acid in a pH range of up to about 6.0. Particle fineness and high chemical purity control the effectiveness of materials used for this purpose. A fine lime or limestone product with a fineness in the minus No. 200 sieve size and a calcium and magnesium carbonate content in excess of 95% is a preferred product. Quarry fines in categories IV, V, and VI could be used for AMDA. Approximately 674,000 tons of fines were used in the U.S. in 1989 for this purpose (Ref. 12). Agricultural limestone is used at very high rates, in excess of 100 tons per acre for the treatment of coal refuse containing pyrite, which if not treated, produces sulfuric acid and other strong acids when exposed to atmospheric oxidation (Ref. 21).

LANDFILL LAYER

A layer of Aglime is sandwiched between the landfill layers for precipitating out certain heavy metals that would otherwise migrate from solid waste in landfills with the leachate. Hazardous waste material, especially nickel hydroxide, present in solid waste landfills dissolve very easily in acidic rain water (low pH) and migrate into the ground, contaminating the ground water. When a 1 inch layer of calcium carbonate is introduced it raises the pH of the rain water up to 8.5 and hence reduces the solubility of waste material in water to acceptable limits (up to 3 mg/l). A product with a very high calcium carbonate content is desired to be used as a landfill layer. Agricultural lime stone is preferred for this purpose because of its wide geographic distribution, particle sizes and relatively low cost. The specifications for the product are the same as discussed under aglime (Ref. 21, 38).

MISCELLANEOUS USES

Quarry Fines are used in Miscellaneous industries such as Paper/Pulp manufacture, Industrial filler or extenders, plastic industry, paint industry etc., in some form. All these miscellaneous uses require quarry fines to be of uniform gradation and in a comparatively pure form. Approximately 2,867,000 tons have been used in these industries in 1989 alone (Ref. 12).

A list of the limestone fines usage in all the uses mentioned above are given below in Table 4.3. Additionally, the uses of other crushed stone fines other than limestone fines are given in Table 4.4. It may be noted that the quantity of limestone fines sold is about four times the quantity of other types of quarry fines sold.

No.	USE	LIMESTONE	
		QUANTITY (In thousand tons)	VALUE (In thousand dollars)
1	Agricultural Limestone	18934	89283
2	Poultry grit and mineral feed	2362	21115
3	Other Agricultural uses	913	4764
4	Glass	266	3063
5	Sulfur Oxide	1159	4536
6	Mine dusting or Acid water treatment	674	7433
7	Asphalt fillers or extenders	1639	11727
8	Whiting or whiting substitute	665	11344
9	Other fillers or extenders	2085	50304
10	Roofing granules	117	3483
11	TOTAL	28814	207052

TABLE 4.4 Crushed limestone fines, used in the United States by documented use (In thousand tons and thousand dollars)

SOURCE: MINERALS YEAR BOOK - 1989 (Ref. 12)

No.	USE	QUANTITY (In thousand tons)	VALUE (In thousand dollars)
1	Agricultural Limestone	Nil	Nil
2	Poultry grit and mineral feed	829	4567
3	Other Agricultural uses	Nil	Nil
4	Glass	36	542
5	Sulfur Oxide	Nil	Nil
6	Mine dusting or Acid water treatment	41	644
7	Asphalt fillers or extenders	231	1669
8	Whiting or whiting substitute	977	58408
9	Other fillers or extenders	2440	31565
10	Roofing granules	2967	10580
11	TOTAL	7521	107975

Table 4.3 Crushed stone fines other than limestone fines used in the United States by documented use (In thousand tons and thousand dollars)

SOURCE: MINERALS YEAR BOOK - 1989 (Ref. 12)

CHAPTER 5

POTENTIAL USES FOR QUARRY FINES

INTRODUCTION

Quarry fines are composed of very fine graded particles. Quarry fines, especially pond screenings, have high moisture contents. Due to this fine gradation and high moisture content their use in engineering and environmental applications is limited. This chapter identifies some potential engineering and environmental uses for quarry fines. Some of these uses may require natural dewatering or, in some cases even, drying of quarry fines. In addition, some of these uses may have specific gradation requirements and may have limitations on the type of quarry fines to be used.

READY MIXED FLOWABLE FILL

Flowable fill is a mixture of cement, fly ash, sand, and water designed as a low strength, fluid material requiring no subsequent compaction efforts like vibration or tamping for consolidation. The other names for flowable fill material are "Controlled Low Strength Material" (CLSM- ACI committee 229), controlled density fill, and flowable mortar. Flowable fill is neither concrete nor soil. It is stronger than compacted soil, but can be excavated if desired.

STRENGTH CHARACTERISTICS

Flowable fill achieves compressive strengths from 20 to 200 psi. Most state and other agencies, who have specified or used flowable fill, specify that the 28 day unconfined compressive strength could be in the range of 40 - 1000 psi but more than 30 psi. The specifications for 3-day strength calls for a compressive strength of 20 psi or more. A higher strength material may complicate the excavation process if it is later decided to remove the material.

Flowable Fill Mix Specification: Various mix specifications are suggested by different agencies. To date the American Concrete Pavement Association, Iowa Department of Transportation, and Ohio Department of Transportation are some agencies that have developed a mix specification for flowable fill. The following mix specification is suggested by all these agencies with minor variations:

Portland Cement (Type I or Type II)	100 - 200 lbs/yd^3
Fine aggregates (sand)	2200 - 3000 lbs/yd^3
Fly ash (to ensure flowability)	100 - 300 lbs/yd^3
Water	60 - 70 gallons

All agencies require that the fine aggregates be fine enough to be flowable, in the gradations of 100% passing 3/4" sieve and 0-10% passing No. 200 sieve. Crushed stone fines inherently have very low or zero plasticity, hence do not significantly affect the compressive strength of concrete unlike natural sands that contain high amount of passing No. 200 fines(Ref. 15,33). Hence it can be suggested that quarry fines could be used in flowable fill, with some modifications in the above specification. Due to an increase in the fines content in quarry fines, resulting in an increased surface area of the particles, it may be necessary to increase the water content and/or the cement content of the mix to create a flowable mix.

APPLICATIONS

The applications of flowable fill are numerous. They are mainly used wherever backfilling is needed. Some of the applications of flowable fill incorporating quarry fines are cited below (Ref. 17,18,19).

Back fill:

Sewer trenches

Utility trenches

Building excavations

Bridge abutments

Conduit trenches

Structural fill:

Foundation subbase

Sub footing

Floor subbase

Pipe bedding

Column excavation back fill

Other Uses:

Filling abandoned underground storage tanks

Filling abandoned wells

Voids under existing pavement

Abandoned sewers and manholes

Retaining wall back fill

Where ever compacted soil back fill is required

BENEFITS

Following are some of the listed benefits of Flowable Fill incorporating quarry fines: (Ref. 17,18,19):

1. Positive uniform density: Since flowable fill incorporating quarry fines will be manufactured using standard mix design procedure and uniform quarry fines, the

density achieved in the field will be uniform, compared to the conventional back fill materials.

2. No on-site compaction testing required: Flowable fill need not be compacted since it is in a self leveling consistency, and settles by itself, achieving the necessary strength. Compaction tests are critical for backfilling materials, to check if they have received the desired compactive effort and hence the designed strength.

3. Reduced in place cost: The cost of flowable fill may be less in some cases as discussed in chapter VI.

4. Minimized settlement: Flowable fill achieves desired strength in 3-days and since it is stronger than most backfilling material, the settlement is to a minimum.

5. Easily removed if necessary: Flowable fill is not as strong as concrete. Its 3-day compressive strength is in the range of 20 to 50 psi. Its 28-day compressive strength ranges from 40 to 200 psi. Hence it can be easily removed by excavation equipment when necessary.

6. Faster construction: Construction time is greatly reduced by using flowable fill, since no on-site compaction is necessary. The concrete truck unloads the material in the desired location, the material flows into place and settles down.

7. Easily ordered from local ready mixed concrete producers:

8. Stronger in strength than compacted soil and hence reduction of erosion and washout: Compressive strengths of 40 - 200 psi are achieved by flowable fill. This strength is stronger than most compacted soil. Also since the materials in flowable fill are bound together by fly ash and cement, erosion and washout are reduced to a minimum.

EXAMPLES OF THE USAGE OF FLOWABLE FILL

1. Water main project in the City of Temple

The fill was placed up to the top elevation of the paving at intersections to serve as temporary traffic crossing.

When the pavement over the trench was replaced, the flowable fill was readily removed to the depth of the paving patch.

2. Interstate 10 East of San Antonio

Eight feet (deep) trenches were dug along the shoulders of IH-10 for installation of impermeable membranes along the pavement. After installation, the trenches were back filled with granular materials and covered with a concrete cap.

The back fill materials consolidated, causing voids beneath the concrete cap, and flowable fill was pumped into the voids to fill them, through the holes drilled into the cap.

3. City of Austin convention center

Seven hundred feet of abandoned water main beneath the new convention center was filled with flowable fill.

4. About 11,000 cubic yards of flowable fill was used in the reconstruction of a Pampa chemical plant.

5. About 20,000 cubic yards of flowable fill was used as a structural fill for a new industrial plant near Dallas.

CONCLUSIONS

Flowable fill can definitely be advantageous over conventional compacted back fill. The May 1984 report of the Iowa HRB project (HR-219), "Settlement at culverts", concluded that the most cost effective methods (of back fill) with a minor amount of total settlement was the flowable mortar back fill.

Since the fine aggregates are intended to be fine enough to stay in suspension in the mortar to the extent required for proper flow, most quarry fines could be used in flowable fill. Though the fine aggregate gradation requirements state that only 0- 10% of aggregates can pass the No. 200 sieve, it is only over cautiousness on the part of departments that could have made them specify those gradations. Even in high strength concrete mixes 5-15% fines can be allowed if crushed stone aggregates are used (Ref. 15,25). Moreover, flowable fill mix is essentially designed as a low strength concrete mix, where shrinkage and other durability considerations are not considered. Flowable fill materials, buried in the ground or otherwise confined, continue to act as granular fill even after deterioration. Nina Balsamo (ref. 5), in an article stated that " non - specification aggregates and by-products may also be used as mix components (for flowable fill)". All VI categories of quarry fines discussed earlier in chapter III can be used as aggregates for flowable fill.

A preliminary study was conducted to determine the suitability of the use of quarry fines in flowable fill. The results and conclusions of the study are provided in chapter VI.

SANDBAGS

Sandbags have been in use since ancient times. Their usage have been primarily in areas of flood control, shoring for water structures, and in military for testing purposes. Most types of quarry fines could be used, economically and successfully, in the sandbag applications.

A well-known use for sandbags in the U.S. is in temporary flood control measures, where the sandbags are stacked to form a dike or a temporary structure to prevent flooding. Depending on the situation the quantity of sandbags required may vary. Mark Gibson of the U.S. Corps of Engineers, during a telephone conversation, said that they stock more than 20,000 unfilled sand bags for emergency use. Mr. Gibson has quoted instances where more than 15,000 bags of sand were used for flood control. The bags used for this purpose, he quoted, where made of semi-plastic woven cloth (polypropylene). A typical sand bag weighs about 50 to 60 lbs and consists of about 1 cubic foot of sand. During periods of heavy rains and expected floods, the bags are filled with locally available or hauled in sand, hauled to desired locations, and stacked.

Barrier sand bags are used to stop scour, erosion and washouts under and around offshore structures. One system of using barrier sandbags have been developed by Centennial Corporation of Kenner, Louisiana (Ref. 44). The barrier bags are filled by a two man crew on-site or with specialized equipment at depths of up to 1,000 ft. The bags which range in size from 24,000 lbs on up, act as a perimeter confinement or form work and anchor the soil underneath, providing support for the structure. The bags are made of polypropylene for permanent applications. Also these barrier sandbags can be used to support pipelines in free-span areas (Ref. 44).

For quarry fines to be used in these rather low-scale applications, they should be fairly close to the operation sites and should not have a high percentage of water soluble particles.

SOLID WASTE LANDFILLS

Solid waste landfills offer wide potential uses for quarry fines. Quarry fines could be used in those landfill applications if the user considers the product advantageous due to one or more of the factors given below :

1. Low cost of quarry fines compared to sand or gravel,
2. Very fine gradation of quarry fines, and
3. Acid neutralizing properties of carbonate rock quarry fines.

High potential uses for quarry fines in landfill treatment are:

1) As a layer in the landfill to neutralize acidic waste and

2) As a cover layer for the landfill.

Another potential use for quarry fines in landfill is as a layer separating the pond liners from the waste.

Landfills containing hazardous sludges have the potential to leach and contaminate the ground water. An ideal solution for dealing with such problems is to excavate the waste, treat the waste, and replace it in the landfill. This solution is very expensive. An alternate solution for some landfills containing toxicants such as nickel hydroxide, especially waste water treatment sludges from electroplating operations could be indefinitely stabilized by providing a layer of $CaCO_3$ (Ref. 38). Quarry fines from limestone and dolomitic operations contain very high percentages of $CaCO_3$ (up to 98%) and can therefore be used for this purpose.

Two common situations in a landfill where such a layer may be needed are:

1. If the leachate is highly acidic, it is often collected by some means below the landfill and is treated before it is sent back to the landfill. If a layer of quarry fines containing high percentage of $CaCO_3$ is provided below the landfill where the leachate is collected, it could reduce the treatment costs substantially.

2. The landfill may contain contaminants, like nickel hydroxide, which are highly soluble in an acidic medium. If the pH of the waste is 8.5 or more, no significant quantities of contaminants may leach to contaminate the ground water. However, over time, the sludge alkalinity will be exhausted in certain spots of the waste mass. Subsequent acid rains will leach contaminants from the sludge and possibly carry it to the ground water under the sludge bed. Such a situation can be corrected by covering the site with a layer of quarry fines, to neutralize the acid rain before it reaches the waste.

Quarry fines could be used to cover landfills. When sludge disposal sites are closed it is customary to cover with a 12" to 18" layer of bank run gravel or other fill materials and top it with a 3" to 9" topsoil. Instead of the bank gravel, quarry fines could be used and compacted into place. They can also be used as an admixture for the topsoil, especially when it is advantageous to use carbonate rock quarry fines due to acid waste problems. Additionally, quarry fines material could be used as daily cover for landfills when local fill material is not available or again, when there is an acid waste problem.

MISCELLANEOUS SAND APPLICATIONS

Sand is used as a leveling layer in most of the construction operations. Three inches to six inches of sand is specified by most architects whenever concrete is poured on excavated surfaces or leveled surfaces, except on solid rock surfaces. Quarry fines, dry screenings as it is and pond screenings after natural dewatering, could fill this market economically.

Some of the applications, commonly specified by designers and architects, where quarry fines could be used are:

1) Under concrete footings as a leveling layer,

2) Under slab-on-grade,

3) Under concrete walkways,

4) Under basement concrete floors,

5) Under utility pole footings, and

6) Under domestic sewage pipes as a leveling layer.

Also, quarry fines could be used as a floor hardener. Slag, trap rock and granitic fines could be sprinkled on the top layer of concrete floors to impart wear resistance. Quarry fines may also be used as a dense graded base material for under ground cables, if the material has a high thermal and a low electrical conductivity (Ref. 35).

Some of the aesthetic and dry quarry fines can be packed in bags and sold to wholesale dealers for markets in two potential but low volume uses:

1) Use as trash sand for cigarette disposal containers in large shopping malls, cinemas, public recreation areas etc.

2) Use as absorbents, floor cleaners or skid preventing agents in workshops where oil spills on the floor are quite frequent. Some fines have already been reported to be used in animal shelters as absorbents (Ref. 35).

SAND BLANKETS

One high potential use for quarry fines is in the petroleum industry as a sand blanket to seal disposal pits made for drilling wastes. The drilling waste disposal pits associated with drilling operations for oil and gas exploration are suspected to discharge contaminants into ground water resources. These drilling pits accumulate and store as much as 100,000 barrels of waste fluids per site. The fluids often contain appreciable quantities of heavy metals and other potentially harmful substances that can leak through permeable materials such as sand, gravel or fractured rock and contaminate the ground water (Ref. 45). This can be prevented by lining the disposal pit with a 4.5 inch layer of quarry fines. The bentonitic clay particles found in the drilling waste will fall out of suspension and become lodged in the sand's pore channels, thereby plugging up the pores and forming a seal. The effectiveness of the seal is dependent upon the fines content of seal and is found to improve with increased fines content. Quarry fines, which contain a large amount of fines, could therefore be economically and advantageously used as a sand blanket to prevent ground water contamination by drilling wastes.

Substantial amounts of mercury is released by some mercury-enriched river beds. (e.g.., Detroit river). A 3 inch layer of sand applied over the mercury enriched segments has prevented the release of such toxic materials (Ref. 46). Some of the coarser gradations of quarry fines could be used in such hydraulic fill uses successfully.

LOW COST MASONRY USES

The potential use of quarry fines in masonry are discussed in regards to the following specific applications:

1. Concrete Block,
2. Masonry Mortar,
3. Gypsum Plaster,
4. Masonry Cement,
5. Masonry Grout, and
6. Bricks

Concrete Block and Masonry Mortar: Gradation requirements set by ASTM Specification C33 for concrete aggregates (Fine and Coarse aggregates) apply for the manufacture of concrete blocks and gypsum plaster. If quarry fines are to be used for these applications it needs to be uniform and satisfy the gradation requirements. Since quarry fines contain No. 200 fines and do not meet the specifications, it cannot be used successfully.

Gypsum Plaster: Aggregates used in gypsum plaster are required to meet the ASTM specification requirements set forth in ASTM C35 (Inorganic Aggregates for Use in Gypsum Plaster). This application is more suited for sand with very less passing No.200 content and thus are not highly suited for quarry fines.

Masonry Cement: Baghouse dust collector fines, fine dust collected from baghouses used in asphalt manufacture plant, are presently used as mineral fillers in the manufacture of masonry cement. Sorokka (Ref. 42), reported an increase in the strength of 1:2.75 cement mortar with the addition of crushed stone fillers up to 40% of the cement weight. Considerable savings could be achieved by adding crushed stone fines to cement. However, for use as mineral filler, quarry fines have to be dried and further ground.

Bricks: A high potential use for quarry fines is in the manufacture of steam cured bricks. An investigation by the Bureau of Mines demonstrated that building bricks can be produced by the steam-curing process using various types of industrial mineral wastes (Ref. 46). Copper mill tailings, zinc mill tailings, roofing granule fines, and asbestos fines were bonded with either $Ca(OH)_2$ or portland cement to produce building bricks that met ASTM specification C73-67 for grade SW and MW bricks.

Quarry fines which possess pozzolonic properties such as basalt could be studied for economical usage in manufacturing such building bricks.

Masonry Grout: Some potential exists for quarry fines to be used in grout for reinforced masonry. Though stringent gradation requirements are set by ASTM C 404 (Aggregates for Masonry Grout), coarser gradations of quarry fines in category I would meet these specifications since up to 10% material passing No. 200 sieve is permitted.

CEMENT TREATED QUARRY FINES FOR SUBBASE LAYERS

Currently, the majority of the available subbase materials are generally a low grade crushed aggregate or gravel material or in-situ materials stabilized with lime or portland cement. When stabilized with cement, quarry fines could be used as a low strength subbase or base material, provided the quarry from where the material is transported is located within 100 miles radius from the job site. It must be noted, however, that quarry fines do not meet state specifications for manufactured sand, mainly because it contains more than 15% fines.

Sharpe et. al (Ref. 8) used a stabilized subbase material (limestone fines + fly ash) on a project in Kentucky and achieved compressive strength of about 300 psi in 7-days. The authors recommend a minimum compressive strength of 600 psi in 7-days and a minimum tensile modulus of elasticity of 250,000 psi for a stabilized base course material. A preliminary feasibility study of the use of quarry fines in cement stabilized subbase layer was done and the results and recommendations of the study are discussed in a detailed manner in chapter VI of this report.

Since the amount of quarry fines which could be sold in this particular application is high and since the quality of quarry fines themselves depend on the parent quarry, extensive testing and negotiation would be needed for acceptance.

SUBSURFACE SEWAGE DISPOSAL SYSTEM

On-site sewage disposal systems (commonly septic tank/ soil absorption systems) provide a viable and permanent management alternative for the treatment and disposal of waste water in rural, unsewered communities. One of the major challenges in rural area development is to develop an economical and efficient on-site sewage disposal system.

Building on-site sewage disposal systems in fill can be used to overcome site limitations such as high ground water and shallow depth to ledge. Selected quarry fine material, meeting design requirements of hydraulic and renovation capacity, can be used as such a fill material. This section reviews the procedures for identifying and verifying suitable quarry fines material and for placing it in fill to meet design specifications.

PERMEABILITY CONSIDERATIONS:

Design of subsurface sewage disposal systems in emplaced fill involves the determination of the following:

1. The required leaching structure infiltrative area to provide adequate hydraulic capacity.

2. The lateral flow cross section to provide adequate lateral hydraulic capacity under design conditions.

3. The vertical transmission zone size to assure unsaturated flow conditions between the leaching structure and the saturated lateral flow zone (Ref. 16).

Since many sites are geometrically constrained, the designer relies on emplaced fill permeability to achieve a workable design. The permeability specification for emplaced fill has a large impact on the retention time, i.e., providing residence time for bacterial renovation. A minimum of 21 days is specified by the Connecticut Department Of Environmental Protection for retention time. The travel time within the fill, T, is a function of fill seepage velocity, Vs, and the length of the fill section in the direction of flow, X: T=X/Vs . Seepage velocity and travel times are in turn a function of fill permeability.

$$Vs = K\ i\ /\ n \quad \text{.......eqn. 5.1}$$

Where K = saturated fill permeability,

i = hydraulic gradient, and

n = drainable porosity .

Lower the permeability, lower the seepage velocity and greater the residence time. By similar reasoning, higher the permeability, lower the residence time. A high value of fill permeability is desired to minimize the infiltrative area and provide hydraulic capacity. A low value of fill permeability is desired to maximize the residence time. Therefore it is most desirable to balance the requirements of residence time, hydraulic capacity, and infiltrative area to produce an economical design for a given set of site considerations (Ref. 16).

EVALUATION AND VERIFICATION OF QUARRY FINES TO MEET PERMEABILITY SPECIFICATIONS:

The suitability of fines to satisfy the required permeability considerations could be preliminarily evaluated using the grain size testing. An important equation to determine the permeability based on the D_{10} fraction, porosity, and percent passing the NO. 200 sieve, as given by Moulton (Kilduff: ref. 16) is :

$$k = \frac{6.214 \times 10^5 \times D^{1.478} \times n^{6.654}}{P_{200}^{0.597}} \quad \text{.......eqn. 5.2}$$

Where k = permeability, ft/day ;

D_{10} = sieve size passing 10% of sample, mm ;

n = porosity , 1- [D_s / D_w X G] ;

P_{200} = percent passing # 200 sieve ;

G = specific gravity of soil grains, assume 2.65-2.70;

D_s = dry density of soil, M/L^3; and

D_w = density of water, M/L^3

Some quarry fines in categories III and IV could be successfully used to obtain fill permeabilities of 1.0 to 2.0 m/day. As an example, the permeability of sample No.III (in category IV, Fig 3.4) works out to 5.07 m/day or 1.545 m/day.

The falling head permeability test is also a simple, rapid test suitable for materials with fairly low permeability. A satisfactory fines material must meet permeability at a density high enough to assure its structural stability. Laboratory tests to ensure the above statement should be done followed by pilot testing in the field. This is done to determine the in situ permeability and density along with the effects of various construction parameters such as number of compaction passes, machine type and size etc.

CASE STUDY

A case study construction of a subsurface sewage disposal system in fill is described by Kilduff (Ref. 16). The system was designed for a total waste water design flow of 2400 gal. per day (9084 L/day) from 24 housing units. Approximately 765 m^3 of fill material was used in the construction of the system. The material used was chosen from a borrow area, that had large, uniform deposits. The approximate grain size distribution of the sample used in the study is given below:

SIEVE NUMBER	PERCENT PASSING
# 40	100%
# 60	98%
# 100	60%
# 200	21.2%

A minimum design permeability of 1.83 m/day was required based on an allowable load rating of 21.2 L per m^2 of infiltrative area. The specified permeability corresponded to a dry density of about 1468 Kg/m^3 which corresponded to the theoretical relationship predicted by the Moulton equation. Laboratory tests indicated that the fill material had a maximum and minimum dry density of 1283 and 1600 Kg/m^3 respectively. The optimum water content for construction purposes was found to be at 4% from the moisture content - dry density curve obtained by the proctor compaction tests.

The construction site preparation was done by removal of top soil and scarification. An 18,000 kg bulldozer was used for compaction during dry conditions and smaller machines when the bank moisture content was high. The fill was constructed in 30 cm lifts. Falling head permeameter samples were taken at various grid locations on a daily basis, and an average permeability value of 2.26 m/day was obtained. The embankment was stabilized with vegetation to prevent erosion. To allow sampling of the ground water and evaluate the degree of renovation provided by the system, continuous monitoring is done by installation of five 5 cm diameter polyvinyl chloride (PVC)wells.

SUMMARY

The case study illustrates that quarry fines, equivalent to the fill material used on the project, can also be used in the construction of a subsurface sewage disposal system. The disposal system in emplaced fill provides safe, effective treatment and disposal. However, it may be noted that the construction of on-site sewage disposal in fill on limited sites is more expensive than conventional systems due to fill requirements and intensive engineering involvement in material testing.

Thus it can be concluded that there is some potential for the use of quarry fines in subsurface sewage disposal. It may produce a good market when high quantities of fill material (case project used 765 m^3) are used in one project. However, it may be noted that only material from selected quarries, passing stringent fill requirements may be used. Also another significant factor is the proximity of the quarry to the construction site. Since in most cases, constructing the sewage disposal system in fill is necessary for any site development to occur, it will be advantageous to the crushed stone manufacturer to monitor the needs for a fill material in the surrounding area and promote his material.

CONCLUSIONS

Potential applications discussed under the above seven sections provide high volume uses for quarry fines. The potentially highest volume uses are in the applications of cement treated quarry fines for subbase layers and ready mixed flowable fill, followed by miscellaneous sand applications, solid waste landfills, subsurface sewage disposal systems, low cost masonry applications and sandbags. Most of the specifications for all these applications preclude use of fine aggregates with more than 15% passing No. 200 sieve. But again it should be noted that crushed stone fines do not contain any clayey particles and do not adversely react in the presence of moisture nor react with the bonding agents. More work should be done to challenge the specifications provided in each of these areas. It is imperative that the specifications barrier be removed for wide spread usage of quarry fines in these applications.

CHAPTER VI

EVALUATION OF USE OF QUARRY FINES IN FLOWABLE FILL AND CEMENT STABILIZED SUBBASE

FLOWABLE FILL

Industry is constantly searching for new alternate construction materials that are economical and energy saving with desirable strength characteristics. One such material is flowable fill concrete, which is an economical alternative to placing and compacting soil or granular materials due to the saving of labor and time.

The flowable fill material was discussed in an earlier chapter. Quarry fines could be used in the manufacture of flowable fill concrete, when stabilized with cement, mixed with fly ash and adequate water to achieve desirable consistency. Since quarry fines are a low cost by-product of the crushed stone industry, considerable energy is saved when the material is put into effective use. It must be noted, however, that quarry fines do not meet the specifications called for by some agencies as the material contains more than 20% fines. This chapter discusses the utility of quarry fines as an alternative to the fine aggregates in the flowable fill concrete based on the performance criteria specified by those agencies and the test results obtained by the actual testing of the flowable fill material using quarry fines.

OBJECTIVES & SCOPE

The objective of this sub-study is to determine the viability of quarry fines to be used as a substitute for the fine aggregates in flowable fill. This study is based on available information on flowable fill material and actual tests done in the laboratory using quarry fines. The cost of the flowable fines is determined and the advantages and disadvantages are discussed with respect to a conventional backfilling operation.

TESTING DISCUSSIONS

The procedure used for testing the compressive strength of flowable fill material is essentially the same, with slight modifications, as described in the procedure for testing of compressive strength of cylindrical concrete specimens - AASHTO designation T 22-86 and ASTM designation C 39-86, Revised. Four types of quarry fines and one local natural river sand material were selected to be used in molding specimens for testing. The fines material were selected based on the grain size range graphs illustrated in Fig. 3.3 thru Fig. 3.8. It was decided to have:

1. One specimen with natural river sand to serve as a reference specimen (Test specimen No. I made with sample No.1, from Fig. 3.8).
2. One specimen of fines material with most preferred gradation range (Test specimen No. II made with sample No.5, from Fig. 3.7).
3. Two specimens from the middle of the grain size distribution (Test specimens No. III & IV made with sample Nos. 8 & 24 respectively, from Fig. 3.4).
4. One specimen of quarry fines with more than 75% material passing the No. 200 sieve (Test specimen No. V made with sample No. 14, from Fig 3.5).

Fig. 6.1 illustrates the grain size range of the above selected samples.

The samples were cast in 3" dia x 6" high cylinders made of waxed cardboard. This is one primary deviation from the ASTM and AASHTO specifications calling for a 6" dia x 12" high cylinder. It was decided to use a smaller cylinder size for two reasons:

1. The material used was very fine material, the maximum size of the aggregate passing 3/8" size.

2. To cast two specimens in 6" dia x 12" high cylinders at least 47 lbs of quarry fines is required, which was not available. The samples available were approximately 20 lbs each.

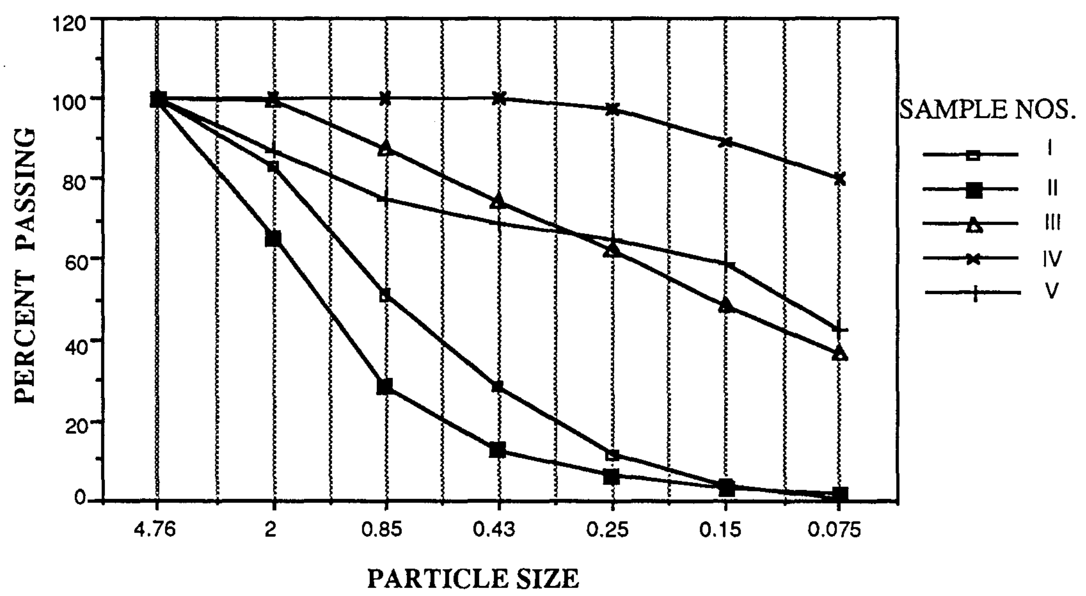


Fig. 6.1 Grain size range of fine samples selected

Five mixtures, two specimens per mixture, were prepared with a constant mix of fines, fly ash, and cement. The mixture proportions were adopted from the "Municipal Concrete Pavement Manual - guide specifications and design standards", American Concrete Pavement Association. The specification is given below:

402.2 FLOWABLE LOW STRENGTH MORTAR BACKFILL.

Flowable low strength mortar backfill may be used as an alternate for backfilling utility trenches. The desired consistency is achieved using a mix of the following proportions per cubic yard:

Quantity of Dry Material/Cu. Yd.	
Cement	100 lbs.
Fly Ash	250 lbs.
Sand	2800 lbs.
Water (maximum)	500 lbs.

It is intended that the sand be a fine sand that will stay in suspension in the mortar to the extent required to obtain a flowable consistency. Fine aggregate gradations meeting the following specifications provide satisfactory results:

Sieve Size	% Passing
3/4	100%
200	0-10%

The same specification cannot be used as such for flowable fines using quarry fines primarily due to the fact that quarry fines have a significant quantity of material passing the No. 200 sieve and hence have greater surface area of particles than the conventional aggregate specified above. Due to an increase in the surface area of the particles, additional paste comprising of cement, fly ash, and water is needed. However, it was decided to use the same proportion of cement, fly ash and sand, but vary only the amount of water required to achieve the desired consistency.

The weights of the above materials expressed as a percentage of the dry weight of the mix is : Cement (3.17%), Fly Ash (7.94%), and sand (88.89%). The water cement ratio is 5:1. The ratios so obtained were used to calculate the weight of individual materials to make a certain amount of mix, i.e, the material needed was approximately 0.050 cu. ft., which is equal to the volume of two 3" dia x 6" high cylindrical molds (0.049 cu. ft) and some excess material for waste. Water was initially added to an amount equal to five times the weight of cement. Additional water was added in increments of 50 grams to achieve the right consistency. For samples with large amounts of material passing No. 200 sieve water cement ratio was more than 10:1. Again, this is due to the fact that the surface area of the material is much higher and the amount of water needed to coat the surface area of each particle is great. The proportion by weight of material and the amount of water added in the mixture are all tabulated and shown in Table 6.1.

The final consistency is equivalent to that of material flowing through an inverted slump cone in 3.1 seconds and can be described as like that of ice cream consistency flowing into a cone, only slightly more fluid. No other consistency test was done. It was not possible to use the slump cone tests since the material has a very wet consistency. However, it will be to the manufacturer's/user's advantage if a flowability test is developed to set the limits of consistency/flowability and if a relationship between the consistency and the strength is developed. In fact such a test can be developed along the lines of the ASTM procedure C939-87, "Standard Test Method for FLOW OF GROUT FOR PREPLACED-AGGREGATE CONCRETE (FLOW CONE METHOD).

The prepared mix was then poured into a mold. No compaction was done but the mold was tapped slightly on the sides for all the material to settle properly. The specimens along with the mold were cured in a humidity room with controlled temperature at 72° F for 3 days.

3- DAY UNCONFINED COMPRESSION STRENGTH										
BATCH 1	DATE MOLDED: 6/12/92					DATE TESTED: 6/15/92				
SPECIMEN IDENTIFICATION	I A	I B	II A	II B	III A	III B	IV A	IV B	V A	V B
QUARRY FINES (Lbs per Cu.Yd)	2800	2800	2800	2800	2800	2800	2800	2800	2800	2800
Percentage of dry weight	88.88	88.88	88.88	88.88	88.88	88.88	88.88	88.88	88.88	88.88
FLY ASH (Lbs per Cu.Yd)	250	250	250	250	250	250	250	250	250	250
Percentage of dry weight	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93	7.93
PORTLAND CEMENT (Lbs per Cu.Yd)	100	100	100	100	100	100	100	100	100	100
Percentage of dry weight	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17
WATER (Lbs per Cu.Yd)	500	500	500	500	620	620	735	735	1030	1030
Water - cement ratio	5 : 1	5 : 1	5 : 1	5 : 1	6.2 : 1	6.2 : 1	7.3 : 1	7.3 : 1	10.3 :1	10.3 :1
COMPRESSION LOAD (LBS)	100	116	127.3	128.5	298.6	326	149.5	145.5	87.82	145.5*
COMPRESSION STRENGTH (PSI)	14	16	18	18	42	46	21	21	12	20.62*
* 7-day results										

TABLE 6.1 Flowable fill: Unconfined Compression test results

RESULTS

The specimens were tested in a manual loading soil compression testing machine. The concrete compression testing machine could not be used for these specimens, since the specimens were very small and hence, the heads would not correspond to the maximum diameter limits specified by ASTM. Also the rate of loading was quite high (300 lbs per minute). The specimens were not capped, which could have affected the results to a certain extent. The specimens, however, were quite plain on the top and bottom surfaces. Sulfur capping was avoided due to the low strength of the material, and it was felt even the neoprene caps would not work very well. The soil-compression machine was calibrated before the experiment and the compression load equations were given. The rate of loading was approximately 100 pounds per minute. The compression strength of the specimens varied from 12.42 psi for the bag house fines sample to 42 psi for sample No. III. The 3-day compression test results are tabulated in Table 6.1. The identities of the samples received from the quarries are not given here for confidentiality purposes.

DISCUSSION OF RESULTS

The highest compressive strength, 46.12 psi was obtained for sample No. III, which had 37.11% passing N0.200 sieve. The specimen was found to be hard, by touch, compared to other specimens.

One surprise result was that the natural sand specimen had a compression strength of only 15 psi (average). This is possibly due to the non-flowable nature of the aggregates themselves. It was noted that during mixing, the sand tended to segregate. When water was slightly excessive in an area, cement and fly ash did not mix well with the sand particles. After the natural sand specimen was cured there were noticeable voids along the mold contact surface, which were not found in any other specimen. These facts might explain the testing results of the specimen and the conclusion that some natural river sands are not suitable to be used in flowable fill.

The lowest 3-day compression strength of 12.42 psi was obtained for specimen No. V made with bag house fines. As can be seen from Fig. 6.1, fines material has more than 80% passing the No. 200 sieve. The low compressive strength may be due to the fact that the amount of cement paste available to coat the fine particles was minimal. Also it was noted that the specimen had not completely dried up and was sticky when removed from the mold. Since two specimens were prepared with the same mix and because a poor result was obtained from the first sample, the second sample was not tested immediately, but was continued curing for 7 days. The strength of the second sample improved to 21 psi in 7 days.

The compression strength results of the other samples, i.e. No. II and No. IV, were around 20 psi.

Some of the agency recommended minimum 3-day compression test results are provided below as examples for evaluation purposes:

1. Department of Aviation - 25 psi
2. National Ready Mix Association - 20 psi

Considering the above recommendations, two of the four quarry fines specimens were found to have the required strengths, with a minimal amount of cement. Yet another sample had 18 psi compression strength. Considering that the samples were tested without capping (due to reasons stated earlier) and only a minimal required quantity of cement was used, the results are considered good.

COST CONSIDERATIONS

The following backfilling costs are approximate costs quoted by two local Austin excavation contractors (Ref. 37). The prices quoted are conservative and may vary depending on the back fill material specified or available on-site. The rates quoted are for hand compaction.

Backfilling, watering, and compaction using material available in site: $7 - $8 / Cu. Yd.

Select back fill material costs : $5.50 - $8.00 / ton

Assuming approximately 1.80 tons / Cu. Yd

Costs for select back fill, watering and compaction = $17.00 - $22.50 / Cu. yd

Flowable fill costs per cubic yard: Considering the same mix ratios per Cu. Yd, as given earlier, and considering a delivery of about 25 miles for quarry fines and fly ash, costs per Cu. Yd are:

Cement Costs : 100 lbs x $4.00 / bag = $ 4.25 (94 lbs = 1 bag)

Fly ash Costs : 250 lbs x $3.00/ ton = $ 0.36
(Fly ash in most cases is free and only transportation costs are necessary)

Quarry Fines Costs: 2800 lbs x $4.35 / ton = $6.09

Water costs : 500 lbs : 60 gal. x $ 0.01/ gal = $ 0.60

Total flowable fill costs including overhead and profits: 11.30 x 1.05 = $ 11.80/Cu. Yd

It can be seen from the above that flowable fill costs are much lower than backfilling with select back fill, but are higher than the costs of backfilling with material available in site. In certain cases it should be noted that the costs for hauling the excavated material should also be considered. But considering the time to complete the operations it is noted that using the flowable fill material will consume very little time as compared to using the conventional backfilling. In spite of the cost difference, it should be noted that in some special cases it may be necessary and easier to use flowable fill than the other operations, such as some cases cited in the earlier chapter on flowable fill.

CONCLUSIONS AND RECOMMENDATIONS

1. Flowable fill using quarry fines has advantages over select back fill in terms of time, cost and effort. It also has advantages in most cases over conventional backfilling in terms of time and effort.
2. The 3-day compression strengths of the fines in the flowable fill vary considerably. Hence it is recommended that the mix ratio for the flowable fill needs to be determined by testing each batch of fines used from the parent source.
3. It may be necessary, while using some fines material, to add additional cement or water and hence the costs may be slightly higher than those stated.
4. It is recommended that the individual mixes be tested for bearing values, giving an idea of setting times of concrete, to allow traffic to pass through. It may be necessary to add admixtures in some cases.
5. It is also necessary to design the mix for a certain consistency and to administer the designed consistency limits in the field for the right flowability.

CEMENT STABILIZED QUARRY FINES

In today's pavement construction field, good subbase materials in terms of reasonable cost, adequate strength, and good durability characteristics are difficult to find. The majority of the available subbase materials are generally a low grade crushed aggregate or gravel material or in-situ materials stabilized with asphalt concrete, lime or portland cement.

When stabilized with cement, quarry fines could be used as a low strength subbase or base material. It must be noted, however, that quarry fines do not meet state specifications for manufactured sand, mainly because they contain more than 15% passing No. 200. This chapter explains a preliminary feasibility study to define a potential use for quarry fines. Since the amount of quarry fines which could be sold in this particular application is high and since the quality of quarry fines themselves depend on the parent quarry, extensive testing and negotiation would be needed for acceptance. For purposes of this study, limestone fines, classified as No. 100 gradation material, provide a portion of the aggregate source for the stabilized-base pavement layer. Again this small study has used only limestone fines and there is no guarantee that the fine material from other types of parent rock will provide the same results.

OBJECTIVES:

The objectives of quarry fines project are to determine the potential engineering and environmental uses of quarry fines. This chapter deals with the study of potential use of limestone quarry fines as a subbase aggregate source, based upon the following criteria:

1) A minimum unconfined-compressive strength of 300 psi at 7 days,

2) The maximum percentage of quarry-limestone fines allowed based upon strength, strain and layer stiffness (tensile modulus of elasticity) for repeated 18-kip axle loading requirements, and

3) The cost of the stabilized quarry-fines subbase per short ton.

SCOPE

The scope of this sub-study is to determine from samples cast from various proportions of cement, sand and quarry-limestone fines,

1) the unconfined compressive strength,

2) tensile modulus of elasticity, and

3) Poisson's ratio values.

After calculating these material characteristic values using established equations (Ref. 28), an equivalent stabilized, quarry-limestone subbase (base) thickness can be determined based upon controlled-fatigue, interior, horizontal strain values for an asphalt concrete pavement structure with a gravel subbase.

The cost of the stabilized, quarry-fines subbase is determined based upon layer thickness and the portions of constituent materials. From this, a cost difference determination can be made between the quarry-fines subbase versus the conventional subbase. The design of the base is based on fatigue strains produced in the bottom of the asphalt concrete surface layer and the bottom of the stabilized-fines layer. A positive cost differential demonstrates the utility of stabilized-quarry fines as a low-cost, alternative, subbase material.

TESTING PROCEDURES

The most widely used procedure for the standard, moisture-density relationship of soils and soil aggregates is the ASTM D 698-78 procedure (Ref. 29). It involves the use of a standard mold for 4-inch or 6-inch diameter specimens and is compacted using a 5.5 lb. rammer at a 12-inch drop. A modified, moisture-density relationship test also exists that involves compacting the molds using a 10-lb. rammer at an 18-inch drop.

The dry mix samples included portions of cement, sand and quarry-limestone fines. Proportioning by weight and assuming an estimated dry density value of 135 lb. /cu. ft, the portions were determined for the known volume (1/30 cu. ft) of a mold with a diameter of 4.0 inches and height of 4.5 inches. From the total weight quantity, additional weight was added to provide enough material when mixed and compacted.

Several batches of the varying dry-mix portions and water were prepared according to ASTM D 698-78. Once each sample was mixed and compacted, it was extracted from the mold using a hydraulic-extruder device, identified, wrapped in plastic and weighed before being placed in the constant temperature and humidity curing room. Batch 1 samples were compacted by hand using a hand-held, 5.5 lb. rammer, while Batches 2 and 3 were compacted using a mechanical 5.5 lb. rammer. All samples were cured for 7 or 14 days in a curing room at 72^{o} F and 100% relative humidity.

At the end of the appropriate curing period, the samples were tested for tensile or compression values. The first batch was tested in tension using the Indirect Tensile Test (Ref. 28). Batches 2 and 3 were tested in compression. The results from both tests used formulas (Ref. 28) to determine the elastic properties of the material.

MIXING AND TESTING

Three batches of concrete samples were cast using mixtures of limestone quarry fines and siliceous river sand. The siliceous river sand and limestone quarry fines had a Fineness moduli of 3.22 and 1.39 respectively (Table 6.5). For batches 1 and 2 the water cement ratio was held constant at 8% cement and 5% water. Sand content varied from 0 to 92%. The first sample in each batch was used as a controlled strength reference with 92% sand and 8% cement (no quarry fines). Samples containing 82% fines and 92% fines were very dry and difficult to compact, a decrease in workability was observed as the fines content in the samples increased.

For batch 3, quarry fines to cement ratio was held constant (95% and 5% cement) and water percentage varied from 6 to 12.5%. Batch 3 was tested only in compression. The compressive strength varied between 244 psi to 369 psi at 7-days curing with optimum compressive strength occurring at 7.5% water content. The workability varied significantly with increasing water content. The only problem with workability in Batch 3 occurred for the sample with 6% water due to the high percentage of fines (95%) and the lack of sufficient water-cement paste. The 6% mixture was very dry and difficult to compact as was the 82% fines to 5% water mixture of Batch 1.

The compression strength differences between batches 2 and 3 is attributed to the higher percentage of fines. The strength difference is attributed to an increasing water-cement ratio and the optimum moisture content of quarry-fines, which is around 7.5%.

The tensile modulus of elasticity was calculated according to Anagnos (Ref. 28), using load and strain values from the Indirect Tensile Test. The modulus was affected by the varying percentage of river sand. For the control (92% sand) sample the tensile modulus of elasticity was 82,000 psi. The tensile modulus increased to a maximum of 425,000 psi in the sample containing 50% sand, 42% quarry fines and 8% cement (Table 6.2). This significant increase is due to quarry fines filling in the voids between the sand particle structure causing a complex system with point to point, sand particle contact.

Modulus of elasticity of the other samples ranged from 69,000 psi to 176,000 psi, which is comparable to the tensile modulus of elasticity of the control sample. The optimum percentage of quarry fines in a sample would be evidenced by the highest tensile modulus of elasticity. A mixture of 42% quarry fines mixed with 50% sand had the highest tensile modulus (425,000 psi), and therefore this sample is the one considered for the stabilized quarry fines subbase application.

COMPUTATIONAL EXPERIMENT DESIGN*

An elastic layer theory program called BISAR (Bitumen Structure Analysis of Roadways), produced by the Shell Oil Company, was used to evaluate a stabilized quarry fines subbase. BISAR determines stress, strain and deflection in 3-dimensional directions (x, y, z) for a given loading application, at specified points within the layered pavement structure.

First, BISAR was used to determine the minimum asphalt concrete thickness which produces a strain less than the limiting, fatigue-controlled, interior-pavement horizontal-tensile strain due to a specific number of load applications (Yoder 30). Next, the program is used to determine the thickness of the AC base course layer, based on the controlling-fatigue strains shown in Table 6.7. The resulting asphalt concrete thicknesses layers, determined for surface and base course layers, are shown in Figure 1, and Table 6.7

Thickness of the equivalent stabilized quarry-fines layer needed to replace the asphalt concrete base layer was determined from BISAR in a similar manner (Figure 2, Table 6.6). The same AC surface layer used with the asphalt base layer was used in quarry fines pavement structure (Figure 2). The thickness and the significant basic properties (Modulus of Elasticity and Poisson's Ratio) of all other layers in the AC pavement structure, and the Quarry fines pavement structure remains constant.

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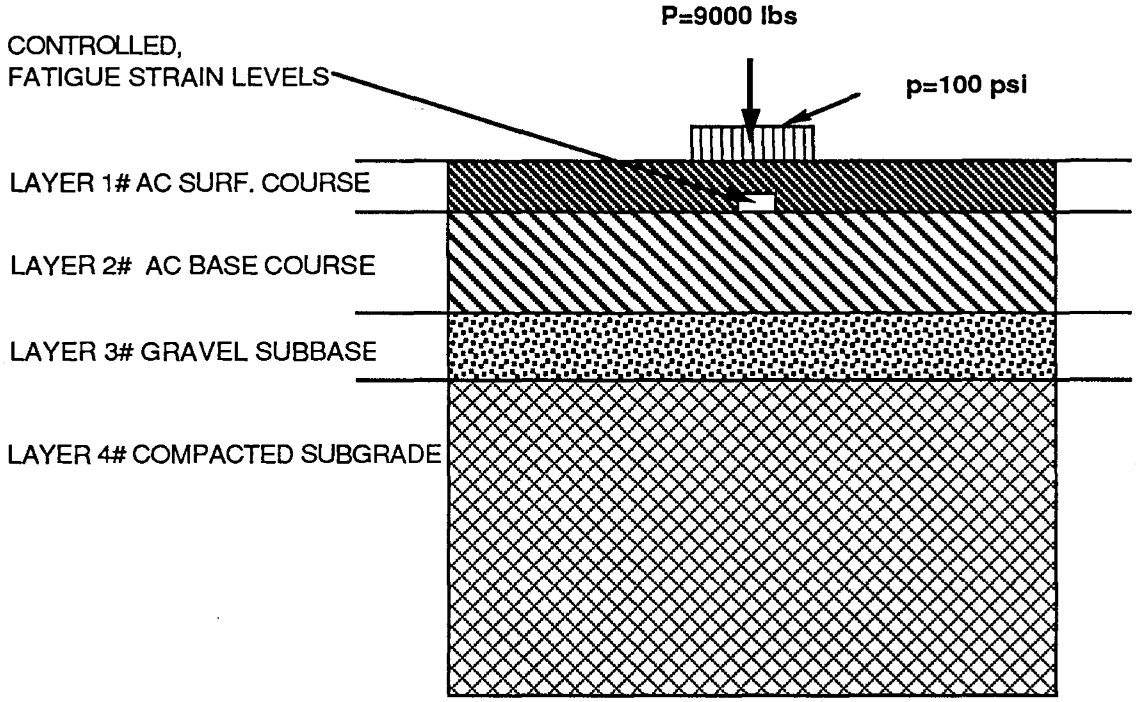
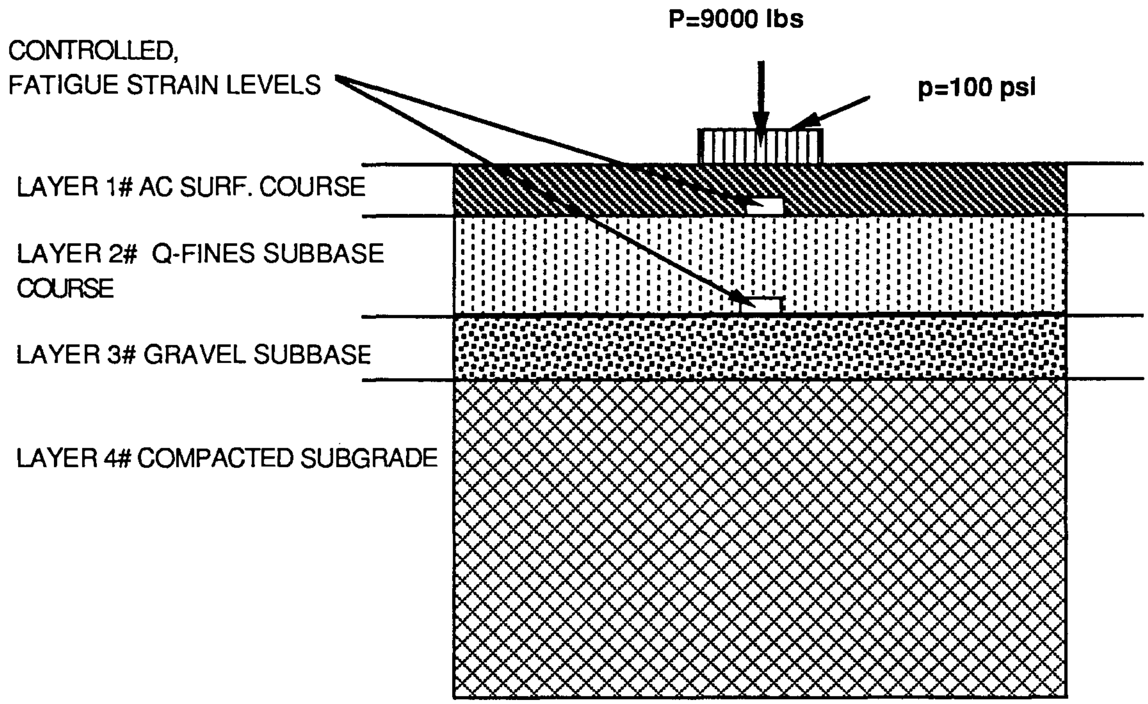
* This section was entirely done by Mr. Michael Jones, Graduate Research Assistant, The University of Texas at Austin. Mr. Jones worked with the Author on the topic of cement stabilized fines subbase to apply it towards one of his class projects (Ref 31). Please note that this design is just one of the numerous designs that may be used for a pavement structure. This simple design is treated here for a comparative cost analysis purpose, and it is very possible to design more economical pavement structures under the same stated conditions using the quarry fines base layer.



LAYER 1# :	**LAYER 2# :**	**LAYER 3#:**	**LAYER 4#:**
h1 = 1.5 in.	h2 = 2.5 in.	h3 = 4 in.	h4 = infinity
E1 = 700,000 psi	E2 = 350,000 psi	E3 = 20,000 psi	E4 = 5,000 psi
v = 0.35	v = 0.15:	v = 0.40	v = 0.40

Figure 1: Asphalt concrete pavement structure



LAYER 1# :	LAYER 2# :	LAYER 3#:	LAYER 4#:
h1 = 1.5 in.	h2 = 3.5 in.-5.5 in.	h3 = 4 in.	h4 = infinity
E1 = 700,000 psi	E2 = 429,960 psi	E3 = 20,000 psi	E4 = 5,000 psi
v = 0.35	v = 0.15:	v = 0.40	v = 0.40

Figure 2: Quarry fines pavement structure

DISCUSSION OF RESULTS

The results shown in Tables 6.6 and 6.7, compare the necessary base thickness for an asphalt concrete pavement structure versus a stabilized quarry-fines pavement structure. The stabilized quarry fines and sand mixture is referred to as a subbase material, but in the actual design it is analyzed as a base course layer. It is classified as a subbase material based upon a target compressive strength of greater than or equal to 600 psi in 7-days for a stabilized-base course material, according to Sharpe et. al, (Ref. 8). The material used in the study has a compressive strength of only 462 psi (Table 6.3). The compressive strengths from Batch 2 were comparable to Sharpe's recommended minimum 600 psi compressive strength value. The recommended tensile modulus of elasticity according to Sharpe et al., based on fatigue constraint is a minimum of 250,000 psi. The tensile modulus of elasticity of the samples from Batch 1 ranged from 69,000 psi to 425,000 psi (Table 6.2). Therefore, for the purpose of this study the cement-stabilized sand and limestone quarry-fines material is considered a subbase material.

The Portland Cement Association (Ref. 33), however, mentions that the typical ranges of compressive strength at 28 days for a wide variety of soil-cement desired for durability are 400-900 psi and a 28-day modulus of elasticity of 600,000 psi to 2,000,000 psi. Also, Sharpe et al., stated, from experience on a project which used a stabilized-subbase material in Kentucky, that a compressive strength of 300 psi in 7 days was achieved when cured according to ASTM C 593.

In the sample that provided the best results, the amount of limestone quarry fines equaled 42% by weight. This sample included 50% siliceous river sand, 8% cement and 5% water by weight, and was the only one analyzed for thickness determination based on controlling strains within the pavement structures. At the above mix proportions, the material characteristic properties were:

1) Tensile strength of 163 psi,

2) Tensile modulus of elasticity of 425,000 psi in 14 days, and

3) Compressive strength of 488 psi in 7 days.

These results compare to Sharpe's values, which recommend for low-strength (pozzolonic) base a flexural stress of 150 psi, a minimum compressive strength of 600 psi and a minimum modulus of elasticity of 250,000 psi in 7 days (Ref. 1).

The results shown in Tables 6.6 and 6.7 also illustrate that as the controlling strain criteria become more stringent, the required thickness increases. The required thickness for the stabilized, quarry-fines subbase layer is greater than twice the needed thickness of an asphalt concrete base layer. The stabilized material has a greater modulus but a smaller Poisson's ratio (Table 6.2).

COST EVALUATION

Even though a greater thickness of quarry fines subbase may be required for equal performance design, the significant difference between the cost of quarry fines per ton versus asphalt may make quarry fines a viable alternative. The cost difference between replacing a 2.5 inch asphalt concrete base layer with a 3.5 inch to 5.5 inch cement-stabilized, sand and limestone quarry-fines base layer provides a minimum cost savings of approximately $13/ton. The following data shows the estimated costs for each material.

Quarry fines subbase cost /ton in-place:

Estimated density of sample with 50% sand, 42% quarry fines and 8% cement = 1879 g/ 0.33 cft before curing. Hence the wet density in lbs/cft is :

$$\text{WET DENSITY} = \frac{1879\text{ g} \times 1\text{ Kg} \times 2.204\text{ lbs} \times 3.0}{1000\text{ g} \times 1\text{ Kg} \times 1\text{ cft.}} = 124.24\text{ lbs/cft}$$

$$\text{DRY DENSITY} = \frac{124.24\text{ lbs/ cft}}{1 + 0.05\ (= \text{placement water content})} = 118.32\text{ lbs/ cft}$$

$$\text{DRY WEIGHT} = \frac{1879\text{ g}}{1 + 0.05} = 1789.524\text{ g}$$

$$\text{VOLUME OF DRY MIX} = \frac{2000 \text{ lbs/ton}}{118.37 \text{ lbs/cft}} = 16.903 \text{ cft/ ton}$$

Per ton of dry mix, the volume of individual materials required are:

$$\text{CEMENT WEIGHT} = \frac{1789.524 \text{ g x 1 Kg x 2.204 lbs x 8\% x 16.903 cft}}{1000 \text{ g x 1 Kg x cft x ton}}$$

$$= 160.00 \text{ lbs / ton}$$

By the same reasoning,

SAND WEIGHT = 1000.00 lbs/ton

QUARRY FINES = 840.01 lbs/ton

TOTAL DRY WEIGHT = 160 + 1000 + 840 = 2000 lbs/ton (Check)

The costs of the above weights of materials per ton of dry mix of the cement stabilized fines mixture are:

CEMENT COSTS = 160 lbs/ton x $ 4.00 /bag* = $ 6.81 /ton (1 bag = 94 lbs)

SAND COSTS = 1000 lbs/ton x $ 7.82 / ton* = $ 3.91 /ton (1 ton = 2000 lbs)

QUARRY FINES COSTS = 840.01 lbs/ton x $ 4.35 / ton* = $1.83 /ton

PLACEMENT COSTS (Crew B-25 Means - on the conservative side) = $ 3.87

MIXING AND DELIVERY COSTS (20 miles) = $ 3.00

TOTAL COSTS = $ 20.00 /short ton (conservatively)

* Costs include appropriate delivery mileage and are obtained from manufacturer quotes

Asphalt base course cost/ton in-place:

From Means Heavy Construction Cost Data - 1990, Item number 025104.0813, interpolated thickness of 2.5" and including 25 miles delivery = $ 33.00 / ton

CONCLUSIONS

This preliminary study suggests that quarry fines can be used as an aggregate source, for low traffic conditions (175,000 to 850,000 ESAL).

1. An appropriate quarry fines - sand - cement mixture provided adequate compressive strength, modulus of elasticity and tensile strength required for subbase course materials. Based on the characteristics of the fine material and the parent rock type, the percentages of sand and cement to be added may vary.

2. Subbase material using quarry fines can be more economical than a comparable asphalt concrete layer for the equivalent load carrying capacity.

3. Referring to the Batch 3 testing results, at least one sample of each water-cement ratio, gave a compression strength value near 300 psi, which is the minimum required for the subbase course of a pavement. When using quarry fines, in the field, the water-cement ratio should be kept at or slightly below the optimum.

4. The fines - cement stabilized base course may be used under circumstances such as :

A. An acute shortage of regular sized construction aggregates in the area,

B. Low volume, low traffic road design with a very low budget attached to it,

C. The fines are economically transportable (100 mile radius) to the area and

D. No acceptable soil or gravel is found in the area for soil - lime - fly ash or cement stabilization, or is not economical to transport.

RECOMMENDATIONS

As already stated this was only a preliminary feasibility study. The following are recommendations to the crushed stone industry regarding the use of quarry fines in cement treated subbases:

1. It is necessary that cement stabilized quarry fines be tested for durability to further verify its validity as a base or subbase material. In this study, the stabilized, quarry fines was used as a base material without a preventive, intermediate, reflective cracking layer between the surface and base layers. Before use of stabilized quarry-fines as a base material, it must be determined whether it can perform under durability restraints of freeze-thaw, shrinkage, moisture, etc.

The problem of shrinkage is very important in the determination of amount of cracking that will occur in the material. That is, as the material shrinks, the friction force, provided by the contact-layer interface, restrains the movement of stabilized material, causing internal stress to accumulate. When the accumulated stress exceeds the tensile strength of material, cracking occurs in the stabilized material and eventually reflects up through the surface layer. The determination of the shrinkage (movement) amount is important in determining if a reflective-cracking layer is required. If an extra pavement layer to prevent reflective cracking to surface layer is required, the consequential cost increase should also be accounted for in the cost comparison study. The durability restraints may increase the cost significantly to a point that stabilized quarry-fines cannot be used as a replacement for asphalt concrete base in a low-volume pavement structure.

2. The performance criteria of the fines base course also needs to be studied in detail.

3. Conducting a demonstration project study may prove to be worthwhile. Especially,

   a. Limestone fines from different areas can be studied and appropriate design tables may be designed and tested in the field.

   b. Other types of fines such as granitic or trap rock fines with very little or no plasticity may also be considered.

c. A cement stabilized quarry fines road may also be studied under favorable conditions, in a private low traffic situation. If proper drainage and adequate surface conditions are provided, it may prove to be an economical and efficient pavement system.

INDIRECT TENSILE STRENGTH AT 14-DAYS						
BATCH 1						
DATE MOLDED: 3/31/92						
DATE TESTED: 4/14/92						
SPECIMEN IDENTIFICATION	1B	2	3	4	5B	6
QUARRY FINES(%)	0	42	52	62	72	82
SILICEOUS RIVER SAND (%)	92	50	40	30	20	10
PORTLAND CEMENT (%)	8	8	8	8	8	8
TENSILE STRENGTH (PSI)	67.65	162.68	153.02	126.67	101.72	104.22
CALCULATED POISSON'S RATIO,v	-0.06	0.06	1.25	1.91	0.14	0.20
ASSUMED POISSON'S RATIO,v	0.25	0.15	0.15	0.15	0.15	0.15
MODULUS OF ELASTICITY, E(tensile) (PSI)	81,653	424,960	102,486	69,277	132,918	176,936
HORZ. STRAIN AT FAILURE (IN./IN.)	1.43E-03	7.04E-04	1.35E-03	1.52E-03	6.50E-04	4.88E-04

Table 6.2. Indirect tensile test results

UNCONFINED COMPRESSION STRENGTH AT 7-DAYS

BATCH 2

DATE MOLDED: 4/9/92

DATE TESTED: 4/17/92

SPECIMEN IDENTIFICATION	I	II	III	IV	V	VI	2F
QUARRY FINES(%)	0	42	52	62	72	82	92
SILICEOUS RIVER SAND (%)	92	50	40	30	20	10	0
PORTLAND CEMENT (%)	8	8	8	8	8	8	8
WATER (%)	5	5	5	5	5	5	5
COMPRESSION LOAD (LBS)	5740	5800	8650	7200	7000	5830	4220
COMPRESSION STRENGTH (PSI)	457	462	688	573	557	464	336

NOTE: REMOVING SULFUR-CAPPED SPECIMENS FROM MOLD CAUSED SPLITTING OF THE SPECIMEN AT THE TOP OR BOTTOM SURFACE.

Table 6.3. Unconfined Compression test results

UNCONFINED COMPRESSION STRENGTH 7-DAY										
BATCH 3										
DATE MOLDED: 4/23/92										
DATE TESTED: 4/30/92										
SPECIMEN IDENTIFICATION	F1A	F1B	F2A	F2B	F3A	F3B	F4A	F4B	F5A	F5B
QUARRY FINES(%)	95	95	95	95	95	95	95	95	95	95
PORTLAND CEMENT (%)	5	5	5	5	5	5	5	5	5	5
WATER (%)	6	6	7.5	7.5	9	9	10.5	11	12.5	12.5
COMPRESSION LOAD (LBS)	3440	4200	4640	5340	3680	3060	3960	3540	3780	3160
COMPRESSION STRENGTH (PSI)	274 SULFUR CAPPED 1@	334 SULFUR CAPPED 1@	369	425	293	244	315	282	301	251

1@NOTE: SPECIMEN TOP OR BOTTOM SURFACE SPLIT WHEN TRYING TO REMOVE SULFUR-CAPPED SPECIMEN FROM MOLD

Table 6.4. Unconfined compression test results (batch 3)

SILICEOUS RIVER SAND

SIEVE SIZE	WEIGHT RETAINED (g)	AMOUNT RETAINED (wt. %)	CUMULATIVE AMOUNT RETAINED (%)	CUMULATIVE AMOUNT PASSING (%)
4	0	0	0	100
10	85	0.17	17	83
20	158	0.316	48.6	51.4
40	116	0.232	71.8	28.2
60	84	0.168	88.6	11.4
100	37	0.074	96	4
SAMPLE WT.=	500 g			
FINENESS MODULUS =	**3.22**			

QUARRY FINES-No. 100 GRADATION CLASSIFICATION

SIEVE SIZE	WEIGHT RETAINED (g)	AMOUNT RETAINED (wt. %)	CUMULATIVE AMOUNT RETAINED (%)	CUMULATIVE AMOUNT PASSING (%)
4	0	0	0	100
10	0	0	0	100
20	2	0.004	0.4	99.6
40	42	0.084	8.8	91.2
60	221	0.442	53	47
100	119	0.238	76.8	23.2
SAMPLE WT.=	500 g			
FINENESS MODULUS =	**1.39**			

Table 6.5. Fineness moduli for siliceous river sand and quarry fines

ASPHALT CONCRETE BASE COURSE THICKNESS RESULTS			
TRAFFIC (18-KIP ESAL)	HIGH 850,000	MEDIUM 500,000	LOW 175,000
AC SURFACE MODULUS OF ELASTICITY, E1 (PSI)	700,000	700,000	700,000
E1/E2 RATIO	2	2	2
LIMITING FATIGUE TENSILE STRAIN AT BOTTOM OF AC SURFACE COURSE (IN./IN.)	1.10E-04	1.40E-04	2.90E-04
BISAR PREDICTED STRAIN (COMPRESSION) AT BOTTOM OF AC SURFACE COURSE (IN./IN.)	-1.28E-04	-1.28E-04	-1.28E-04
AC SURFACE COURSE THICKNESS (IN.)	1.5	1.5	1.5
AC BASE COURSE THICKNESS (IN.)	2.5	2.5	2.5

Table 6.6. Asphalt Concrete base course thickness results

STABILIZED QUARRY FINES SUBBASE COURSE THICKNESS RESULTS			
TRAFFIC (18-KIP ESAL)	HIGH 850,000	MEDIUM 500,000	LOW 175,000
AC SURFACE MODULUS OF ELASTICITY, E1 (PSI)	700,000	700,000	700,000
LIMITING TENSILE STRAIN AT BOTTOM OF AC SURFACE COURSE (IN./IN.)	1.10E-04	1.40E-04	2.90E-04
AC SURFACE COURSE THICKNESS (IN.)	1.5	1.5	1.5
LIMITING FATIGUE TENSILE STRAIN AT BOTTOM OF STABILIZED QUARRY FINES SUBBASE COURSE (IN./IN.)	2.90E-04	4.00E-04	4.50E-04
BISAR PREDICTED TENSILE STRAIN AT BOTTOM OF STABILIZED QUARRY FINES SUBBASE COURSE (IN./IN.)	2.70E-04	3.68E-04	4.12E-04
STABILIZED QUARRY FINES SUBBASE COURSE THICKNESS (IN.)	5.50	4.00	3.50

Table 6.7. Stabilized quarry fines subbase thickness results

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Crushed stone industry faces increasing difficulty day-by-day in marketing fine aggregates with more than 10% passing No. 200 sieve. Twenty one companies participating in a quarry fines survey, which is a part of this study, reported about 22.5 million tons of fines stockpiled in their sites. On average, this accounts for about 13% of their total annual aggregate production. However, individual companies estimated stockpiling (Over Years) of 0% to 96% of their total annual aggregate production as quarry fines. Also companies reported about 6.5 million tons of fine aggregates unsold every year. On average, this amounts to about 3.7% of their total annual aggregate production. This study confirms that the industry faces a great difficulty in marketing quarry fines and, to a certain extent, the marketing of fine aggregates. Most companies reported difficulty in marketing fine aggregates with a high percentage of No. 200 fines.

Grain size tests conducted on 24 fines samples, sent by survey participants, indicated percentages varying from 2% to 95% passing No. 200 sieve. Based on the percentage passing No. 200 sieve, quarry fines were divided into six categories . An optimum use of quarry fines in any category would take advantage of their fineness while minimizing the disadvantages due to their high water content. To assist the crushed stone industry, this report presents the uses of quarry fines in three views:

1) Possible uses of quarry fines from literature review.

The uses of quarry fines in construction works and other miscellaneous applications are discussed briefly in this report.

2) Present uses of quarry fines.

Quarry fines are currently used for :

i) asphalt related applications such as slurry seal aggregate and mineral filler,

ii) agricultural industry as aglime, fertilizer filler, and livestock feed,

iii) environmental applications in control of SO_2 emissions, pond and watershed liming, acid mine drainage abatement, and landfill layer, and

iv) miscellaneous applications such as industrial fillers, paint industry etc.

About 36 million tons of quarry fines are cuurently used in these applications. The uses of fines could be increased by at least 25% if economical drying methods are found and if a vigorous fines marketing strategy is followed. These uses are discussed in detail in Chapter IV of this report.

3) Proposed engineering and environmental uses of quarry fines.

There is potential for using quarry fines in several engineering and environmental applications given below:

i) ready mixed flowable fill,

ii) sandbags,

iii) solid waste landfills,

iv) sandfilling applications,

v) low cost masonry uses,

vi) cement treated quarry fines subbase, and

vii) subsurface sewage disposal systems.

The potentially highest volume uses are in the applications of cement treated quarry fines for subbase layers and ready mixed flowable fill, followed by miscellaneous sand applications, solid waste landfills, subsurface sewage disposal systems, low cost masonry applications and sandbags. A conservative estimate of 2-3 million tons of quarry fines could be used in these applications per year. Since transportation costs account for about five times the basic material cost for a distance of 50-100 miles, the main consideration in use of quarry fines in these applications would be the location of quarries to the job site.

The preliminary study of the use of quarry fines in flowable fill and in cement treated pavement subbases suggests that quarry fines could be economically used in these two applications. From this preliminary study it can be concluded that when performance criteria rather than material specifications are considered, applications using quarry fines could emerge as alternatives to conventional methods and may be technically acceptable and economically advantageous.

RECOMMENDATIONS

Of all the promising engineering and environmental applications recommended in this report, the use of quarry fines in ready mixed flowable fill and cement stabilized subbase looks most promising. It is recommended that study of use of quarry fines in these two applications be further expanded to conducting project demonstration studies.

There is no single use applicable to all types of quarry fines produced nationwide. Therefore, it is recommended that uses of quarry fines mentioned in this report be used as guidelines by the crushed stone industry in developing new products. It is the responsibility of crushed stone manufacturers to evaluate their own by-product for a specific end use. The considerations in this regard should be:

1) Characteristics of quarry fines available,

2) Amount of quarry fines available for the particular use,

3) Location of quarry with respect to markets, and

4) Market demand of the product.

FURTHER STUDY

Additional research is also needed in the following areas:

1) A detailed and complete study, involving all the crushed stone manufacturers in the U.S., should be conducted to study all the types and quantitives of quarry fines produced and their quantities. This study should be as detailed as the study conducted by the Bureau of Mines on crushed stone production. The result of such a study would define the exact amount of quarry fines present industry wide and would further justify research on a broad scale to seek potential uses for quarry fines.

2) Investigations should be conducted to further explore the potential uses suggested in this report. Research on potential uses suggested in this report and also other potential uses, if any, should be followed up by independent demonstration project studies. Demonstration project studies are imperative to convince agencies such as ASTM, AASHTO etc., for inclusion of specifications on applications using quarry fines.

3) The industry should conduct research on finding the most economical means of drying quarry fines. It appears that the product may be more salable when it is completely dried.

3) The industry should continue to create an awareness in the society of engineers, architects, designers and contractors that quarry fines are available at low cost and may very well serve their requirements either as a primary or alternative product. Such an awareness may trigger innovative design approaches using quarry fines, based on performance criteria. Large scale uses of quarry fines would not only generate additional revenue for the industry but would also ensure disposal of quarry fines in an environmentally friendly way.

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APPENDIX

LIST OF COMPANIES PARTICIPATING IN THE SURVEY

1. Captiol Aggregates, Inc.,
   1001 Ed Bluestein Blvd.,
   Austin, TX 7876

2. Chico Crushed Stone,
   P. O. Box 324
   Dallas, TX 75221

3. Martin Marietta Aggregates,*
   11197 Aurora Avenue
   Des Moines, IA 50322

4. L. R. Falk Construction Co.,
   Box 189
   St. Ansgor, IA 50472

5. Bruening Rock Products, Inc.,
   325 Washington Street, Box 127
   Decorah, IA 52101

6. Pete Lien and Sons, Inc.,
   Box 440
   Rapid City, SD 57709

7. Genstar Stone Products Co.,
   11350 McCormick Road
   Hunt Valley, MD 21031

8. MeshBerger Brothers Stone Corp.,
   P. O. Box 345
   Bekne, IN 47371

9. National Lime and Stone,
   337 S. Main,
   Findlay, OH 45840

10. P. J. Keating Co.
    998 Reservoir Road
    Lunenburg, MA 01462

11. Wyandot Dolomite, Inc.,*
    P. O. Box 16
    Carey, OH 433

12. Vulcan Materials Co.,*
    P.O. Box 698
    South Boston, VA 24592

13. Dolese Bros. Co., *
    13 N.W.... 13th
    Oklahoma City, OK 73120

14. Balf Co.,*
    301 Hartford Ave.
    Newington, CT 06874

15. Beck Materials Co.,
    822 W. Stadium Blvd.,
    Jefferson City, MD 65109

16. Martin Marietta Aggregates,
    2710 Wycliff Road
    Raleigh, NC 27607

17. Rinker Materials Corp.,
    1501 Belvedere Road
    West Palm Beach, FL 33406

18. W.W. Boxley, Co.,
    416 S. Jefferson Street
    Roanoke, VA 24011

19. Bayer Const. Co., Inc.,
    120 Deep Creek Road
    Manhattan, KS 66502

20. Luck Stone Corporation
    P.O. Box 29682
    Richmond, VA 23229

21. Roverud Const. Co.,
    601 Hwy. 44 East, Box 606
    Spring Grove, MN 55974

22. American Limeston Co.,#1
    P. O. Box 2389
    Knoxville, TN 37901

Note: Indicates companies which had participated in the questionnnaire study and had also sent quarry fines samples for the study.

*1 Company participated by sending samples alone.

CRITERIA USED TO SELECT COMPANIES FOR SURVEY

1. Questionnaires were sent to all NSA directory listed quarries in the state of Texas - addressed to plant superintendents.
2. Outside the State of Texas, questionnaires were sent only to those companies that had some quarries listed under their name. If only one quarry was listed the questionnaire was sent to the plant Supd.t and if more than one quarry was listed questionnaires were sent to appropriate contact persons within the state division of the company. A request was made to them to include as many quarries as possible in their reply and also to use one questionnaire per aggregate type.
3. Research on quarry fines is also done by researchers at Southern Illinois University at Carbondale, sponsored by the National Stone Association. To avoid duplication of effort questionnaires were not sent to quarries in Illinois and Georgia.
4. No more than four questionnaires were sent to each state other than Texas.

NOTE SENT WITH QUESTIONNAIRE

PLEASE....

1. Include in your completed questionnaire data from as many quarry operations as possible that are <u>under your jurisdiction</u>. Indicate in question III the number of quarries that you have considered.
2. Use one questionnaire per type of aggregate. (e.g.: one per granitic type, one per limestone type etc.)
3. For questions V to X the approximate average values/quantities (per quarry) will suffice. We will calculate the total values/quantities.

COVER LETTER SENT ALONG WITH QUESTIONNAIRE

DATE: March 10, 1992

Mr. FINE,
Vice President,
Crushed Stone Products,
S410, IH-35 North,
Austin, Texas 78278

Dear Mr. Fine,

We need your help with a research project which may be important to you.

We are working with the National Stone Association as part of an effort to find potential markets for screening fines produced by stone crushing operations. Our first step is to conduct a survey to establish the magnitude of the problem and its source. Hence, the attached questionnaire has been developed to gather basic data.

We know your time is valuable but we hope you can take a few minutes to complete the questionnaire and return it to us at your earliest convenience. The information you send will help us in our efforts to find a market for a material that is a costly by-product of some crushing operations.

Any suggestions or comments you may have will also be helpful in addition to the questionnaire.

Thank you for your early reply. If you have any questions please call Dr. German Claros or Mr. Senthil Doraiswamy at 512-471-7741. Our fax number is 512-471-0592

Sincerely,

Dr. W. Ronald Hudson
The Dewitt C. Greer Centennial Professor

QUESTIONNAIRE FOR THE AGGREGATE INDUSTRY
FINES MARKET STUDY

SPONSORED BY:

NATIONAL STONE ASSOCIATION

STUDY CONDUCTED BY:

UNIVERSITY OF TEXAS AT AUSTIN

I. The name and head office address of your company. (Did we address you Correctly ?)

____
Name of your company

____
Street address

____
City State zipcode

____
Telephone

____

II. Please give the name of the person we can contact for future clarifications:

NAME: ______________________ TITLE: ______________________

TEL: ______________________

III. What is/(are) the location(s) of your pit(s) or operation(s) ?

	CITY	COUNTY	STATE	ZIPCODE
1.				
2.				
3.				

IV.1. What type of aggregate production do you run ? (circle the appropriate product)

a. LIME STONE b. DOLOMITE c. GRANITE d. SANDSTONE

e. QUARTZITE f. MARBLE g. TRAPROCK

h. Other (please explain) ______________________

2. What are your market areas ?

(ex: South Western Texas, Texas and Eastern Louisiana, New York and New Jersey etc.)

____

Thanks for your cooperation

V. What is your plant's approximate annual production ?(please mark with a ✓ mark)

a. ________<500,000 short tons
b. ________ 500,000 - 1,000,000 short tons
c. ________ 1 to 1.5 million tons
d. ________ 1.5 to 2.5 million tons
e. ________ 2.5 to 3.5 million tons
f. ________ 3.5 to 4.5 million tons
g. ________ 4.5 to 6 million short tons
h. ________ 6 to 8 million short tons
i. ________ 8 to 10 million short tons
j. ________ > 10 million tons

VI. Approximately what percentage of your aggregates produced (per year) are dry 3/8 inch or lesser size?

approximate __________% approximate _____________ tons

VII. How many tons of the 3/8 inch and lesser sized products do you market on an average per year ?

________________ tons

VIII. what are the sizes and approximate annual quantities of the very fine products you find difficult to market ?

Size:	No.4 - No 20 mesh product	approximate________tons
Size:	No.20 - No.100 mesh product	approximate________tons
Size:	No 100 - No.200 mesh product	approximate________tons
Size:	< No.200 mesh product	approximate________tons
Other sizes:	____________product	approximate________tons

IX. What is the approximate plasticity index of the above materials ?
Plasticity :_______________

X. What are the current markets for the following sized products. (Disregard the sizes you don't produce or seperate) **MARKETS** (mention briefly)

Size:	No.4 - No 20 mesh product	________________________
Size:	No.20 - No.100 mesh product	________________________
Size:	No 100 - No.200 mesh product	________________________
Size:	< No.200 mesh product	________________________

Other ____

Thanks for your cooperation

XI. Approximately how many total tons of the above fines products have you stockpiled at your sites ? (i.e total tonnage accumulated over the years)

____________________ tons

XII. What kind of shipping facilities do you have ?

A - TRUCK_______

B - RAIL ________

C - BARGE _________

D - OTHER ___________ (Please specify)

XIII. Would you be willing to supply us with some of the following :

1. Sieve analysis of your fines material ?

☐ YES ☐ NO

2. Typical chemical analysis for your fines or fine aggregates ?

☐ YES ☐ NO

(We would keep the information confidential if you so desire).

CONFIDENTIAL : ☐ YES ☐ NO

3. A 1 to 5 lb sample of an identified fine aggregate product ? (If YES please have it sent to us by U.P.S)

☐ YES ☐ NO

4. A typical 5 gallon sample of the waste fines from your tailings or operations? (If YES please have it sent to us by U.P.S)

☐ YES ☐ NO

Please send completed questionnaires to:
Senthil Doraiswamy,
University of Texas at Austin,
ECJ 6.10,
San Jacinto and E 26,
Austin, TX- 78712.

Thanks for your cooperation

FINES QUESTIONNAIRE- RESPONSES SUMMARY

A	B	C	D	E	F	G	H	I
1	1	1,250,000	500,000	40.00%	200,000	400,000	T	L,S,Q
2	1	3,000,000	120,000	4.00%	15,000	100,000	T,R	L
3	3	3,750,000	562,500	15.00%	1,000,000	525,000	T,R	L
4	3	1,500,000	300,000	20.00%	150,000	180,000	T	L,D
5	3	6,000,000	N.A	N.A	100,000	N.A	T	L,D
6	3	6,000,000	900,000	15.00%	0	900,000	T,R	L
7A	1	5,250,000	1,260,000	24.00%	400,000	1,100,000	T,R	L
7B	1	3,000,000	600,000	20.00%	400,000	500,000	T,R	M
7C	1	1,250,000	225,000	18.00%	200,000	100,000	T	T
8	3	1,500,000	120,000	4.00%	100,000	108,000	T,R	D
9	7	10,750,000	3,000,000	N.A	1,400,000	2,700,000	T,R	L,D
10	2	2,500,000	1,125,000	45.00%	750,000	440,000	T,R	T
11	1	1,250,000	312,500	25.00%	1,200,000	150,000	T,R	D
12	10	10,000,000	2,500,000	25.00%	300,000	2,000,000	T,R	G,T
13	3	4,750,000	712,500	15.00%	1,500,000	500,000	T,R	L,S
14	1	1,250,000	287,500	23.00%	58,000	172,629	T	T
15	2	1,000,000	250,000	25.00%	250,000	100,000	T	L,D
16	40	30,000,000	7,000,000	18.00%	7,000,000	6,500,000	N.A	L,D,G,Q
17	2	18,000,000	11,096,000	N.A	3,000,000	9,896,000	T,R	L
18A	1	300,000	60,000	20.00%	N.A	20,000	T	BASALT
18B	1	500,000	50,000	10.00%	N.A	30,000	T	APLITE
18C	1	750,000	112,500	15.00%	70,000	30,000	T	G
18D	1	500,000	165,000	33.00%	N.A	100,000	T	Q
18E	1	750,000	150,000	20.00%	150,000	100,000	T,R	L
18F	1	500,000	100,000	20.00%	150,000	100,000	T,R	L
18G	1	1,250,000	250,000	20.00%	150,000	100,000	T,R	L
19	4	3,000,000	450,000	15.00%	180,000	90,000	T	L
20A	1	500,000	50,000	10.00%	2,700	46,000	T	L
20B	1	500,000	80,000	16.00%	22,800	36,300	T	T
20C	1	1,250,000	212,500	17.00%	96,100	32,300	T,R	G
20D	1	750,000	75,000	10.00%	45,000	32,000	T	G
20E	1	500,000	50,000	10.00%	20,600	37,600	T	G
20F	1	750,000	127,500	17.00%	6,500	76,000	T	G
20G	1	2,000,000	200,000	10.00%	60,000	200,000	T	T
20H	1	750,000	90,000	12.00%	48,200	14,000	T	G
20I	1	1,250,000	125,000	10.00%	10,000	46,600	T	G
20J	1	2,000,000	240,000	12.00%	29,600	139,200	T	T
20K	1	500,000	65,000	13.00%	235,600	16,000	T	D
20L	1	750,000	97,500	13.00%	42,500	42,200	T,R	METABASALT
21	60	45,000,000	2,880,000	8.00%	3,000,000	2,400,000	T	L,D
		176,050,000	36,501,000		22,342,600	30,059,829		

A - ID no. of company participating
B- No.of quarries represented in the survey by the participating company .
C- Total Annual Aggregate production (In Tons)
D- Annual production of 3/8" and smaller size aggregates (In Tons)
E- Annual production of 3/8" and smaller size aggregates expressed as a % of annual aggregate prodn.
F- Quarry fines, accumulated and stockpiled over years (In Tons)
G- Quantities of 3/8" and smaller size aggregates annually marketed (In Tons)
H- Shipping facilities - T-truck, R-rail, O-other
I- Type of aggregate produced : L-limestone, D-dolomite,S-sandstone,Q- quartzite,
G-granite, T-traprock, M- marble
Please note N.A -Data Not Available

FINES QUESTIONNAIRE - ANALYSIS SUMMARY

A	B	C	D	E	F	G	H	I
1	1	1,250,000	500,000	200,000	400,000	40.00%	8.00%	16.00%
2	1	3,000,000	120,000	15,000	100,000	4.00%	0.67%	0.50%
3	3	3,750,000	562,500	1,000,000	525,000	15.00%	1.00%	26.67%
4	3	1,500,000	300,000	150,000	180,000	20.00%	8.00%	10.00%
5	3	6,000,000	N.A	100,000	N.A	N.A	N.A	1.67%
6	3	6,000,000	900,000	0	900,000	15.00%	0.00%	0.00%
7A	1	5,250,000	1,260,000	400,000	1,100,000	24.00%	3.05%	7.62%
7B	1	3,000,000	600,000	400,000	500,000	20.00%	3.33%	13.33%
7C	1	1,250,000	225,000	200,000	100,000	18.00%	10.00%	16.00%
8	3	1,500,000	120,000	100,000	108,000	8.00%	0.80%	6.67%
9	7	10,750,000	3,000,000	1,400,000	2,700,000	27.91%	2.79%	13.02%
10	2	2,500,000	1,125,000	750,000	440,000	45.00%	27.40%	30.00%
11	1	1,250,000	312,500	1,200,000	150,000	25.00%	13.00%	96.00%
12	10	10,000,000	2,500,000	300,000	2,000,000	25.00%	5.00%	3.00%
13	3	4,750,000	712,500	1,500,000	500,000	15.00%	4.47%	31.58%
14	1	1,250,000	287,500	58,000	172,629	23.00%	9.19%	4.64%
15	2	1,000,000	250,000	250,000	100,000	25.00%	15.00%	25.00%
16	1	30,000,000	7,000,000	7,000,000	6,500,000	23.33%	1.67%	23.33%
17	2	18,000,000	11,096,000	3,000,000	9,896,000	61.64%	6.67%	16.67%
18A	1	300,000	60,000	minimal	20,000	20.00%	13.33%	0.00%
18B	1	500,000	50,000	minimal	30,000	10.00%	4.00%	0.00%
18C	1	750,000	112,500	70,000	30,000	15.00%	11.00%	9.33%
18D	1	500,000	165,000	minimal	100,000	33.00%	13.00%	0.00%
18E	1	750,000	150,000	150,000	100,000	20.00%	6.67%	20.00%
18F	1	500,000	100,000	150,000	100,000	20.00%	0.00%	30.00%
18G	1	1,250,000	250,000	150,000	100,000	20.00%	12.00%	12.00%
19	4	3,000,000	450,000	180,000	90,000	15.00%	12.00%	6.00%
20A	1	500,000	50,000	2,700	46,000	10.00%	0.80%	0.54%
20B	1	500,000	80,000	22,800	36,300	16.00%	8.74%	4.56%
20C	1	1,250,000	212,500	96,100	32,300	17.00%	14.42%	7.69%
20D	1	750,000	75,000	45,000	32,000	10.00%	5.73%	6.00%
20E	1	500,000	50,000	20,600	37,600	10.00%	2.48%	4.12%
20F	1	750,000	127,500	6,500	76,000	17.00%	6.87%	0.87%
20G	1	2,000,000	200,000	60,000	200,000	10.00%	0.00%	3.00%
20H	1	750,000	90,000	48,200	14,000	12.00%	10.13%	6.43%
20I	1	1,250,000	125,000	10,000	46,600	10.00%	6.27%	0.80%
20J	1	2,000,000	240,000	29,600	139,200	12.00%	5.04%	1.48%
20K	1	500,000	65,000	235,600	16,000	13.00%	9.80%	47.12%
20L	1	750,000	97,500	42,500	42,200	13.00%	7.37%	5.67%
21	60	45,000,000	2,880,000	3,000,000	2,400,000	6.40%	1.07%	6.67%
		176,050,000	36,501,000	22,342,600	30,059,829	20.73%	3.66%	12.69%

A - ID no. of company participating
B- No.of quarries represented in the survey by the participating company .
C- Total Annual Aggregate production (In Tons)
D- Annual production of 3/8" and lesser size aggregates (In Tons)
E- Quarry fines, accumulated and stockpiled over years (In Tons)
F- Quantities of 3/8" and lesser size aggregates annually marketed (In Tons)
G- Annual production of 3/8" and lesser size aggregates, expressed as a % of total annual agg. prodn.
H- 3/8" and lesser size agg. NOT marketed each year, expressed as a % of total annual agg. prodn.
I- Quarry fines, accumulated and stockpiled over years, expressed as a % of total annual agg. prodn.
Please note N.A -Data Not Available

ANNUAL AGGREGATE PRODUCTION BY AGG. TYPE AND COMPANY ID (In Tons)

COMPANY ID	LIMESTONE	DOLOMITE	GRANITE	TRAPROCK	OTHER
1	416,667				833,333
2	3,000,000				
3	3,750,000				
4	750,000	750,000			
5	3,000,000	3,000,000			
6	6,000,000				
7A	5,250,000				
7B					3,000,000
7C				1,250,000	
8		1,500,000			
9	5,375,000	5,375,000			
10				2,500,000	
11		1,250,000			
12			5,000,000	5,000,000	
13	2,375,000				2,375,000
14				1,250,000	
15	500,000	500,000			
16	12,500,000	7,500,000	7,500,000		2,500,000
17	18,000,000				
18A					300,000
18B					500,000
18C			750,000		
18D					500,000
18E	750,000				
18F	500,000				
18G	1,250,000				
19	3,000,000				
20A	500,000				
20B				500,000	
20C			1,250,000		
20D			750,000		
20E			500,000		
20F			750,000		
20G				2,000,000	
20H			750,000		
20I			1,250,000		
20J				2,000,000	
20K		500,000			
20L					750,000
21	22,500,000	22,500,000			
TOTAL	**89,416,667**	**42,875,000**	**18,500,000**	**14,500,000**	**10,758,333**

OTHER - Sandstone, quartzite, marble, basalt, aplite, metabasalt

ANNUAL 3/8" AND LESSER SIZE AGG. PRODUCTION BY AGG. TYPE (In Tons)

COMPANY ID	LIMESTONE	DOLOMITE	GRANITE	TRAPROCK	OTHER
1	166,667				333,333
2	120,000				
3	562,500				
4	150,000	150,000			
5	N.A	N.A			
6	900,000				
7A	1,260,000				
7B					600,000
7C				225,000	
8		120,000			
9	1,500,000	1,500,000			
10				1,125,000	
11		312,500			
12			1,250,000	1,250,000	
13	356,250				356,250
14				287,500	
15	125,000	125,000			
16	3,000,000	1,750,000	1,750,000		500,000
17	11,096,000				
18A					60,000
18B					50,000
18C			112,500		
18D					165,000
18E	150,000				
18F	100,000				
18G	250,000				
19	450,000				
20A	50,000				
20B				80,000	
20C			212,500		
20D			75,000		
20E			50,000		
20F			127,500		
20G				200,000	
20H			90,000		
20I			125,000		
20J				240,000	
20K	#NUM!	65,000			
20L	#NUM!				97,500
21	1,440,000	1,440,000			
	#NUM!				
TOTAL	**21,676,417**	**5,462,500**	**3,792,500**	**3,407,500**	**2,162,083**

OTHER - Sandstone, quartzite, marble, basalt, aplite, metabasalt

3/8" AND SMALLER SIZE AGGREGATES PRODUCED BUT NOT MARKETED PER YEAR
(In Tons)

COMPANY ID	LIMESTONE	DOLOMITE	GRANITE	TRAPROCK	OTHER
1	33,333				66,667
2	20,000				
3	37,500				
4	60,000	60,000			
5	N.A	N.A			
6	0				
7A	160,000				
7B					100,000
7C				125,000	
8		12,000			
9	150,000	150,000			
10				685,000	
11		162,500			
12			250,000	250,000	
13	106,250				106,250
14				114,871	
15	75,000	75,000			
16	208,500	125,000	125,000		41,500
17	1,200,000				
18A					40,000
18B					20,000
18C			82,500		
18D					65,000
18E	50,000				
18F	0				
18G	150,000				
19	360,000				
20A	4,000				
20B				43,700	
20C			180,200		
20D			43,000		
20E			12,400		
20F			51,500		
20G				0	
20H			76,000		
20I			78,400		
20J				100,800	
20K		49,000			
20L					55,300
21	240,000	240,000			
TOTAL	**2,854,583**	**873,500**	**899,000**	**1,319,371**	**494,717**

OTHER - Sandstone, quartzite, marble, basalt, aplite, metabasalt

QUARRY FINES ACCUMULATED OVER YEARS AND STOCKPILED AT QUARRY SITES
(In Tons)

COMPANY ID	LIMESTONE	DOLOMITE	GRANITE	TRAPROCK	OTHER
1	66,667				133,333
2	15,000				
3	1,000,000				
4	75,000	75,000			
5	50,000	50,000			
6	0				
7A	400,000				
7B					400,000
7C				200,000	
8		100,000			
9	700,000	700,000			
10				750,000	
11		1,200,000			
12			150,000	150,000	
13	750,000				750,000
14				58,000	
15	125,000	125,000			
16	2,916,550	1,750,000	1,750,000		583,328
17	3,000,000				
18A					N.A
18B					N.A
18C			70,000		
18D					N.A
18E	150,000				
18F	150,000				
18G	150,000				
19	180,000				
20A	2,700				
20B				22,800	
20C			96,100		
20D			45,000		
20E			20,600		
20F			6,500		
20G				60,000	
20H			48,200		
20I			10,000		
20J				29,600	
20K		235,600			
20L					42,500
21	1,500,000	1,500,000			
TOTAL	**11,230,917**	**5,735,600**	**2,196,400**	**1,270,400**	**1,909,161**

OTHER - Sandstone, quartzite, marble, basalt, aplite, metabasalt