MICHIGAN
STATE HIGHWAY DEPARTMENT
G. Donald Kennedy
State Highway Commissioner

# A REPORT ON MANUFACTURED STONE SAND AND ITS USE IN CONCRETE MIXTURES

By

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Research Project 39 B-11 (6)

Research Laboratory
Testing and Research Division
Report No. 15
May 15, 1941

# LIMESTONE SAND IN CONCRETE MIXTURES

## Introduction

The use of stone sand as a fine aggregate in concrete construction has been in disfavor not only in Michigan, but also in other states where this material is available. The main objections to its use in concrete are reduced workability, excessive bleeding, difficult finishing and a tendency to produce scaling of pavement surfaces.

There has been a feeling on the part of certain individuals that some of the available local sources of desirable natural aggregates may become depleted and because of the fact that there is available to certain areas of Michigan a supply of stone sand, the Research Division of the Michigan State Highway Department has been requested to make a study of the advisability of using stone sand in concrete construction.

The purpose of the study is to establish future Departmental policies in regard to the use of stone sand as a fine aggregate in concrete construction.

The study of stone sand has included a review of the use of stone sand in Michigan, the characteristics of manufactured stone sand, and their effect upon concrete mixtures, the manufacture and characteristics of Inland limestone sand, a summary of the scaling survey made of existent concrete pavements containing stone sand, the results from the scaling study made on the durability section of the Michigan Test Road during the previous winter and a description of the Manistique stone sand durability project which will be constructed this year to study further the characteristics of this material when used with certain admixtures.

The Use of Limestone Sand by the
Michigan State Highway Department

In 1931 the use of stone sand as an alternate for natural sand in concrete mixtures was considered by the Michigan State Highway Department. Before that time, stone screenings, either alone or in combination with natural sand was not allowed in concrete mixtures. In April, 1931, at the request of C. E. Foster, Chief Engineer, specifications for the use of stone sand were prepared by W.J. Emmons, Laboratory Director of the Highway Department. Mr. Emmons collaborated with Dr. Kriege of the France Stone Company, and Mr. Goldbeck of the National Crushed Stone Association, in preparing the specifications. With the exception of a change in the washing requirements from max. 2-1/2% to 4% the specifications as presented by Mr. Emmons in 1931 have remained unchanged until 1940. A copy of the original specification is presented in the appendix.

In 1940 a change was made in the sieve sizes with consequent change in gradation limitation requirements. The Public Roads Administration, after reviewing the 1940 Standard Specifications made the following recommendation "Natural Sand 2NS, along with stone sand, we believe that a finer sand might be permitted in some cases in the interest of greater workability for which purpose we suggest the use of the following requirements:"

| | | | |
|---|---|---|---|
| Passing No. | 50 | | 10 - 30% |
| " " | 100 | | 0 - 10% |
| Loss by washing | | Max. | 3% |

The present and proposed supplemental specifications for Natural and Stone Sands is given in the appendix.

Under present Michigan State Highway Department specification requirements for stone sand 2SS, the sand must be manufactured from stone meeting all of the physical requirements of 4 A coarse aggregates. Also, it must meet all of the requirements of natural sand 2NS except loss in washing which shall be not more than 4 per cent. In addition, stone sand is used only when specifically provided for by the Highway Department. At the present time only one source of limestone aggregate in Michigan is approved by the Public Roads Administration for use in concrete mixtures and that source is the limestone quarry at Manistique, operated by the Inland Lime and Stone Co. Consequently, only stone sand from this source will be considered in the report.

## Characteristics of Manufactured Stone Sand

Stone sand is a residue resulting from the crushing and screening of large blocks of quarried limestone. The method of crushing and characteristics of the parent material determine the final shape of the sand particles. A study by Goldbeck (1) of samples of stone sand produced in different plants shows that there is a difference in the shape of the particles. Sand from some plants is decidedly angular, flat in shape and with sharp edges; other sands are more cubical, but none of them exhibits much rounding of the edges. Further study by Goldbeck on the effect of shape of particle on mortar-making properties of stone sand reveal that the shape of the particle is largely responsible for the many undesirable characteristic of concrete containing stone sand. For example: the more angular the sand the higher must be the water content for a given consistency, when a contractor must work with very angular and sharp cornered sands containing slabby and needle like pieces, it is clearly indicated that he must use a much higher percentage of water than is the case with a more rounded sand.

Laboratory tests on cement mortars (as reported by Goldbeck) containing rounded sands showed a higher strength, greater density, and greater resistance to freezing and thawing cycles than the cement mortars composed of angular stone particles.

A study of the results indicate that slabby and angular particles which occur in many stone sands are undesirable.

The National Crushed Stone Association (2) after considerable study on this problem states that the harshness found in some stone sands is largely a function of the shape of the stone particles. A cubical shape was found to give satisfactory workability whereas flat, elongated grains were associated with harsh mixes, which require either more water per sack of cement, or an increased cement factor for a work-able mix. Also, they state that cubical shaped grains are being produced with a variety of equipment such as core crushers, ring rolls, rod mills, hammer mills, and that the type of equipment suitable for any particular quarry is dependent on the characteristics of the rock to be crushed and particularly on its silica content; in other words, equipment found to be satisfactory at one location might not necessarily be found to be satisfactory at another where the stone has different characteristics.

On large construction projects where limestone aggregates are to be used, it is customary to send samples of the rock to several manufacturers for reduction in their mills to determine which manufacturer has the proper equipment to produce the most cubical shaped particles.

Recent researches by the Ohio State Highway Department in collaboration with several manufacturers of stone aggregate, have shown that in those cases where a rock deposit is operated for the express purpose of producing relatively large sizes of stone for non-aggregate purposes, the resultant aggregate of smaller sizes is of a quality much inferior to what standard tests would indicate that quality to be.

The rock from the harder and sounder ledges are less inclined to break down to small sizes in the crusher while the rock from the softer ledges break down easily. In consequence, the so called "by-product stone" contains the larger percentage of softer stone. When the removal of flux stone therefore reaches as high as 60% of the quarried rock, it can be found that the quality of what remains is unlikely to be a good construction aggregate.

## Characteristics of Inland Limestone Sand

The stone sand manufactured by the Inland Lime and Stone Company is a residue from plant operations designed primarily to produce 2-1/2" x 6" flux stone. The large blocks of quarried limestone are introduced into a cone crusher set to produce 6" maximum size flux-stone. The residue material below 2-1/2" in size is passed over a series of screens and further subdivided into commercial size aggregates for concrete and bituminous work. The finer fractions continue on through a series of rollers which further reduce the stone particles to stone sand. The stone sand is deposited into a settling basin where it is washed and finally stock piled.

A typical gradative analysis of Inland stone sand is shown below:

| Sieve Size | Recent Passing | Proposed 1941 M.S.H.D. Specifications |
|---|---|---|
| 3/8 inch | 100 | 100% |
| No. 4 | 99 | 95 - 100 |
| No. 8 | 88 | 65 - 95 |
| No. 16 | 52 | 35 - 75 |
| No. 30 | 28 | 15 - 55 |
| No. 50 | 13 | 10 - 30 |
| No. 100 | 4.3 | 0 - 10 |
| Loss by washing | 2.0 | 4% |
| Fineness modulus | 3.14 | |

Soundness test on 10A Inland Stone consisting of five alternations of magnesium sulfate.

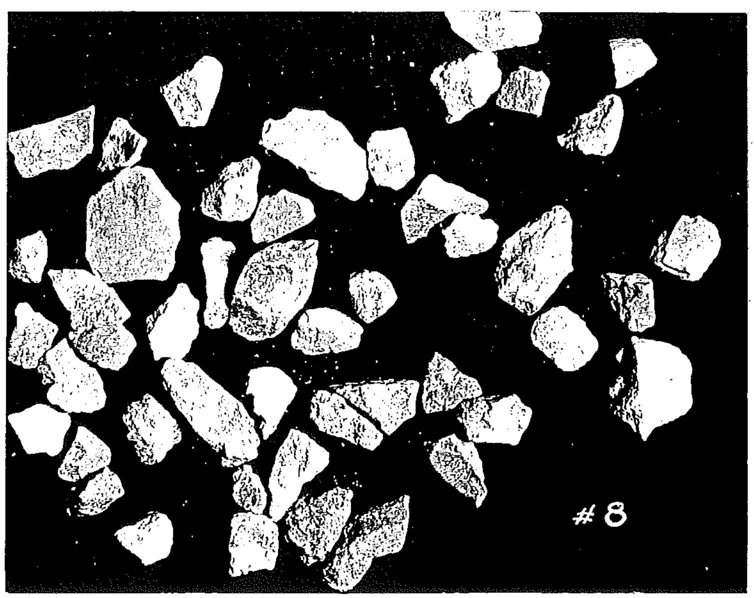
| Sieve Passing | Size Retained | % Retained | Weighted Average % Loss |
|---|---|---|---|
| 2-1/2 | 1-1/2 | 5.3 | 0.00 |
| 1-1/2 | 3/4 | 48.6 | 0.00 |
| 3/4 | 3/8 | 33.2 | 0.00 |
| 3/8 | No. 4 | 12.9 | 0.13 |
| Total | | 100.0 | 0.13 |

| Particle Size | Test Fraction | Disintegration | Split | Cracked | Flaked |
|---|---|---|---|---|---|
| 2-1/2 - 1-1/2 | 22 | 0 | 0 | 2- | 3 |
| 1-1/2 - 3/4 | 25 | 0 | 0 | 2 | 1 |

Soundness test on Inland Stone Sand 2SS from Project (F 18-20,C3) consisting of five alternations of magnesium sulfate.

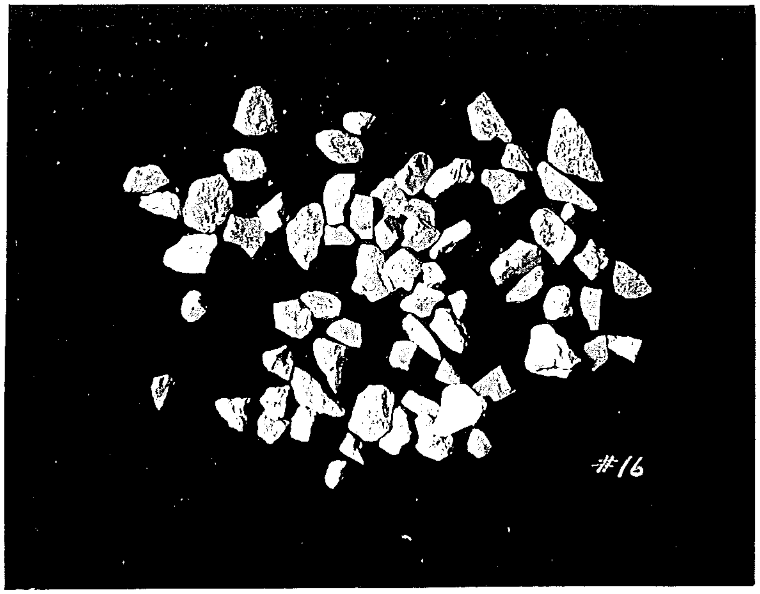
| Sieve Passing | Size Retained on | Gradation % Retained | Weighted Average % Loss |
|---|---|---|---|
| 3/8 | No. 4 | 0.9 | 0.09 |
| No. 4 | No. 8 | 10.6 | 1.06 |
| No. 8 | No. 16 | 36.3 | 2.18 |
| No. 16 | No. 30 | 23.7 | 1.90 |
| No. 30 | No. 50 | 15.0 | 1.80 |
| No. 50 | No. 100 | 9.2 | 1.20 |
| No. 100 | | 4.3 | |
| | | 100 | 8.23 |


A. Stone Sand Particles passing 3/8" sieve retained on #4, magnification 2 times.

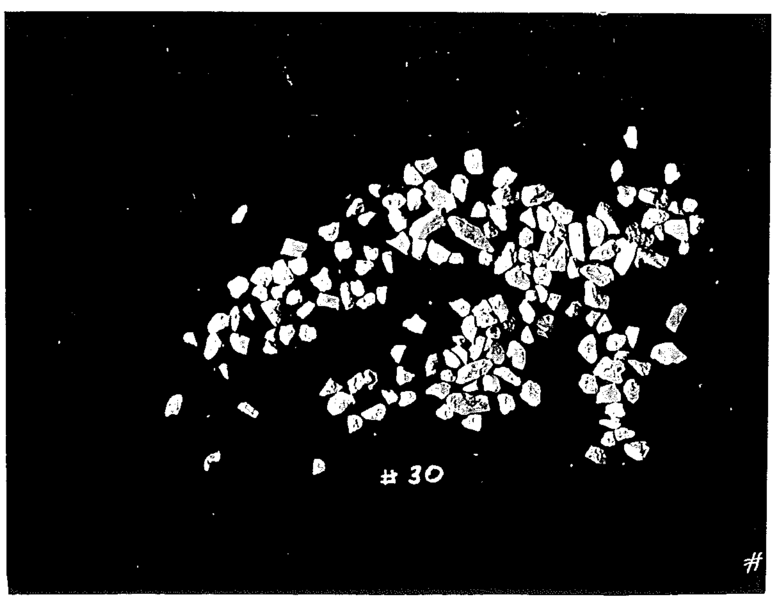



B. Stone Sand Particles passing #4, retained on #8, magnification 3 times.

Fig. 1 Inland Stone Aggregate.



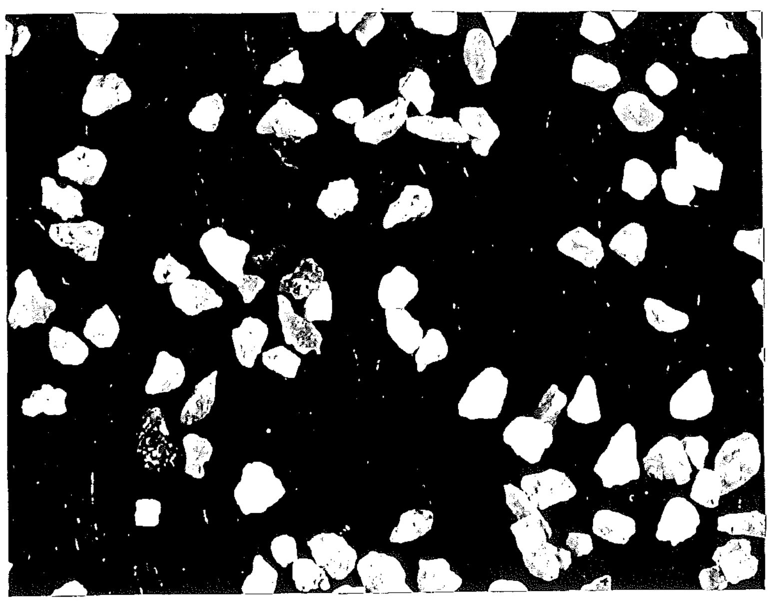

A. Stone Sand Particles passing #8 retained on #16 magnification 2 times.




B. Stone Sand Particles passing #16 retained on #30 magnification 2 times.

Fig. 2 Inland Stone Sand Aggregate.

A. Stone Sand Particles passing #30 retained
on #50 magnification 50 times.

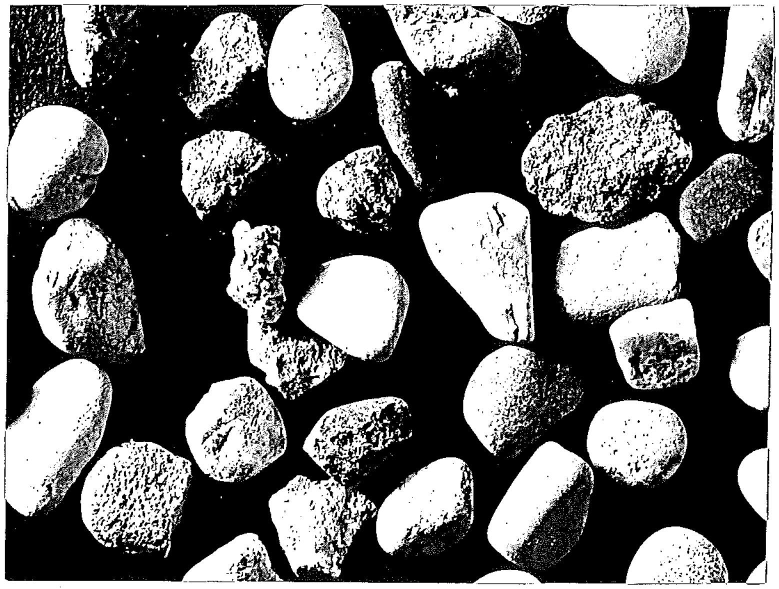


B. Stone Sand Particles passing #50 retained
on #100 magnification 40 times.

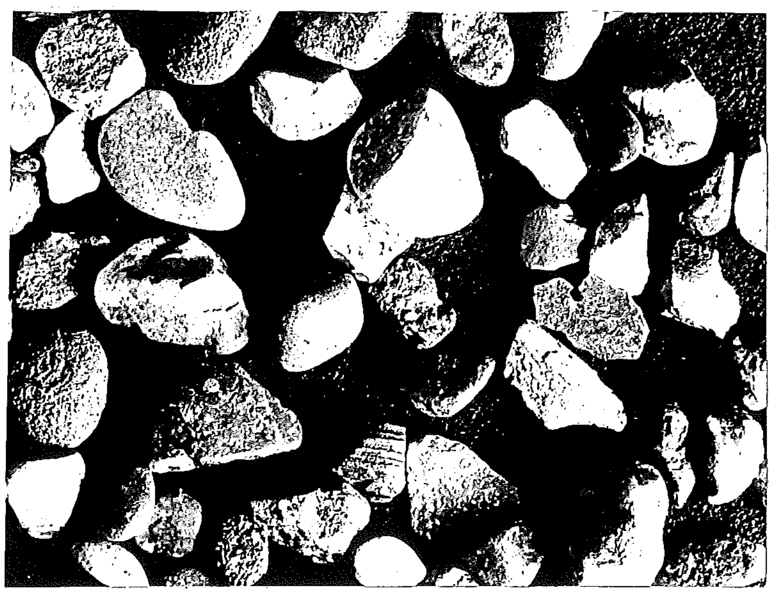
Fig. 3 Inland Stone Sand Aggregate.

A visual examination of the separate fractions of Inland stone sand reveal that the stone sand particles are very angular and irregular in shape. There is a preponderance of flat and triangular shaped pieces, as the photographs in Fig. 1-2-3 show. The percentage of cubical pieces is very small. A stone sand with such particle shape characteristics has been definitely proven to be undesirable for concrete mixtures.

For comparative study a series of photographs of natural sand particles have been included in the report. The photographs are shown in Figure 4-5-6.

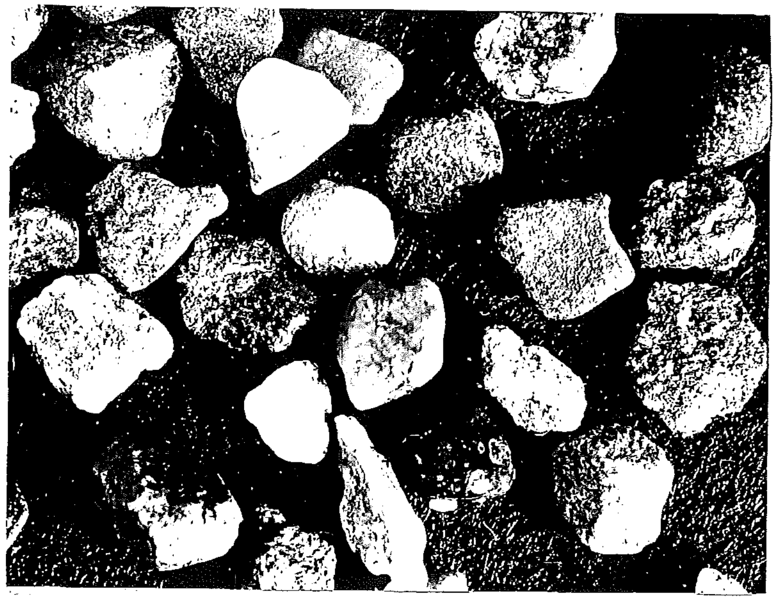


A. Natural Sand Particles passing 3/8 retained on #4 actual size.

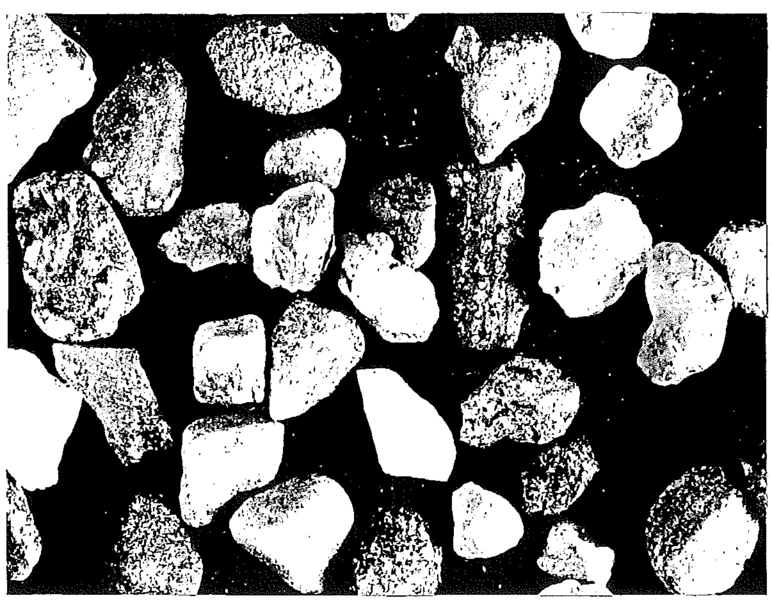


B. Natural Sand Particles passing #4 retained on #8 magnification 4 times.

Fig. 4 Natural Sand Aggregate.

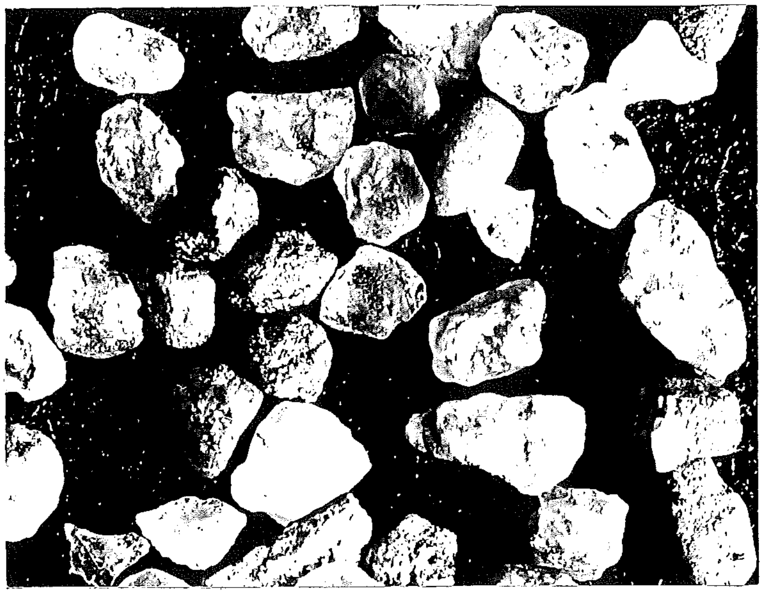


A. Natural Sand Particles passing #8 retained on #16 magnification 6 times.

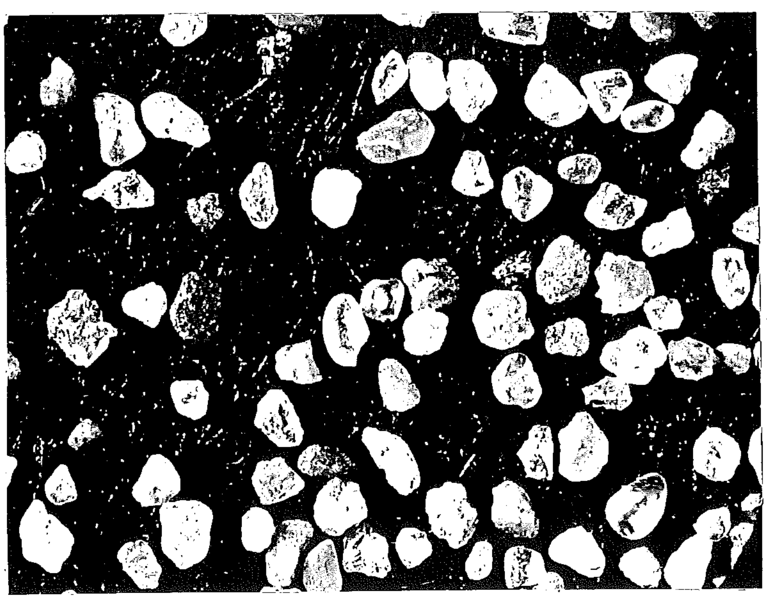


B. Natural Sand Particles passing #16 retained on #30 magnification 15 times.

Fig. 5 Natural Sand Aggregate.



A. Natural Sand Particles passing #30 retained on #50 magnification 30 times.



B. Natural Sand Particles passing #50 retained on #100 magnification 50 times.

Fig. 6 Natural Sand Aggregate.

SCALING STUDY OF EXISTENT CONCRETE PAVEMENTS

In the fall of 1939 a visual examination was made of all concrete pavements constructed on the Michigan State trunk-line system. The purpose of this survey was to determine the amount and degree of scaling prevalent in Michigan. In order to evaluate the type and amount of scaling in accord with similar researches being conducted by other organizations, the intensity of scaling was divided into four classes designated as light, medium, heavy and disintegration of the concrete.

Light scaling may be described as a very thin cement film coat less than 1/16 inch in thickness, medium scaling refers to a thin mortar coat from 1/16 inch to 3/8 inch in thickness. Heavy scaling indicates complete removal of the mortar coat the aggregate being exposed and started to ravel, disintegration of the slab implies that progressive disintegration of the concrete subsequent to scaling has been in progress for some time and that the pavement is in need of immediate repairs or the surface has been repaired.

The results of this survey with respect to projects containing Inland stone sand and natural sand available in the Upper Peninsula are given in table No. 1 and summarized in table No. 2 .

From a careful analysis of the data presented in tables 1 and 2 relative to comparable concrete projects constructed in the Upper Peninsula, it is evident that,

1. Scaling has taken place on 96% of the projects containing stone sand as compared with 58% of the projects in which natural sand was used.
2. On those projects where scaling has occured, with few exceptions the degree and intensity of scaling is greater on the stone sand projects.
3. Such factors as topography and location with respect to cities requiring additional applications of calcium chloride, placing and finishing of concrete, brand of cement, age with respect to first application of calcium chloride, method and degree of curing, and construction conditions must be considered in drawn conclusions.
4. In general, when all factors are considered where stone sand is used, scaling prevails to a greater extent than when natural sands are employed.

Attention is called to two projects constructed in 1936 (projects 2-1-C4) and (2-1-C3) containing stone sand and natural sand respectively under comparable weather, soil and grade conditions. The two projects designated as No. 13 and 14 in table 1, were constructed continuous on route US-41, Trenary North. At the end of 3 years the survey showed that the intensity of medium scale was 21.8% on the stone sand project and 0.1% on the natural sand project.

Table No. 1

COMPARISON OF SCALE INTENSITY
ON PROJECTS USING STONE SAND AND NATURAL SAND

| No. | Project | Year | Age | Length | Cement | Fine & Coarse Aggregates | Percent Scale Intensity Light | Percent Scale Intensity Medium |
|---|---|---|---|---|---|---|---|---|
| 1 | 48-9 C2 | 1931 | 8 | 2.490 | Petoskey | Inland | 0 | 84.7 |
| 2 | 21-9, C1-2-3 | 1931 | 8 | 6.846 | Universal | Whitehead | 0 | 0.8 |
| 3 | 22-26, C5 | 1933 | 6 | 9.741 | Universal | Champion Moon-Lake | 0 | 0.03 |
| 4 | 75-30, C2 | 1935 | 4 | 1.000 | Universal | Inland | 0 | 25.9 |
| 5 | 21-29, C2 | 1935 | 4 | 0.946 | Petoskey | Inland | 0 | 18.3 |
| 6 | 21-28, C1&2 | 1935 | 4 | 4.107 | Manitowoc | Bichler | 0 | 0.8 |
| 7 | 22-2, C2&3 | 1935 | 4 | 1.241 | Universal | Champion Moon-Lake | 3.8 | 0.8 |
| 8 | 36-17, C3&4 | 1935 | 4 | 1.779 | Huron | Champion Beech-wood | 0 | 0 |
| 9 | 21-29, C3-7 | 1936 | 3 | 5.906 | Petoskey | Inland | 1.7 | 0.6 |
| 10 | 21-28, C3-4 | 1936 | 3 | 5.456 | Petoskey | Inland | 0.4 | 0 |
| 11 | 21-29, C8 | 1936 | 3 | 2.576 | Petoskey | Inland | 5.6 | 1.5 |
| 12 | 21-28, C6 | 1936 | 3 | 4.213 | Petoskey | Inland | 0 | 2.3 |
| 13 | 2-1, C4 | 1936 | 3 | 5.332 | Petoskey | Inland | 0 | 21.8 |
| 14 | 49-28, C1&2 | 1936 | 3 | 10.123 | Universal | Inland | 5.0 | 5.6 |
| 15 | 75-30, C1-4-5 | 1936 | 3 | 8.504 | Universal | Inland | 8.7 | 4.6 |
| 16 | 52-25 C5 | 1936 | 3 | 2(approx) | Huron | Inland | 10.0 | 1.0 |
| 17 | 21-32 C2 | 1936 | 3 | 2.091 | Manitowoc | Bichler | 0 | 4.1 |
| 18 | 55-22 C2&3 | 1936 | 3 | 4.010 | Universal | H.Holmes Wallace | 0 | 0 |
| 19 | 55-24 C3 | 1936 | 3 | 8.914 | Universal | Champion Loretto | 0 | 0.02 |

Table No. 1 cont'd

COMPARISON OF SCALE INTENSITY
ON PROJECTS USING STONE SAND AND NATURAL SAND

| No. | Project | Year | Age | Length | Cement | Fine & Coarse Aggregates | Percent Scale Intensity Light | Medium |
|---|---|---|---|---|---|---|---|---|
| 20 | 49-28, C3&4 | 1936 | 3 | 8(approx) | Aetna | Whitehead Brevoort | 0 | 0 |
| 21 | 2-1, C3 | 1936 | 3 | 4.715 | Aetna | Champion Loretto | 3.1 | 0.1 |
| 22 | 21-25, C3&4 | 1937 | 2 | 6.820 | Aetna | Inland | 1.3 | 1.0 |
| 23 | 36-2, C3 | 1937 | 2 | 4.924 | Universal | Champion Beechwood | 0 | 0 |
| 24 | 21-25, C5 | 1938 | | 4.026 | Universal | Inland | 0 | 0 |
| 25 | 75-31,C3-4-5-6 | 1938 | | 11.951 | Petoskey | Inland | 0 | 0 |
| 26 | 55-3, C4 | 1938 | | 2.451 | Universal | Champion Loretto | 0 | 0 |

Table No. 2

SUMMARY OF SCALE STUDY
STONE SAND VERSUS NATURAL SAND

| Year | Age | Stone Sand | | | Natural Sand | | |
|---|---|---|---|---|---|---|---|
| | | length miles | % Scale light | % Scale medium | length miles | % Scale light | % Scale medium |
| 1931 | 8 | 2.490 | 0 | 84.7 | 16.587 | 0 | 0.4 |
| 1935 | 4 | 1.946 | 0 | 22.1 | 7.127 | 1.2 | 0.6 |
| 1936 | 3 | 44.110 | 3.9 | 4.7 | 27.730 | 0.6 | 1.0 |
| 1937 | 2 | 6.820 | 1.3 | 1.0 | 4.924 | 0 | 0 |

TEST ROAD DURABILITY STUDY

In the durability section of the Michigan Test Road there was included in the study two test areas comprised entirely of crushed stone aggregates from the Inland quarries at Manistique. These two test areas were constructed for the express purpose of studying the stone sand problem under controlled conditions.

One test area designated as "8A" is 1084 feet in length, contains limestone coarse aggregate and stone sand with limestone dust admixture added as a possible method to improve the characteristics of the mixture. For comparative study a second test area (8B) 1054 feet in length was established adjacent to area "8A" and contains a straight standard limestone aggregate mixture with stone sand but no admixture added. Both sections were constructed and cured under similar conditions.

During the construction of the limestone test areas, visual observations were made of the concrete mixture including its characteristics and appearance during mixing, placing, and finishing operations.

During the winter of 1940 the limestone aggregate test areas, as well as other test areas containing concrete with natural sand and in some cases admixtures, were subjected to controlled applications of Calcium Chloride to observe the action of ice and salts in an accelerated manner. In conducting the scaling study, definite pavement sections 120 feet in length were chosen with respect to the various concrete mixtures and surface treatments involved in the construction of the pavement. In each section two areas were dyked off, each area being 3 feet wide and 12 feet long. The dyked areas were established along the east edge of the pavement and parallel to it.

Two different types of accelerated test methods were employed. In test area "A", a 10% solution of Calcium Chloride of 1/4 inch depth was applied and allowed to remain in place 5 days. At the end of the period, the solution was removed, the panel flushed and water applied to a depth of 1/4 inch. The water was allowed to freeze for two days after which it was melted by an application of 5 lbs. of flake Calcium Chloride per area. When the ice was decomposed, it was removed from the test area, the surface flushed and allowed to rest one day before completing the next cycle.

Test Area "B" received a different treatment. Water was applied to the test area and allowed to freeze over night. The following morning the ice was melted by distributing Calcium Chloride over the area at the rate of 5 lbs. per area. When the ice was decomposed it was removed from the test area and the surface flushed. Flush water was applied to the test area and the freezing and thawing cycle repeated. On the basis of the quantity of water resulting from the melted ice in each test area, it was calculated that 5 lbs. of flake Calcium Chloride would be sufficient to produce a 10 percent solution.

The percentage of scale appearing after each cycle was determined by means of a special grid which was superimposed over the dyked area. Winter conditions permitted 23 cycles of freezing and thawing cycles to be obtained.

The results from the accelerated scaling tests are shown in Table 3. The data pertaining to stone sand is the analysis of one test panel for each method while the results on natural sand are the average of 4 panels.

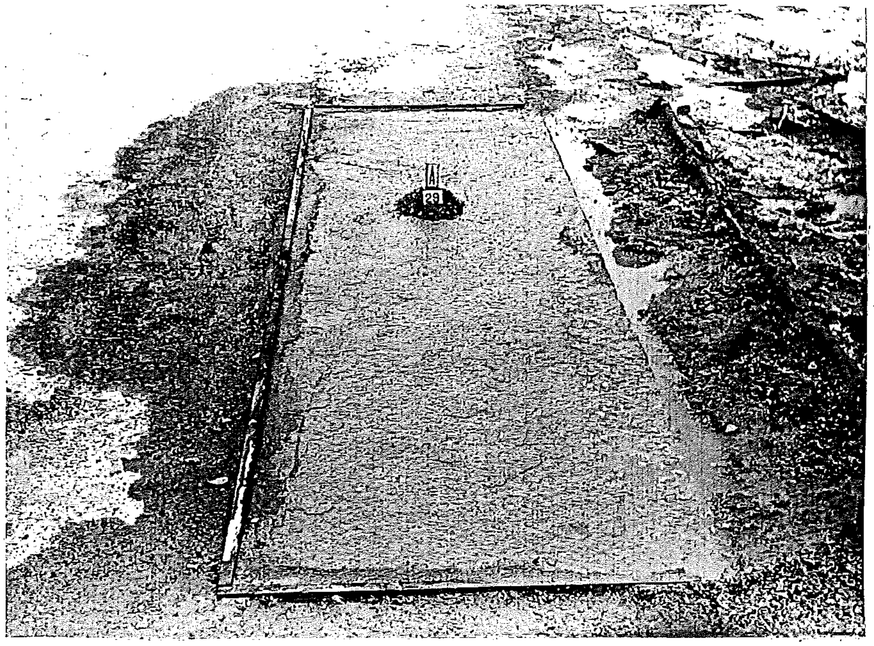
The results of the accelerated tests as presented in Table 3 show definitely that concrete containing stone sand is more conducive to scaling than concrete made with natural sand. The extent to which this relationship will prevail is no doubt dependent upon numerous factors. The use of limestone dust as a corrective measure was not satisfactory only in so far as it improved materially the workability of the concrete mixture.

Table 3 .

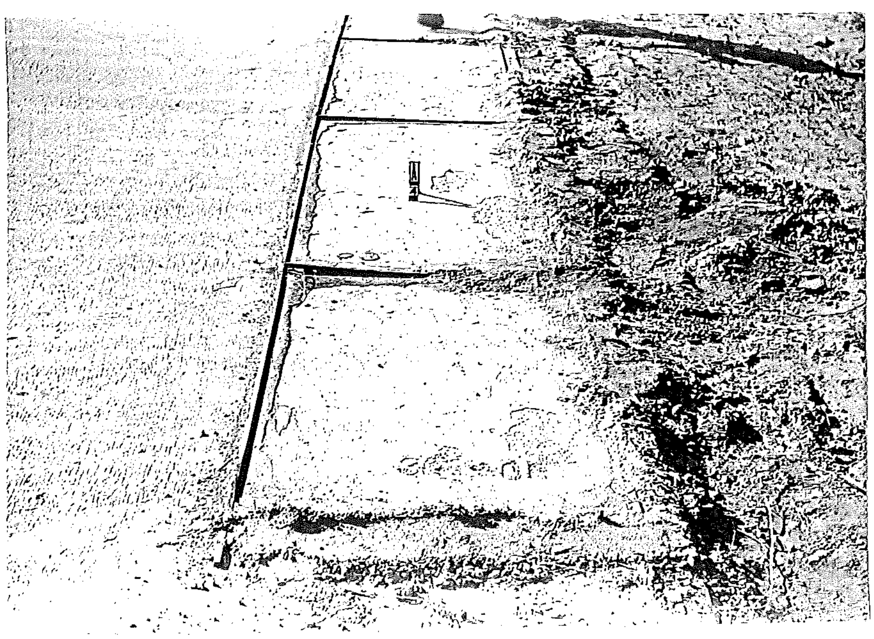
RESULTS FROM ACCELERATIVE FREEZING AND THAWING TESTS ON TEST ROAD

| Cycle of First Scale | Total No. Cycles | Area Tested sq. ft. | Area Scaled Sq. ft. | % Scale | Concrete Mixture |
|---|---|---|---|---|---|
| | Application of Calcium Chloride Solution | | | | |
| 3 | 6 weekly | 36 | 15 | 41 | Standard mix with natural sand. |
| 1 | 3 " | 36 | 36 | 100 | Stone sand plus limestone dust. |
| 2 | 5 " | 36 | 36 | 100 | Standard stonesand mixture. |
| | Freezing and Thawing Tests | | | | |
| 9 | 28 daily | 36 | 24 | 67 | Standard mix with natural sand. |
| 1 | 5 " | 36 | 36 | 100 | Stone sand + limestone dust. |
| 5 | 22 " | 36 | 36 | 100 | Standard stone sand mixture. |

A series of photographs are presented in Figures 7 to 11, to illustrate further the degree and intensity of scaling occurring as the result of the accelerated Calcium Chloride tests on the Durability Section of the Michigan Test Road. The photographs in figures 7, 8, 9, 10 illustrate the amount and type of scaling which occurred on the test areas composed of limestone aggregates as compared with concrete containing natural aggregates under similar controlled Calcium Chloride treatments designated as A and B and described previously in the report. The photographs in figure 11 do not pertain to limestone aggregates. They are included primarily to show what can be accomplished to improve the resistance of concrete to scaling by the use of certain admixtures. The excellent results obtained from these tests relative to the use of Orvus as an admixture in concrete to reduce scaling have been instrumental in requiring the use of Orvus on the Manistique Stone Sand project.

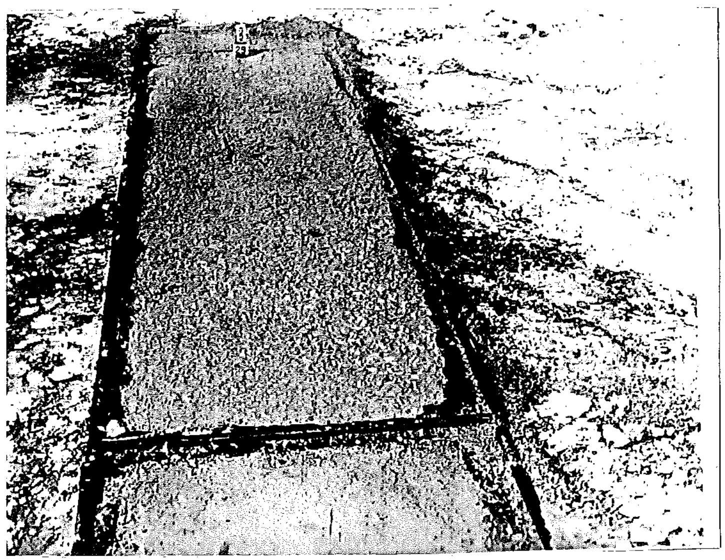


A. Standard Limestone Aggregate
Petoskey Cement, Standard Curing
100% Scaled, 5 cycles, Method A.

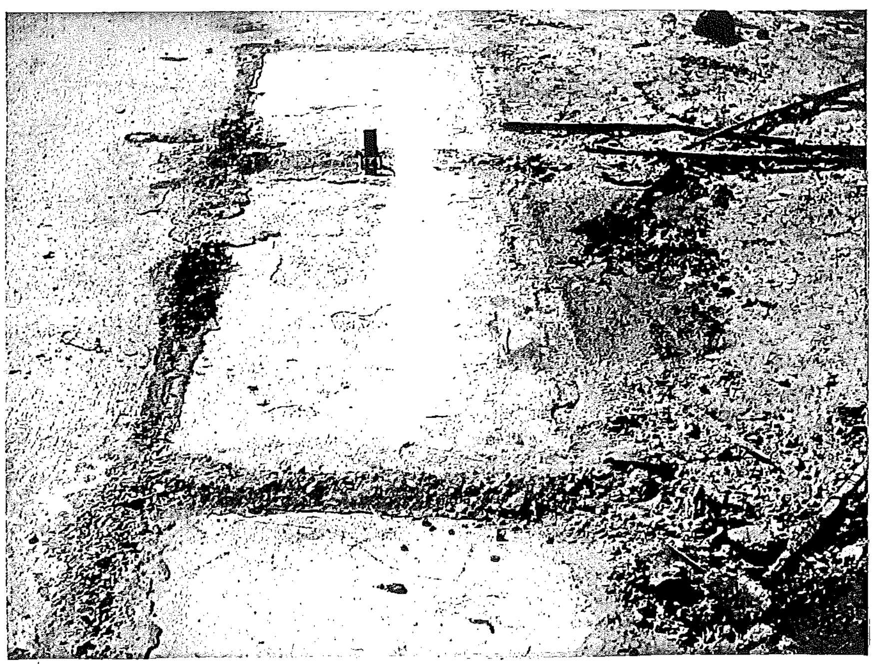


B. Standard Natural Aggregates
Petoskey Cement, Standard Curing
6% Scaled, 6 cycles, Method A.

Fig. 7 Standard Natural and Limestone Aggregates, Treatment A.

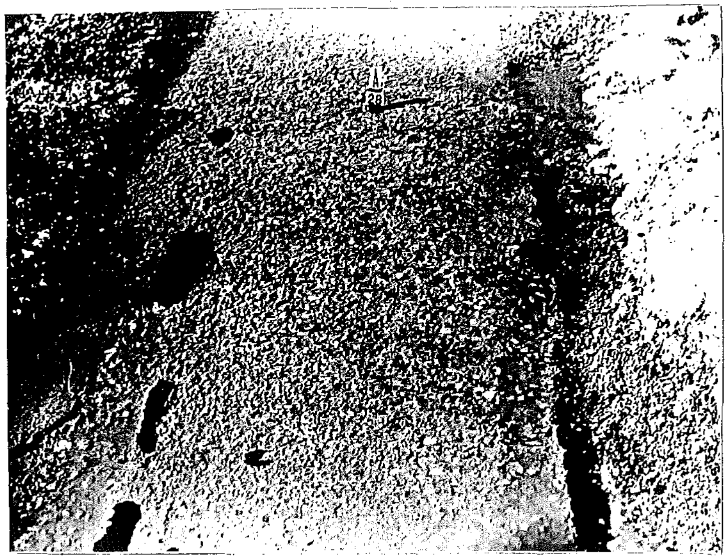


A. Standard Limestone Aggregates
Petoskey Cement, Standard Curing
100% Scaled, 22 cycles, treatment B.

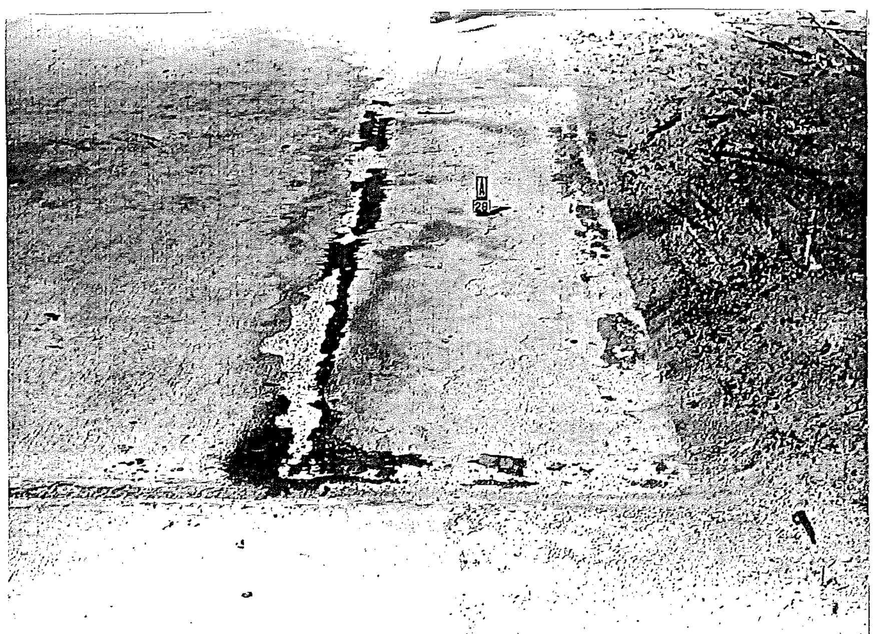


B. Standard Natural Aggregates
Petoskey Cement, Standard Curing
61% Scaled, 33 cycles treatment B.

Fig. 8 Standard Concrete with Natural and Limestone Aggregates, Treatment B.



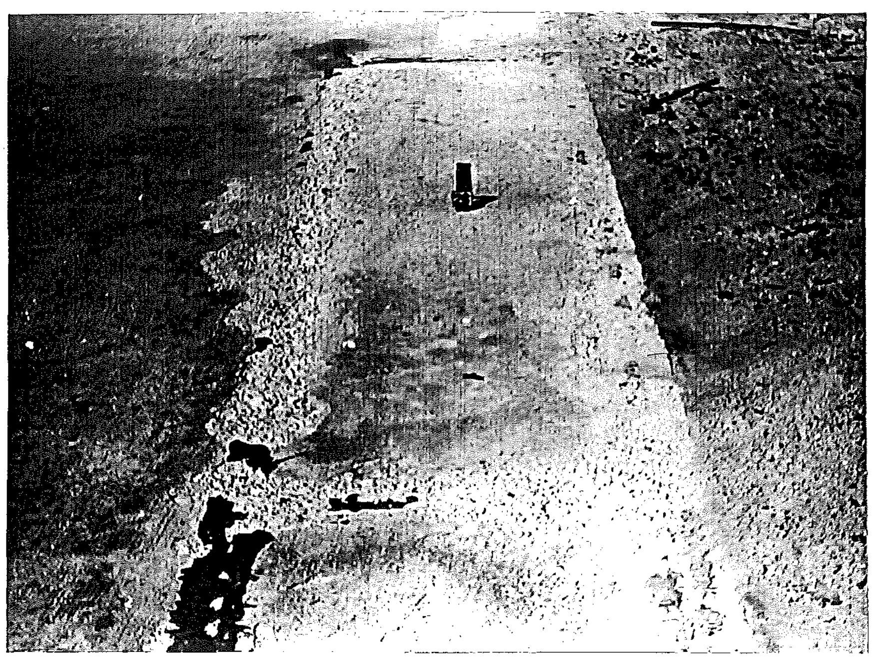
A. Standard Limestone Aggregates and Limestone Dust
Petoskey Cement, Standard Curing
100% Scaled, 3 cycles, Method A.



B. Standard Natural Aggregates + Limestone Dust.
Petoskey Cement, Standard Curing
59% Scaled, 7 cycles, Method A.

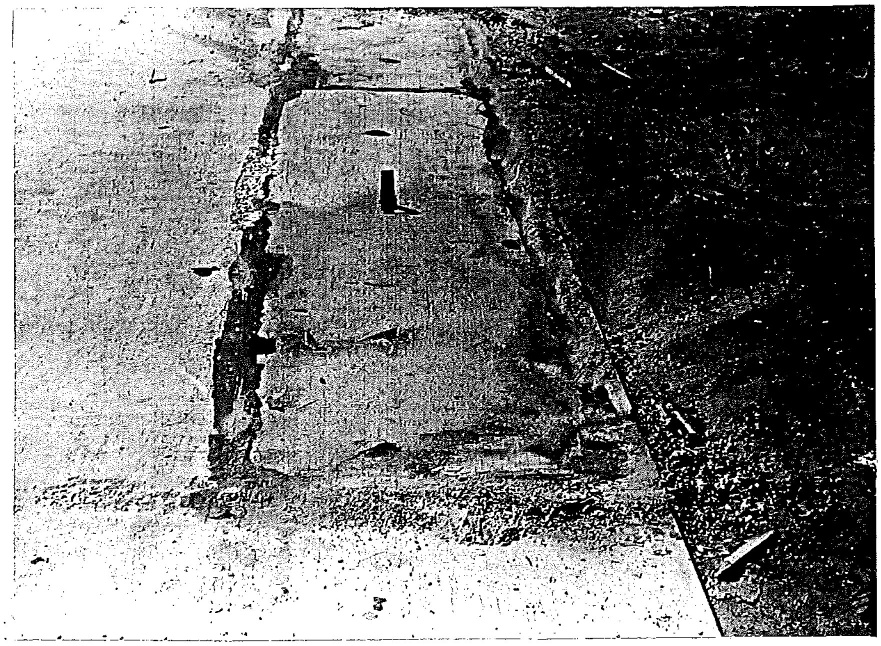
Fig. 9

A. Standard Limestone Aggregate + Limestone Dust
Petoskey Cement, Standard Curing
100% Scaled, 13 cycles, Method B.

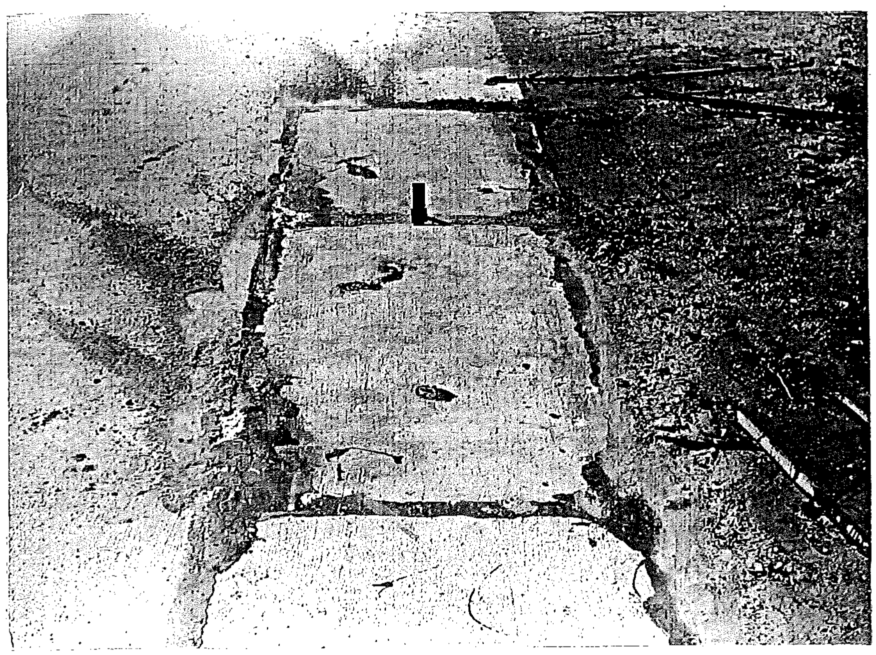


B. Standard Natural Aggregates + Limestone Dust
Petoskey Cement, Standard Curing
94% Scaled 33 cycles, Method B.

Fig. 10



A. Standard Natural Aggregates with Orvus
Petoskey Cement, Standard Curing
No Scale, 7 cycles, Method A.



B. Standard Natural Aggregates with Orvus
Petoskey Cement, Standard Curing
No Scale, 33 cycles, Method B.

Fig. 11 Natural Aggregates Containing Orvus.

## MANISTIQUE STONE SAND DURABILITY STUDY

On the basis of results obtained from the scaling study conducted last winter on the durability section of the Michigan Test Road M-115 relative to the use of admixtures to improve the physical characteristic of stone sand concrete and its ability to resist scaling, it has been proposed to experiment further with the use of admixtures in stone sand concrete mixtures. Consequently, in the construction of a 0.417 mile of 38 ft. - 42 ft. concrete pavement in the City of Manistique with limestone aggregates certain admixtures will be added for comparative study of the resultant concrete mixtures and durability of the finished surface.

The limestone aggregates both coarse and fine will be obtained from the Inland Lime and Stone Company quarries located at Manistique. Orvus wetting agent paste admixture will be added in specified amounts to the concrete throughout the entire project. In the north half of the pavement only, silica dust will be added in addition to the "Orvus" at the rate of 65 lbs. per cubic yard of concrete.

The purpose of this work is an attempt at improving the objectionable characteristics of stone sand in concrete such as bleeding, difficult finishing and scaling by the addition of wetting agents and additional fines.

Throughout the construction of the pavement the concrete operations will be carefully watched and observations recorded for future comparison and study. Complete results from this study will not be available until after at least one season of ice removed with consequent calcium chloride treatments.

## CONCLUSIONS

It is evident from the foregoing information that stone sand as a concrete aggregate is a questionable material. Its performance depends to a certain extent upon quality, gradation and character of the stone sand particles.

Quality, in so far as current laboratory practices can determine it, is a factor which can be controlled by specification requirements in the same manner as for natural aggregates.

The grading of stone sand, in so far as specifications are concerned, is satisfactory. However, due to the general characteristics of the material itself, it has been proven in experimental mixtures that a larger portion of fines passing the 50 mesh sieve aids materially in improving the workability of the mixture.

The characteristic slabby and angular shape of stone sand particles make it undesirable for concrete work, particularly in the construction of concrete pavements. Such characteristic particle shapes reduces the workability of the concrete which is overcome to a certain extent by the addition of more water than would be required normally. This excess water eventually reaches the surface during finishing operations causing bleeding, a condition which is undesirable from the standpoint of durable concrete. Field surveys, experimental tests and laboratory researches substantiate the fact that fine aggregates consisting of slabby and angular particles are undesirable for concrete construction.

Cubical shape stone sand particles have been found to give satisfactory workability and if producers are interested in producing stone sand , having satisfactory properties, it is desirable that they use means of production which will eliminate the slabby and angular shaped particles and to some extent, round off the edges of the particles.

In view of the facts set forth in this report, we hereby recommend that any stone sand which is not properly manufactured, or does not possess adequate properties in quality and gradation shall be excluded from all highway concrete construction work. Specifications for stone sand shall be written to exclude all such material until such time that it can be definitely proven that a sufficient change in characteristics particle shape has been made to overcome its present objections. It is not the intent to exclude a manufacture improving crushing practice for the purpose of improving final products.

The present objections may be overcome successfully by the use of wetting agents admixtures, the addition of fines or a combination of admixtures and fines. Until these conditions are realized, it is suggested that on any future projects, either highway structures or pavement surfaces, where it is necessary to use stone sand because of local natural aggregates, the project be set up as an experimental project with a definite thought be given to the use of certain corrective measures introduced with stone sand.

In keeping with these suggestions a stone sand concrete project will be constructed this year at Manistique, Michigan in which an admixture and additional fines will be incorporated into the concrete mixture to determine what effect these materials will have on changing the objectionable characteristics of stone sand concrete.

We believe that the nature of the problem is such that further consideration should be given to the procuring of comparative field data relative to the use of stone sands from different producers. Consequently, we recommend that another experimental concrete project be set up to include a stone sand manufactured by the Sturgeon Bay Company, Wisconsin.

SPECIFICATION FOR PREPARED STONE SAND, AND COMBINATIONS OF PREPARED STONE SAND AND NATURAL SAND

Stone sand, for use alone or in combination with suitable natural sand, shall be prepared from rock of approved quality. The use of unprepared stone screenings will not be permitted.

Stone sand or combinations of stone sand and natural sand shall meet the following requirements:

1. General:

   It shall meet the general requirements for fine aggregates as defined in Division 12, Section 3, Paragraph 2, of the 1926 Standard Specifications.

2. Grading:

| | |
|---|---|
| Passing 3/8 inch screen | 100% |
| 1/4 " " | 90 to 100 |
| 10 mesh sieve | 60 to 90 |
| 20 " " | 25 to 65 |
| 50 " " | 7 to 25 |
| 100 " " | 0 to 6 |

3. Loss by Elutriation, not more than 2-1/2 per cent.

4. Strength:

   The fine aggregate shall be of such quality that mortar composed of one (1) part of Portland cement and three (3) parts of the fine aggregate made into briquettes according to standard laboratory methods, shall have a tensile strength of at least one hundred (100) per cent of that developed in the same time by mortar of the same proportions and consistency made of the same cement and Ottawa sand.

When a mixture of prepared stone sand and natural sand is proposed, the natural sand shall meet all of the requirements for a natural sand fine aggregate for concrete, with the exception of those for grading and for strength in 1:3 Ottawa sand mortar.

Stone sand and natural sand shall be combined by a method which will insure uniformity of composition throughout each shipment and between various shipments. If uniformity is not maintained the material will be rejected and permission to use such combination will be rescinded.

# MICHIGAN STATE HIGHWAY STONE SAND SPECIFICATIONS

| Sieve | | 1940 | Proposed 1941 Supplemental |
|---|---|---|---|
| Passing 3/8 inch | | 100% | 100% |
| Passing No. 4 | | 95 - 100 | 95 - 100 |
| Passing No. 8 | | 65 - 95 | 65 - 95 |
| Passing No. 16 | | 35 - 75 | 35 - 75 |
| Passing No. 30 | | 15 --55 | 15 - 55 |
| Passing No. 50 | | 8 - 25 | 10 - 30 |
| Passing No. 100 | | 0 - 5 | 0 - 10 |
| Loss by washing | max. | 4% | 4% |

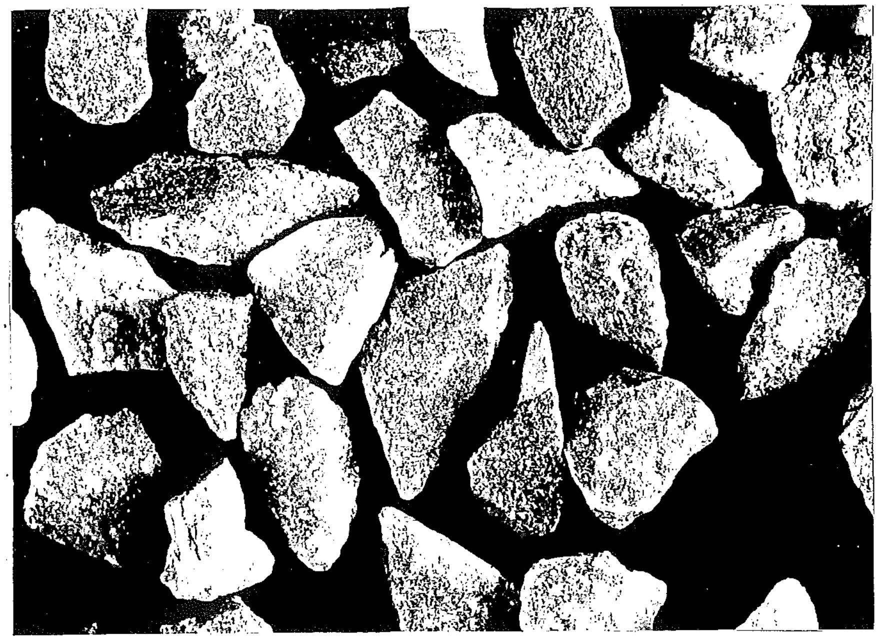
## BIBLIOGRAPHY

1. A.T. Goldbeck, "A Study of the Effect of Shape of Particle on the Mortar Making Properties of Stone Sand", The Crushed Stone Journal, March-April 1938, Vol. XIII, No. 2.

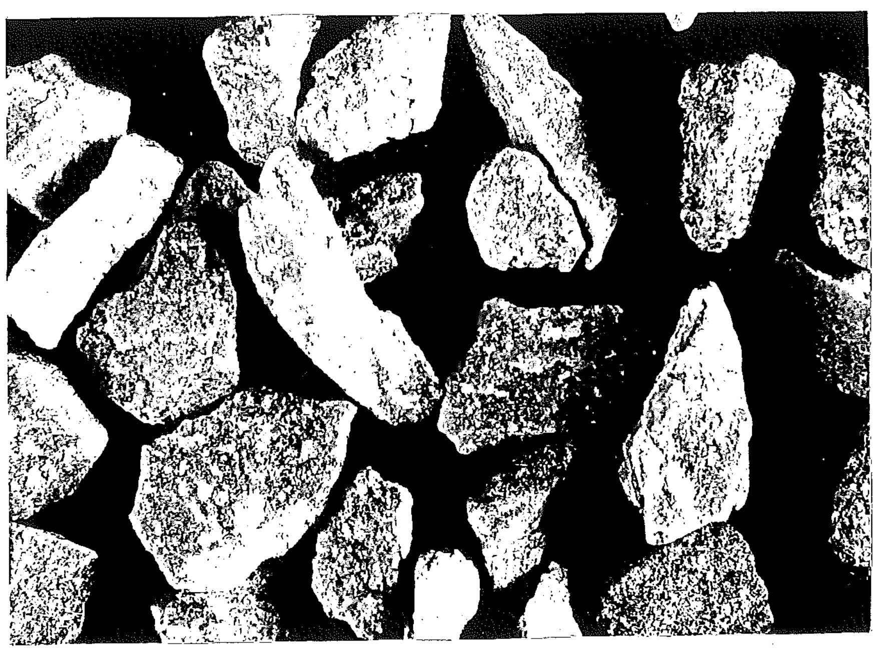
2. National Crushed Stone Association Inc., Bulletin #10, 1936.

SCREEN ANALYSIS
OF
STURGEON BAY STONE SAND

| Screen Size | Percentage Passing | | |
|---|---|---|---|
| | Classified | Unclassified | MSHD Specification |
| No. 4 | 100 | 100 | 95-100 |
| No. 8 | 87 | 90.9 | 60-90 |
| No. 16 | 48.8 | 65.35 | 25-65 |
| No. 30 | 25.3 | 36.50 | 8-25 |
| No. 50 | 11.9 | 14.05 | 0-5 |
| No. 100 | 4.2 | 4.6 | |



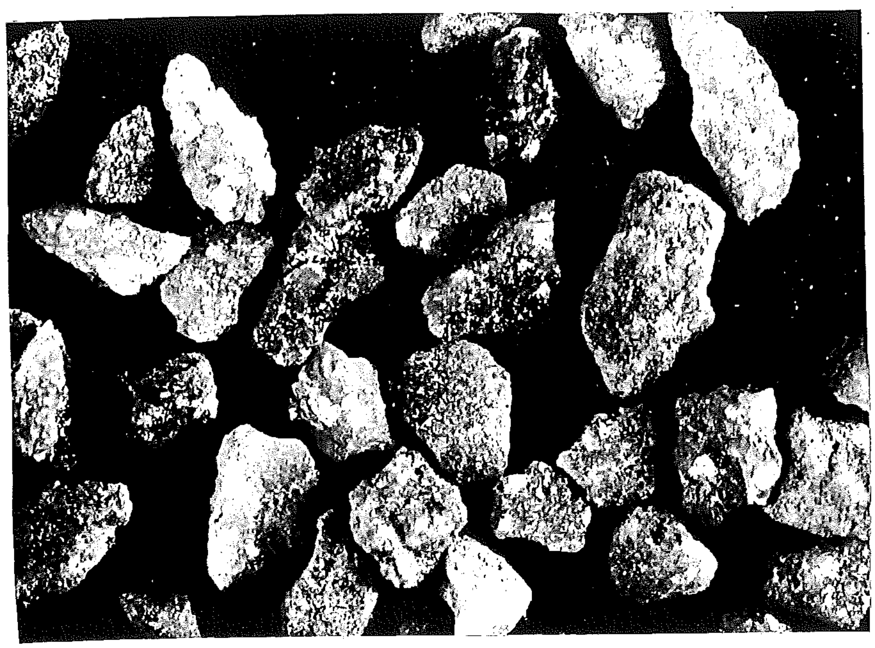
A. Stone Sand passing #4 retained #8
magnification 4 times.



B. Stone Sand passing #8 retained #16
magnification 18 times.

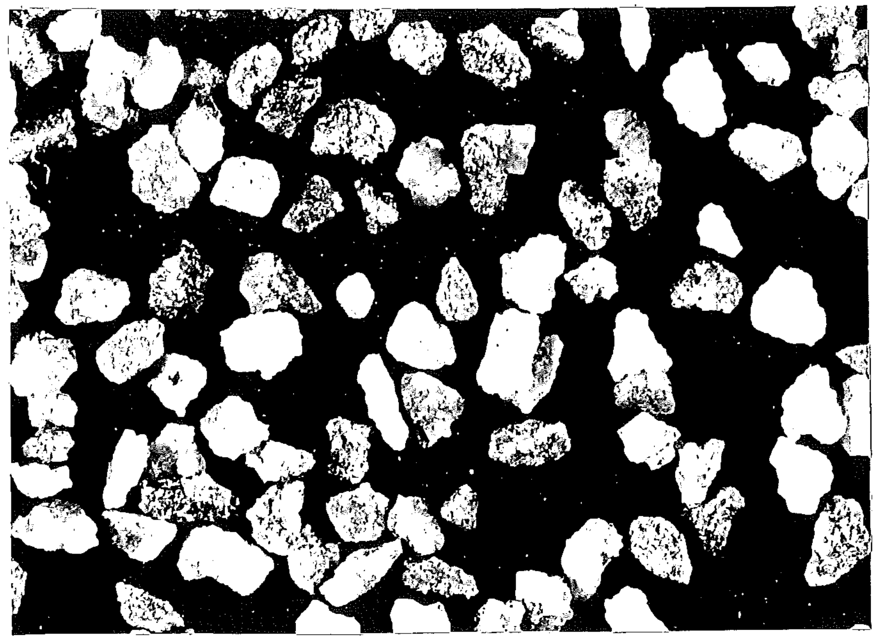
Fig. 1A Sturgeon Bay Stone Sand, Classified.

A. Stone Sand passing #16 retained #30
magnification 30 times.

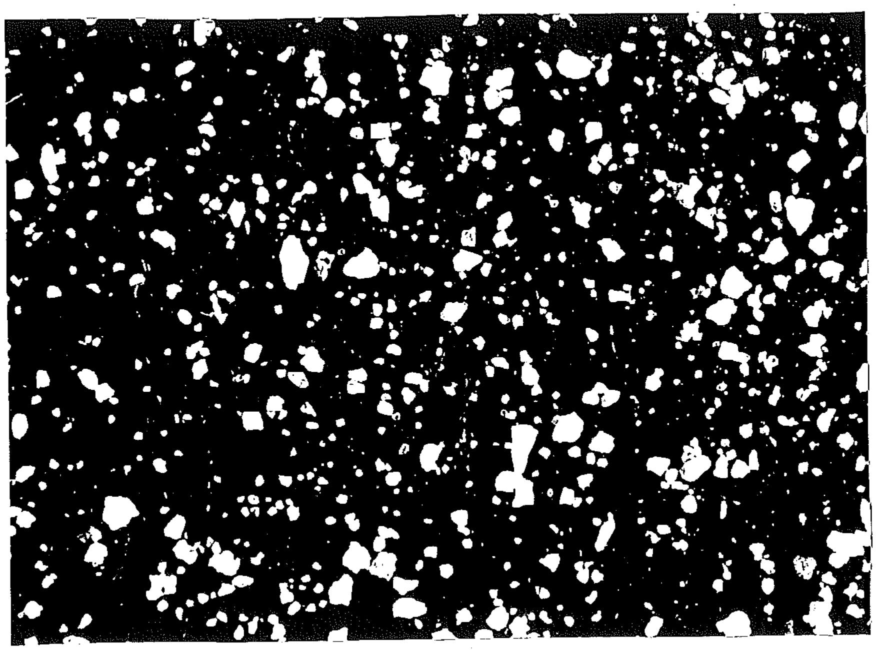


B. Stone Sand passing # 30 retained #50
magnification 80 times.

Fig. 2A Sturgeon Bay Stone Sand, Classified.

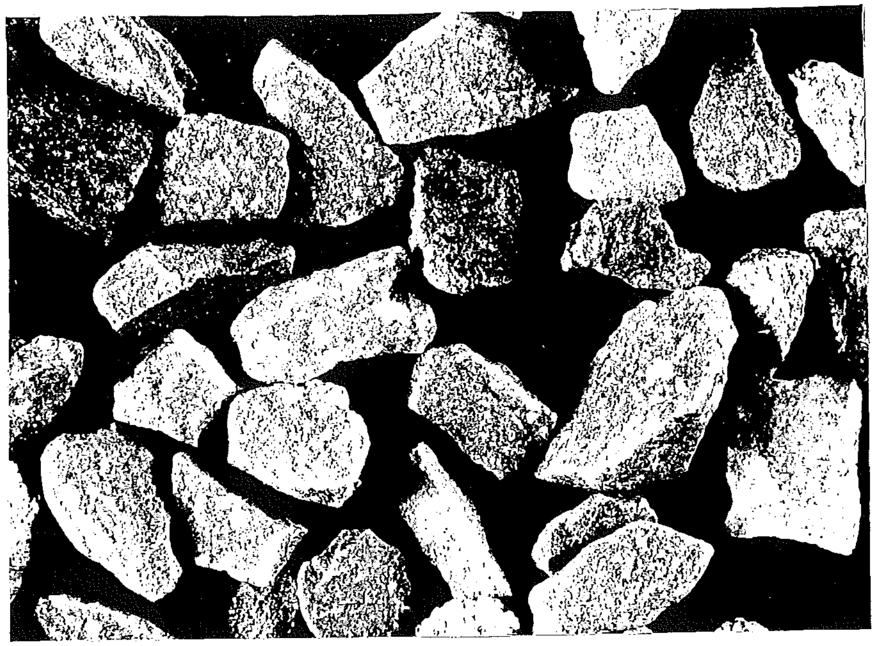


A. Stone Sand passing #50 retained #100
magnification 50 times.

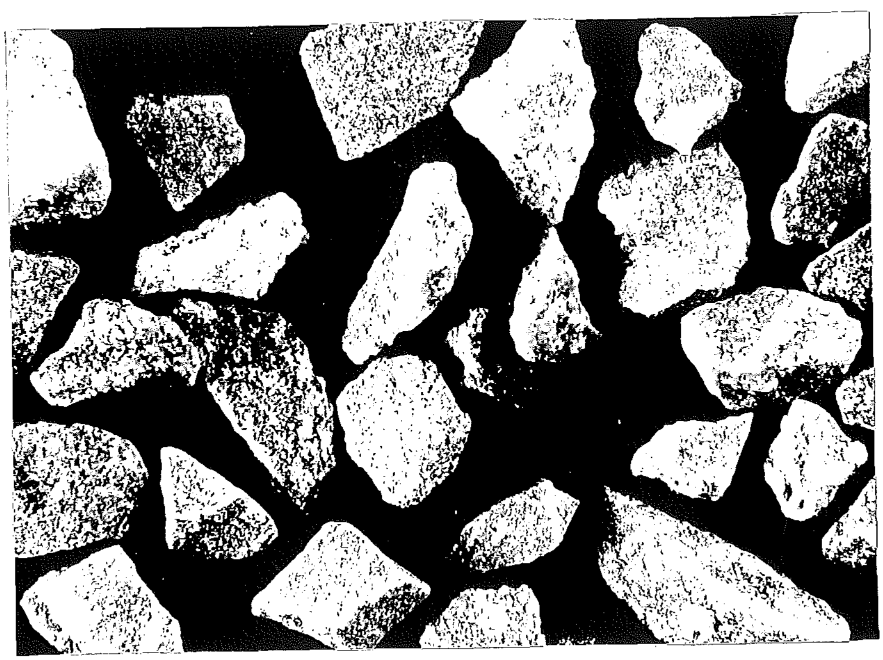


B. Stone Sand passing #100 retained #0
magnification 50 times.

Fig. 3A Sturgeon Bay Stone Sand, Classified.

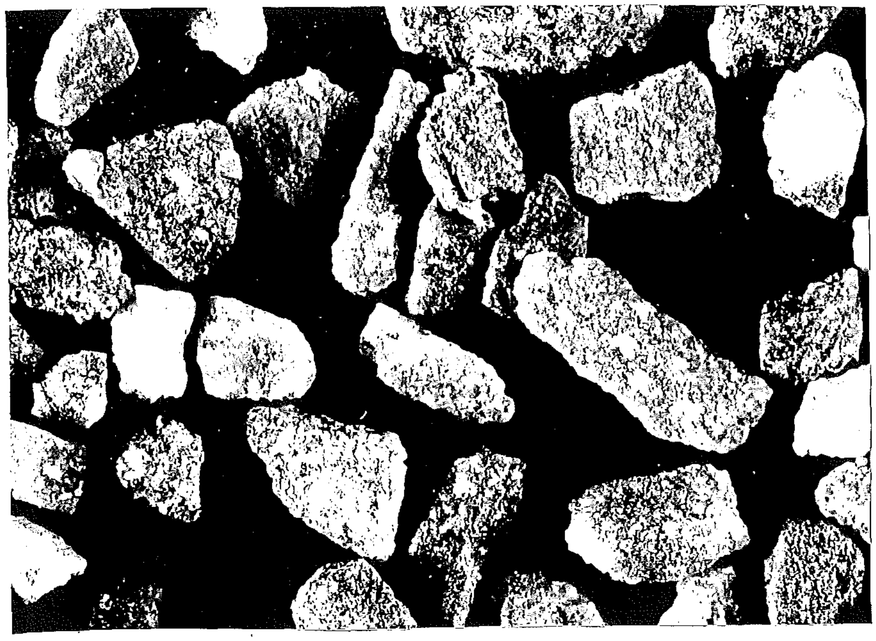


A. Stone Sand passing #4 retained #8
magnification 4 times.

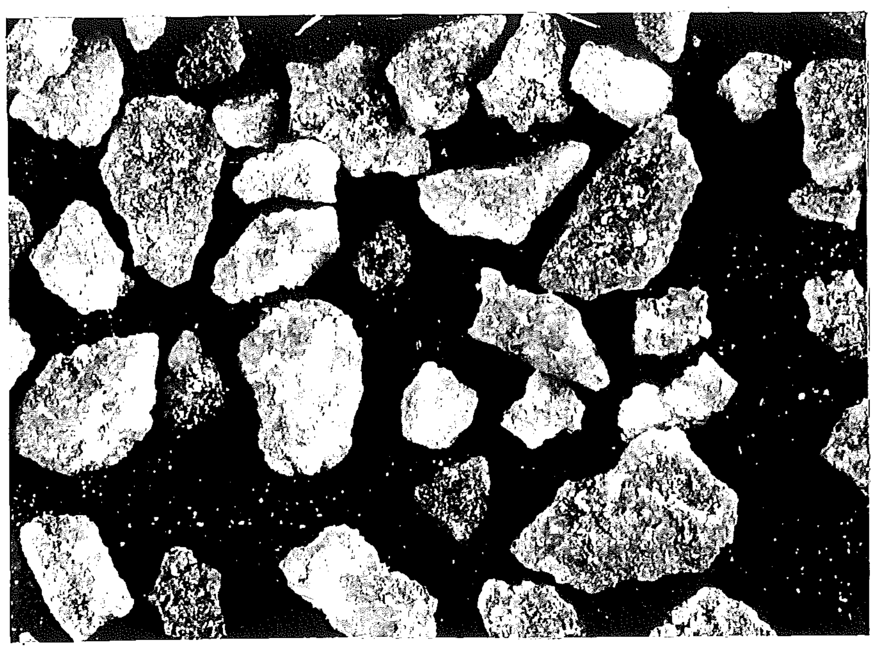


B. Stone Sand passing #8 retained #16
magnification 18 times.

Fig. 4A Sturgeon Bay Stone Sand, Unclassified.

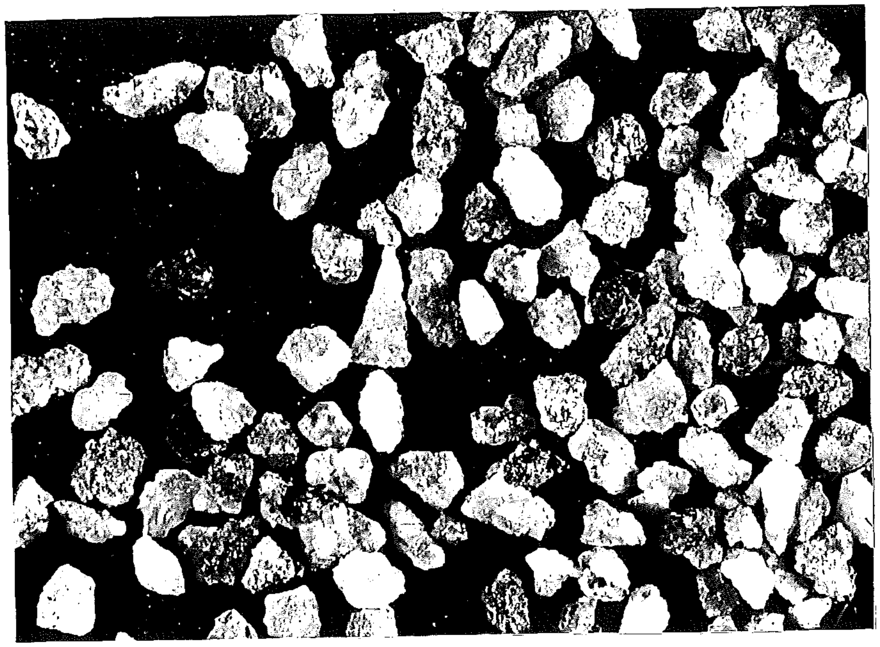


A. Stone Sand passing #16 retained #30
magnification 30 times.

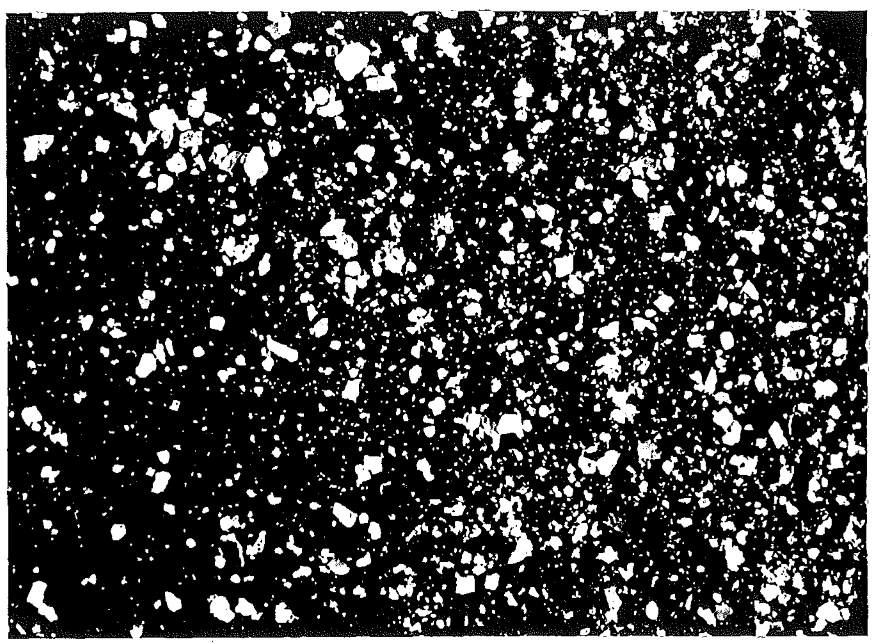


B. Stone Sand passing #30 retained #50
magnification 80 times.

Fig. 5A Sturgeon Bay Stone Sand, Unclassified.



A. Stone Sand passing #50 retained #100
magnification 50 times



B. Stone Sand passing #100 retained #0
magnification 50 times.

Fig. 6A Sturgeon Bay Stone Sand, Unclassified.

By Letter to
J. W. Kushing
May 2, 1941



COPY

April 29, 1941

Mr. O. J. Hannas
Wisconsin Public Service Corporation
Green Bay, Wisconsin

Dear Mr. Hannas:

While you and Mr. Romig were in my office a few days ago we discussed some of the factors entering into the quality determination of crushed stone. These factors very often tend to render tests by laboratories otherwise accurately and honestly made entirely useless for the purpose intended.

Since talking to you, I have had an opportunity to check some tests made a number of years ago in the State of Ohio from productions results of the eleven quarries of which I had charge.

Among these quarries was the Carey plant of the National Lime and Stone Company. This quarry like all quarries had ledges of various textures, physical characteristics and structures. It was operated for fluxing or metallurgical stone for the steel mills in the Youngstown district. This flux stone was sized 2½" x 6" and about 60% of the plant's production was flux stone size. The other 40% was a by-product stone from 2½" down.

Tests of the quarry face established an average quality which conformed to the rigid Ohio specifications. These tests were "specimen" tests, and they were checked in the finished product by subjecting sized aggregate to the "modified abrasion test". This test is similar to the Los Angeles Rattler Test and its purpose is to index the quality of the prepared aggregate. As the result of this test Carey stone was indexed in "B" class while by all Standard tests of the quarry face it was well within the requirements of "A" class. Quite naturally rejection followed and investigation was immediately made. All of these tests were in collaboration with the Testing Laboratory of the Department of Highways, State of Ohio, R. R. Litehiser, Chief Engineer.

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Eighteen tests were made on aggregate prepared in the normal operation of the Carey plant. The Modified Abrasion loss showed the following:

| | Ohio Size 4 (1" x 4 Mesh) | Ohio 34 (1$\frac{1}{2}$" x 1/2") |
|---|---|---|
| | 24.6 | 25.8 |
| | 23.9 | 27.4 |
| | 27.2 | 26.9 |
| | 26.1 | 24.2 |
| | 23.4 | 26.0 |
| | 26.6 | 26.3 |
| | 25.9 | 25.9 |
| | 27.0 | 26.9 |
| | 26.8 | 27.0 |
| Average | 25.7 | 26.2 |
| Max. Permitted | 22.0 | 22.0 |

The conclusion was that either the Modified Abrasion test was not properly related to Standard tests, or that some practice in processing lowered the quality of the stone. In consequence the Carey plant operated two shifts without producing flux stone. That is, the 2$\frac{1}{2}$" x 6" stone which was in normal operations scalped out for shipment to steel mills was recrushed to 1$\frac{1}{2}$" or smaller, thereby entering into the construction aggregate heretofore produced only as a by-product. Again tests, six in number, were made with results as follows:

| | Ohio Size 4 (1" x 4 Mesh) | Ohio 34 (1$\frac{1}{2}$" x 1/2") |
|---|---|---|
| | 18.7 | 22.0 |
| | 22.3 | 20.7 |
| | 21.4 | 19.4 |
| | 20.9 | 17.9 |
| | 19.4 | 21.2 |
| | 19.6 | 20.6 |
| Average | 20.4 | 20.3 |
| Max. Permitted | 22.0 | 22.0 |

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Quite clearly this indicated that where a rock deposit is operated for the express purpose of producing relatively large sizes of stone for non-aggregate purposes the resultant aggregate of smaller sizes is of a quality much inferior to what standard tests would indicate that quality to be.

At Carey, Ohio, these tests were repeated often enough to justify a policy of operation which precluded flux stone operation whenever the plant was required at the same time to produce a stone to meet exacting specifications.

Interesting as the forgoing may be to you, it does not constitute the only research on that subject. The Spore plant of the National Lime & Stone Campany operating at Bucyrus, Ohio, produced for years an aggregate that passed "A" class requirements by a small but comfortable margin. It operated from a ledge having only two distinct ledges, one being very much tougher and harder than the other, but when mixed in their natural proportions, acceptable as Class A.

In 1934 the State of Ohio rejected this quarry's product for the reason that the modified abrasion loss of finished aggregate was not within the maximum limit of 22, reaching in fact as high as 24. In previous years an average of 20 to 21 could be relied upon. In investigating the quarry face no change from previous years was apparent. No change in processing methods had taken place which might be responsible. Unlike previous years however, the plant was enjoying a ballast order of considerable quantity sized $2\frac{1}{2}$" x $1\frac{1}{2}$" and this constituted about 45% of its output. To determine its effect the production of ballast was momentarily suspended and the resultant smaller aggregate tested. The result was an immediate return to the normal average of 20 to 21. Perhaps a hundred tests were made in this instance, too many to include in this letter, but I would be glad to furnish the details.

It will be seen from this information how unfavorably the quality of a crushed stone aggregate is effected when there is re-

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moved from the natural mixture of quarry production sizes larger than normal aggregates. The harder, sounder ledges are less inclined to break down to small sizes in the crusher circuit while the softer ledges breakdown easily. In consequence, the so-called "by-product" stone contains the larger percentage of the softer stone. When the removal of flux stone therefore reaches as high as 60% of the quarried rock it can be said that the quality of what remains is unlikely to be a good construction aggregate. In addition, it must be remembered that stones acceptable for metallurigical purposes must of necessity contain low percentages of Silica and it is Silica that gives limestones and dolomites their soundness, toughness and abrasive resisting qualities. Therefore, their ledges are of necessity of borderline quality and the further removal of that portion of the ledges which represents the harder and sounder part makes the resultant by-product stone an inferior aggregate indeed.

Sturgeon Bay Stone on the other hand is produced for aggregate purposes only, hence the quality of its ledges is preserved in the finished product. This also explains why we are able to ship large quantities of construction aggregates over all of the Great Lakes in competition with the by-product stone.

Yours very truly

STURGEON BAY COMPANY

C. G. Knoblock

AGK:W