MEMO TO: A. O. Neiser
Assistant State Highway Engineer

SUBJECT: Proposed Special Specification for Manufactured (Crushed), Limestone, Fine Aggregate for Portland Cement Concrete, has been prepared as requested for consideration of the Specifications Committee.

The attached, "Proposed Special Specification for Manufactured (Crushed), Limestone, Fine Aggregate for Portland Cement Concrete", has been prepared as requested for consideration of the Specifications Committee.

We are including Mr. James H. Havens' memorandum concerning the development of this specification. Mr. George R. Laughlin, Research Engineering Geologist, has performed the laboratory investigation and research on the specification.

We are available for any further discussion or research on manufactured limestone sand.

Respectfully submitted,

W. B. Drake
Director of Research

WBD:dl
att: 1. Memo
2. Specifications
cc: Bureau of Public Roads (3)
Research Committee Members
MEMO TO: W. B. Drake  
Director of Research  

SUBJECT: Proposed Special Specification for Manufactured (Crushed), Limestone, Fine Aggregate for use in Portland Cement Concrete

Article 7.3.5 of the Department's 1956 Standard Specification..., which heretofore has covered and limited the use of crushed sands for concrete, does not currently provide a satisfactory basis for specifying high-quality, crushed limestone, fine aggregate. Heretofore, there have been two principal objections to manufactured (crushed) fine aggregates: 1) angular particle shapes, which cause the mixes to demand more water in order to achieve a desired consistency than can be safely allowed within the accepted practices for mix design, and 2) the tendency for shaley impurities to concentrate in the finer sizes during the crushing operations. Basically, there has never, to my knowledge, been any doubt as to the ability of crushed limestone to serve as fine aggregate provided that proper care is taken in its manufacture and provided that the specifications can confidently assure proper quality.
Of course, due respect for the abundance of limestone and their widespread use as coarse aggregates has perpetuated a desire to qualify crushed limestone fine aggregate for more general use in concrete.

The specification which we are proposing now attempts to surmount the two principal objections, cited above, by: 1) requiring that the product be manufactured from coarse aggregate which is of sufficient quality to assure the achievement of quality in the fine aggregate, and 2) resorting to the "dry-bulking" test as an empirical control upon particle-shape. The first requirement is intended to eliminate shale and soft particles; the second is intended to control the mortar-making characteristics of the finished aggregate. The latter requirement also, but indirectly, insists that the fine aggregate be produced in the proper type of crushing equipment; and, in fact, should encourage producers to install abrading-type, finishing equipment as a means of further enhancing particle-shape.

The specification consummates more than two years of study and investigation. Most of the background leading to the specification has been reported previously*. As an outgrowth of the findings, we

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were invited to prepare an appropriate specification, which is attached. While it represents our best judgement at the present time, there are some aspects to it which should be considered more thoroughly.

For instance, the gradation proposed is patterned after the Corps of Engineers, ASTM, and The National Crushed Stone Association and is much more restrictive than that presently required for natural sand (Article 7.3.2-C). The question arises from this as to whether our requirement for natural sand is too broad, whether the other specifications are too restrictive or whether we should be more demanding of manufactured sand in this respect than we are now of natural sand.

Article 7.3.2-B, para. 3, requires that the mortar cube strength obtained with a natural sand equal 90 percent of that obtained with graded Ottawa sand and that the tensile strength obtained with the natural sand equal 100 percent of that obtained with Ottawa sand. This requirement has not been included in the proposed specification, but perhaps it should be.

Air-entrainment greatly improves the workability of concrete made with crushed sands and likewise minimizes the amount of water that is needed. In fact, unless air-entrainment is made mandatory with the use of manufactured sand, there is some risk of the water exceeding or becoming critically close to the maximum that is allowed for the class of concrete. The dry-bulking test, of course, attempts to safeguard against this possibility; but, there again, 52 percent may not prove to be sufficiently restrictive.
Ideally, there should be a gradation for fine aggregate to be used in non-air-entrained concrete which would include very fine sizes. Likewise, since entrained air more-or-less supplants fine sand in a mix, there should be a gradation of sand in which the amount of fines would be reduced comensurately. The two gradings sought closely parallel the fine and coarse limits, respectively, of the proposed gradation.

Fly ash could prove to be a helpful "sweetner" for crushed sands which have an adverse particle-shape and a deficiency of fines.

Excess dust has been considered, in the past, to be somewhat problematical also. However, from the standpoint of meeting the specification, this responsibility rests solely with the manufacturer.

From the standpoint of enforcing the specification, wet-sieve testing should probably be adopted as a standard practice.

The proposed specification purposefully excludes the use of limestone fine aggregate in surface courses for pavements and bridge decks. This, of course, is in due recognition of the tendency for limestone to polish and to become slippery.

Jas. H. Havens
Assistant Director of Research

JHH:dl
This Special Specification No. , covers the material requirements for manufactured (crushed), limestone, fine aggregate for use in portland cement concrete. It shall be applicable when indicated on plans, proposals, and bidding invitations; and, when so indicated, it shall supersede all conflicting provisions of the Department's Standard Specifications...

A. DESCRIPTION

Manufactured, limestone, fine aggregate for use in structural concrete, concrete base courses for pavements, and as may be otherwise designated, shall be manufactured by crushing and sizing aggregate-quality limestones and dolomites. Limestone, fine aggregate shall not be used in concrete surface courses for pavements or bridge decks unless it is more specifically authorized by the Engineer.

B. GENERAL REQUIREMENTS

Manufactured, limestone, fine aggregate shall consist of hard, strong, durable, sub-angular particles and shall be manufactured by crushing coarse aggregate meeting the general requirements of Article 7.4.1 and the specific requirements of Article 7.4-2-D. The size of the coarse aggregate from which the sand is manufactured shall be such that 100 per cent will pass the 4-in. sieve and not more than 5 per cent will pass through the No. 4 sieve.
C. PHYSICAL PROPERTIES OF FINE AGGREGATE

In addition to the general requirements set forth in Paragraph B, the shape of the particles shall be so controlled, by crushing and milling, that when the fine aggregate is subjected to the dry-bulking test, as hereinafter described, the volumes of voids shall not exceed 52 per cent.

1. Method of Test. This test procedure describes the method of determining the dry-bulking characteristics of size-fractions of fine aggregate.

a. Apparatus.
   (1) Balance - a balance having a capacity of 1500 grams and a sensitivity of 0.1 gram.
   (2) Drying Pans - at least 1500-gram capacity, suitable for drying samples.
   (3) Cylindrical Cup - a rigid, cylindrical cup having an inside diameter of 2-7/8 inches and a height of 5-1/2 inches.
   (4) Funnel - a truncated, hollow, metal cone, having an over-all height of 4 inches and an inside diameter of 5-1/2 inches for the large opening and 1 inch for the small opening.
   (5) Sieves - (ASTM Designation E 11) of the following sizes are required: No. 4, No. 8, No. 16, No. 30 and No. 50.
   (6) Steel Straight Edge - 1-inch x 6-inch x 1/16 inch.

b. Samples.
   (1) Fine Aggregate. The sample of fine aggregate shall be washed thoroughly, dried to constant weight at 105 to 110°C (221 to 230°F.), and separated into the following sizes:

<table>
<thead>
<tr>
<th>Passing</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>No. 8</td>
</tr>
<tr>
<td>No. 8</td>
<td>No. 16</td>
</tr>
<tr>
<td>No. 16</td>
<td>No. 30</td>
</tr>
<tr>
<td>No. 30</td>
<td>No. 50</td>
</tr>
</tbody>
</table>
Approximately 1500 grams of each of the above sizes shall be required for test.

(2) Coarse Aggregate. A sample of the parent coarse aggregate shall be required for the determination of bulk specific gravity (oven-dry basis). This sample shall consist of 500 grams of material which passes the 1-1/2-inch sieve and is retained on the 3/4-inch sieve and shall be representative of the parent rock used in the manufacture of the fine aggregate.

c. Procedure.

(1) The apparatus shall be assembled, as illustrated in the accompanying diagram.

(2) Each of the 4 sizes of fine aggregate to be tested shall be poured into the funnel while a stiff piece of metal is held against the bottom aperture. The funnel shall be filled until the sand is heaped between 1 and 2 inches above its top level; care shall be taken not to overflow the funnel or to spill material into the cylinder below. The piece of metal used to close the bottom of the funnel shall be quickly withdrawn in a horizontal movement and the sand permitted to flow freely into the cylinder until it overflows. Then, the flow of sand into the cylinder shall be cut off, and any sand remaining in the funnel shall be allowed to flow into a shallow pan.

(3) The cylinder shall then be carefully struck off with the straight edge, level with the top of the cylinder. This is accomplished by holding the straight edge in both hands, edge down;
Diagram of Apparatus for Determining the Dry-Bulking Characteristics of Fine Aggregate.
starting at one side, striking off the sand above the plane of the cylinder. The straight edge is then placed along a diameter of the cylinder and the sand struck off again. This is then repeated in the opposite direction.

Extreme care shall be taken during the striking-off operation to avoid any downward pressure on the sand or any jarring of the cylinder.

(4) After carefully removing any sand that may be adhering to the outside of the cylinder, the weight of the contents shall be determined to the nearest 0.1 gram.

(5) The sand shall then be recombined with the excess from the cone, thoroughly mixed, and two additional determinations made. An average of three determinations having a maximum variation of 4 grams shall constitute a test.

(6) Tests shall be performed separately on each size.

2. Calculations. The per cent voids in each size shall be determined by the following formula:

\[
\text{Per cent voids} = 100 \left(1 - \frac{W}{VG}\right)
\]

\[W = \text{weight of sand in the cylinder}\]

\[V = \text{volume of cylinder in cubic centimeters}\]

\[G = \text{bulk specific gravity (oven dry) of the coarse aggregate as determined by the applicable portions of ASTM Designation C-127-42.}\]

3. Report. The arithmetical average of the per cent void so determined for each of the 4 size-fractions; that is, the sum of the percentages divided by 4, shall be reported.
D. GRADATION

Limestone, fine aggregate shall be well graded from coarse to fine and when tested by means of standard laboratory sieves shall conform to the following gradation requirements:

<table>
<thead>
<tr>
<th>Passing</th>
<th>Percent by Wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8 in.</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>95-100</td>
</tr>
<tr>
<td>No. 8</td>
<td>85-95</td>
</tr>
<tr>
<td>No. 16</td>
<td>65-75</td>
</tr>
<tr>
<td>No. 30</td>
<td>45-55</td>
</tr>
<tr>
<td>No. 50</td>
<td>20-30</td>
</tr>
<tr>
<td>No. 100</td>
<td>5-10</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-5</td>
</tr>
</tbody>
</table>

The fineness modulus of the fine aggregate shall not be less than 2.40 nor more than 2.80. Fine aggregate having a variation greater than .20, plus or minus, from a representative, average fineness modulus for the source shall be rejected.

Note: The fineness modulus shall be determined by adding the cumulative percentages, by weight, of the portions retained on the No. 4, No. 8, No. 16, No. 30, No. 50, and No. 100 sieves and dividing the sum by 100.

Respectfully submitted,

W. B. Drake
Director of Research

MEMO TO: A. O. Binns
Assistant State Engineer

SUBJECT: Special Gradation for Lightweight Concrete

Due to the success of lightweight concrete (three highway structures noted in my memorandum of November 2, 1960) and information derived from laboratory freeze-thaw durability studies, we would recommend that its use in exposed structural concrete be on an experimental basis. It would appear that precast concrete and possibly prestressed structural members would be ideal for realizing any economic advantage of lightweight concrete.

Decorative tile, however, is definitely a problem due to the difficulty of forming it and the higher cost of it as compared to normal concrete.