

## SHALE IN CONCRETE AGGREGATES

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## SYNOPSIS

This report supplements the discussion of the origin, characteristics and metamorphic phases of shale presented by Dr Bean at the Eleventh Annual Meeting by discussing the effects of shale in aggregates upon the characteristics of concrete with particular reference to the formulation of specifications for aggregates. Shaley materials are objectionable in concrete because of their low resistance to the action of the weather. The degree of harmfulness depends upon the severity of the exposure, the nature and amount of shale and the quality of the concrete. Owing to differences in the characteristics of the materials called shale, and in the severity of climatic conditions, specification limits in use in different localities vary widely. A table of the requirements in different places is included. Methods of testing for unsound and non-durable particles are discussed, and the results of investigations by the Minnesota Highway Department, Michigan Highway Department, North Dakota Highway Department, Kentucky Highway Department, National Crushed Stone Association and Portland Cement Association are summarized.

Shales are generally undesirable in concrete because of their weak, friable nature and their low resistance to disintegration by the weather. The objectionable features do not result from characteristics peculiar to shale alone; similar effects will be shown by any of several soft, friable and pervious materials. Most particles of this nature do not expand in volume greatly on disintegration, and, as a result, the most common effect is represented by pits in the surface, spalling and disruption of the concrete occur only rarely.

Investigations which have been made of the action of shale and similar materials in concrete have provided valuable information by indicating trends and pointing to methods of attack for future studies. They have not, however, furnished sufficiently conclusive data to provide a definite basis for specifications. Such a result is, unfortunately, too often the case for researches including as wide a range in variables difficult to control, as are involved in a study of this problem. As a consequence, specification limits are based, for the most part, on engineering judgment formed from observations of concrete in service and from knowledge of the prevalence of impurities in aggregates available for use.

TESTS OF CONCRETE USING SHALE AND GRAVEL AS COARSE AGGREGATE  
(MINNESOTA DEPARTMENT OF HIGHWAYS)

The first comprehensive investigation of the effect of shale in concrete aggregates was carried out by F C Lang of the Minnesota Department

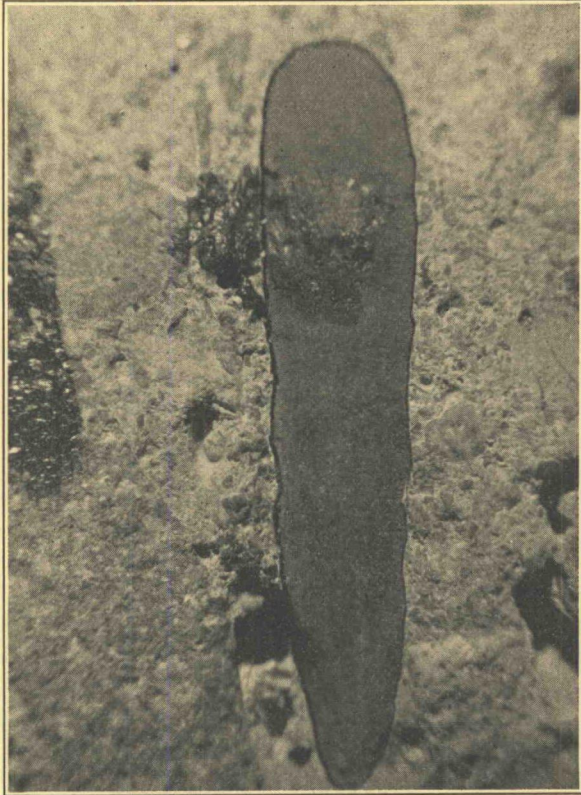


Figure 1. Particle of Shale in Concrete Core. Core drilled from concrete pavement several years old

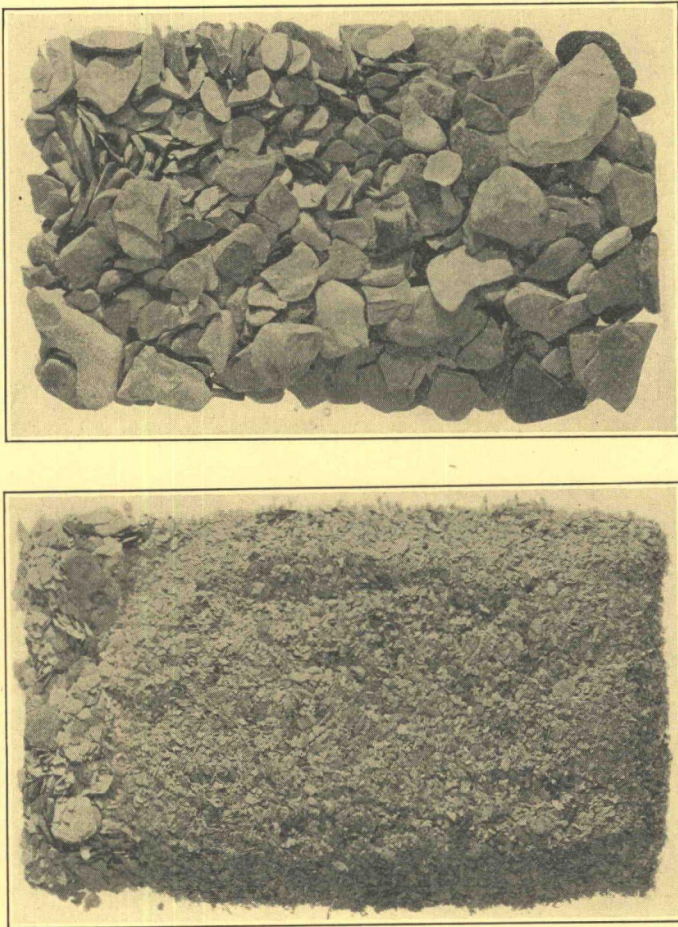


Figure 2. Shale Before and After 20 Cycles of Freezing and Thawing  
Data from "Deleterious Substances in Concrete Aggregates," by F. C. Lang,  
Engineer of Tests and Inspection, Minnesota Department of Highways, Circular  
10, National Sand and Gravel Association, and National Sand and Gravel Bulletin,  
April, 1931.

of Highways (8, 14). Compression tests of 1-2-4 concrete were made to determine the effect of different percentages of shale in gravel on the strength of concrete cured under freezing and thawing conditions and under normal temperatures. The percentages of shale in the coarse aggregate were varied from 0 to 100.



Figure 3. Pits in Concrete Pavement Due to the Presence of Soft Stone in the Coarse Aggregate

Data from "Effect of Soft Particles of Coarse Aggregate on Strength and Durability of Concrete," by W. J. Emmons, Director, Michigan State Highway Laboratory, published in the Proceedings of the Sixteenth Annual Conference on Highway Engineering, University of Michigan, 1930, in the June and July, 1931, Nat'l. Sand and Gravel Bulletin, and in Circular 6 of the National Sand and Gravel Association.

The data of this investigation are summarized in Figure 4. A study of it indicates about 0.6 per cent reduction in compressive strength for each one per cent of shale in the coarse aggregate when the specimens were cured under normal conditions, and, for quantities of shale up to five per cent, about two per cent reduction for each one per cent of shale when the concrete was subjected to eleven alternations of freezing and thawing. For the frozen specimens, the rate of loss of strength with shale decreased as the quantity of shale increased, cylinders made

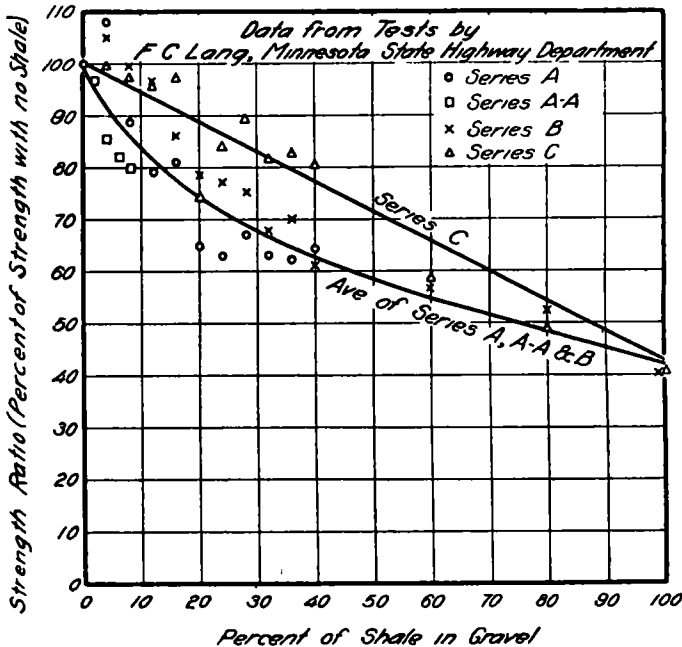


Figure 4. Effect of Shale on Compressive Strength of Concrete

Data from Tests by F. C. Lang, Minnesota State Highway Department. For Details See Proc. 1927, Amer. Conc. Inst., Report of Comm. E-5 on Aggregates, Appendix 3, Page 592. Values Are for Compressive Strengths Expressed as Strength-Ratios, with Values for Aggregate Containing no Shale as 100 Per Cent

with coarse aggregate consisting entirely of shale had a strength of about 40 per cent of those containing no shale.

As a result of these studies, Professor Lang concludes that the amount of shale in coarse aggregate should be restricted to a quantity less than that which will produce a harmful effect on the compressive strength, particularly for wearing surfaces, as he feels that the shale invariably will be worked to the surface and form spots which will disintegrate at an early period under the action of weather and traffic. He points out that, in these tests, care was exercised to avoid segregation of the shale particles which represents a precaution not feasible in ordinary

construction The authors' comment on this conclusion is that if the shale shows evidence of its presence by surface pits only, little harm will be done

Later investigations carried out at the University of Minnesota, on the broader problem of the effect of deleterious substances in concrete aggregates in general, were reported briefly by Professors Lang and Hughes before the Tenth Annual Meeting of the Highway Research Board (25, 26) and by Professor Lang before the Fifteenth Annual Convention of the National Sand and Gravel Association (28) In the latter paper, the difficulty of evaluating the deleterious effects of shale was emphasized Attention was called to photographs of concrete cylinders which had been subjected to freezing and thawing and for which shale had been used as the coarse aggregate in one case and slate in the other The slate concrete cylinders showed relatively little disintegration as compared with the shale concrete, and, in discussing that point, Professor Lang said, "This is another illustration of the difficulty in trying to enumerate the deleterious substances There is no well defined distinction between slate and shale The characteristics of the shale approach those of the slate and those of the slate approach those of the shale The properties of the two vary according to the local designation Shales in different states may have different properties It is how a substance acts in concrete that we are most interested in, not what its local name may be" Had Professor Lang conducted his investigations in another locality, he might have pointed out that shales also range into sandstones and limestones

#### TESTS OF CONCRETE USING GRAVEL COARSE AGGREGATE CONTAINING SOFT PARTICLES (MICHIGAN HIGHWAY DEPARTMENT)

An investigation of the effect of soft particles in gravel aggregates was carried out in a most comprehensive and painstaking way by the Michigan State Highway Laboratory (23) The investigation consisted of determining the effects on concrete of including in the coarse aggregate different percentages of several types of soft particles prevalent in Michigan gravels These were identified as shale, "floaters," ochre, soft sandstone, borderline sandstone, and hard absorbent sandstone Table I gives certain physical characteristics of these materials, reported by W J Emmons, which will provide some information as to their nature

Three groups of cylinders and beams were made for compressive and transverse tests, using concrete proportioned to contain about 15 barrels of cement per cubic yard with gravel as the coarse aggregate containing soft particles in percentages from 0 to 15 One group of specimens was broken after normal moist curing for 28 days, another group was cured for 28 days under normal temperatures in moist air,

and then subjected to 25 alternations of freezing and thawing before test; the third group was held for longer time tests, which have not as yet been reported

The data are too voluminous for an adequate summary in this paper. As would be expected from an investigation of this nature, even for one as carefully controlled as it evidently was, the results obtained were quite erratic. Mr Emmons, in his presentation of the data, warns against attempting to draw too definite and quantitative conclusions from the results. However, in spite of the obvious inconsistencies of certain of the test results, it is believed that a summary of them, such as shown in Table II, will furnish information of interest. The values

TABLE I  
PHYSICAL CHARACTERISTICS OF TYPICAL SOFT PARTICLES OCCURRING IN MICHIGAN GRAVELS

Type of soft particle	Apparent specific gravity	Absorption, lb of water per cu ft of particles	Sodium sulfate soundness tests, (5 alternations) soft particles, per cent		Freezing and thawing in water, 12 alternations	Per cent wear in gravel abrasion test, per cent
			Cracked	Disintegrated		
Shale	2 07	9 1		90	Disintegrated	39 1
Floaters	1 42	24 2	70	30	Surface disintegration	43 2
Ochre	1 65	21 3		100	Disintegrated	82 3
Soft Sandstone	1 91	15 6		100	Many pieces entirely disintegrated	66 8
Borderline Sandstone	2 11	11 8	60	40	Badly disintegrated	58 0
Hard Absorbent Sandstone	2 06	10 1	60	40	Slight surface disintegration	40 8

in the table are calculated from diagrams included in Mr Emmons' paper, assuming that the average relationships for the data may be represented by straight lines

It should be emphasized again that Mr Emmons warns against assigning too much weight to apparently quantitative values such as these, and particularly against comparing the slopes of the curves for the normally cured and frozen specimens as has been done in Table II. One of the factors complicating the test results was the inadvertent inclusion of a certain amount of apparently unsound chert in the so-called "sound" coarse aggregate to which the soft particles were added. As a result of his studies, Mr Emmons concludes that there can be little doubt that the presence in concrete aggregates of materials such as those studied is injurious, the strength of the concrete is reduced and its

liability to deterioration under freezing and thawing conditions greatly increased. He points out that much of the effect of such materials is dependent upon the location of the particle in the structure and that this is a factor which cannot be controlled. He recommends that the permissible quantities of soft and unsound particles in coarse aggregates be reduced to the economic minimum. This economic

TABLE II  
EFFECT OF SOFT PARTICLES ON STRENGTH OF CONCRETE  
Data from investigation carried out by Michigan Highway Department (23)

Type of soft particle	Per cent reduction in strength					
	For each 1 per cent soft particle				For each 1 per cent reduction in section modulus (modulus of rupture)	
	Compression		Modulus of rupture		Normal curing	Frozen and thawed
	Normal curing	Frozen and thawed	Normal curing	Frozen and thawed		
Shale	1.8	1.9	0.6	0.6	0.6	0.7
Floater	0.9	1.6	1.1	1.0	0.8	1.0
Ochre	1.8	1.8	1.4	3.5	0.8	1.4
Soft Sandstone	0.7	2.2	1.8	1.7	1.1	1.2
Borderline Sandstone	0.4	0.6	1.0	0.4	1.0	0.7
Hard Absorbent Sandstone	1.1	0.6	0.8	1.1	1.1	0.7

TABLE III  
SUMMARY OF RESULTS OF FREEZING AND THAWING TESTS  
Data from investigation of the Michigan State Highway Department (23)

Type of soft particle	Number of pieces appearing in disintegration				
	Pits	Spalls	Fractures	Per cent appearing	Rating*
Shale	2			0.1	2
Floater		1	4	0.4	14
Ochre	65	17	29	5.0	186
Soft Sandstone	35	28	22	4.2	157
Borderline Sandstone	23	8	18	2.5	93
Hard Absorbent Sandstone	7	1		0.2	9

\* Arbitrary value of 1, 2 and 3 was assigned respectively to pits, spalls and fractures and a rough rating computed.

minimum will, of course, vary with the locality and the aggregates available for use.

The principal object of the freezing and thawing tests was to determine how the several types of soft particles would affect the durability of the concrete. Based on observations of pits, spalls and fractures, Mr. Emmons calculated a rating for the effects of the various types of particles, which is shown in Table III.

## TESTS OF CONCRETE CONTAINING SOFT PARTICLES AND SHALE (NORTH DAKOTA HIGHWAY DEPARTMENT)

The North Dakota State Highway Department made compression tests of concrete in which various percentages of "soft rock" and shale were included in gravel used as the coarse aggregate. The data were reported by H G Groves (29). The soft rock was a hard-shelled, dark brown particle, which, upon weathering, checked and peeled, exposing a core of more or less soft material. The results of the tests are summarized in Table IV.

Mr. Groves explains the increases in strength indicated for the addition of 2 and 4 per cent of soft particles as due to the high absorption of the aggregate causing reductions in the water-cement ratio. He points out that the tests show that up to six per cent of the "soft rock" and

TABLE IV

## EFFECT OF SOFT MATERIAL IN COARSE AGGREGATE ON STRENGTH OF CONCRETE

Data from investigation of the North Dakota State Highway Department (29)

Compression tests of 6 by 12-in concrete cylinders  
Water-cement ratio, 0.9

Percentage of soft particle	Compressive strength, lb per sq in					
	"Soft rock"			Shale		
	28 days	6 month	1 year	28 day	6 month	1 year
0	3828	4378	4315	3554	4012	3836
2	4087	4489	4498	3572	4212	4181
4	4011	4262	4413	3488	4020	4028
6	3916	4183	4233	2977	3248	3477

four per cent of the shale might be included in the aggregate without any appreciable loss in compressive strength. He emphasizes the fact, however, that this investigation does not show the effect of weathering and that such quantities of these materials should not be permitted in aggregate, except "where the concrete would not be exposed to the weather, such as concrete bases for black-top pavement, foundation walls when waterproofed, etc."

## TESTS OF CONCRETE MADE WITH BLUE SHALE AND BLUE LIMESTONE (KENTUCKY HIGHWAY DEPARTMENT)

An investigation to determine if concrete made from unsound stone would disintegrate when placed in a sodium sulfate solution and when exposed to the weather was conducted by the Kentucky State Highway Department (24). The aggregates investigated consisted of (a) low grade blue shale, (b) fair grade blue limestone, and (c) a mixture con-

sisting of 50 per cent of shale and 50 per cent of limestone. All of the materials came from the same quarry. Opportunity has not been had to study the details of these test data; summaries of them appear in the 1928, 1929, and 1930 reports of the American Association of State Highway Officials' Committee on Highway Research Activities. The following conclusions were stated in the 1930 Report:

"1 The blue shale should not be allowed to the extent of 5 per cent of the coarse aggregate

"2 Screenings from stone containing this shale should not be used

"3 Coarse aggregate that contains blue shale will require more water. If the water-ratio is controlled and the cement factor increased accordingly, satisfactory strength should be obtained and the concrete should not disintegrate

"4 No satisfactory method has been found for the elimination of this shale, except to hand pick the stone from such quarries "

#### TESTS OF EFFECT OF SHALE ON STRENGTH AND DURABILITY OF CONCRETE (TENNESSEE HIGHWAY DEPARTMENT)

The Tennessee State Highway Department carried out an investigation of the effect of shale in coarse aggregate on the strength of concrete and on its resistance to disintegration by freezing and thawing. Compression and flexural tests were made. Each type of specimen was made in two groups,—one of which was subjected to normal curing conditions and the other to freezing and thawing conditions. The report of this investigation states that the inclusion of 5 and 10 per cent of shale in the coarse aggregate had no effect on the durability of concrete subjected to 45 cycles of freezing and thawing and no important influence on either the compressive or transverse strength. It was concluded that five per cent would represent a suitable specification limit on shale, provided that the total of shale and similar substances would not exceed this amount.

#### SPECIFICATION LIMITS ON AMOUNT OF SHALE AND SIMILAR MATERIALS

The investigations which have been summarized represent practically the sum total of quantitative data available from researches directed to the specific problem under discussion. They furnish valuable information, but a study of them will indicate the difficulty of deriving any generally applicable specification limits on shale and similar materials. As has been pointed out, the characteristics of shales and other soft particles vary over a wide range, depending on the conditions of their formation. It has been necessary, therefore, to base specification limits on a consideration of the results in service in various localities and of the feasibility of obtaining aggregates which will serve the purpose economically. In view of this rule-of-thumb basis for specification limits, the summary of the requirements of the different states,

shown in Table V, should be of interest. While the differences in requirements for the various localities depend to a considerable extent on differences in judgment of engineers, it is believed that, in a large measure, they may be assumed to have been dictated by the characteristics of the shale, or materials classified as shale, and the severity of climatic conditions. States not included in Table V usually infer limitations on shale and the like by such general statements as "free from injurious amounts of soft, friable and laminated particles."

TABLE V  
SPECIFICATIONS OF STATE HIGHWAY DEPARTMENTS FOR MAXIMUM ALLOWABLE QUANTITIES OF SHALE AND SOFT PARTICLES IN CONCRETE AGGREGATES

State	Date of specification	Maximum per cent shale in aggregate		Maximum per cent soft, friable fragments and other deleterious particles including shale	
		Fine	Coarse	Fine	Coarse
Florida	1930	1 0	1 0	5 0	5 0
Georgia	1931			1 0	
Illinois	1930	1 0	1 0	3 0	5 0
Indiana	1929				5 0
Iowa	1930	1 0*	0 5		5 0
Kansas	1931		0 5	1 0	3 0
Kentucky	1930		None		
Louisiana	1930				6 0
Maryland	1931				5 0
Michigan	1931				3 0
Minnesota	1931		0 7	2 5	2 5
Mississippi	1931		1 0		5 0
Nevada	1931			3 0	5 0
New Jersey	1931				5 0
North Dakota	1932	2 0	1 0		
Oklahoma	1931	1 0	0 5	5 0	5 0
Tennessee	1931	1 0	1 0	5 0	5 0
Texas	1931		0 25		5 0
Virginia	1931				5 0
Washington	1930			2 0†	10 0
West Virginia	1929				5 0
Wisconsin	1931		1 0		5 0

\* Shale and coal particles larger than .0462 inches

† For particles having a specific gravity of less than 1.95

Specifications for aggregates which are national in scope invariably include mention of shale. The recommendations of the American Society for Testing Materials for aggregates are sufficiently representative of other leading national specifications that excerpts from them will serve to illustrate the nature of the information which they include. For fine aggregate, it is stated that total coal, clay lumps, shale, soft fragments, and other deleterious substances shall not exceed five per

cent Specific limitations are placed on coal and clay lumps, but the only mandatory requirement for shale is that it, together with the other materials named, shall not exceed the five per cent total This recommendation is qualified in the specification by a statement that "It is recognized that under certain conditions percentages of deleterious substances less than those shown in the table should be specified as a maximum " For the coarse aggregate a five per cent limit is placed on the total shale, coal, clay lumps and soft fragments, with a specific limit of one per cent on *shale removed by the flotation test*. These limitations are qualified in the same manner as those for fine aggregates

#### METHODS FOR DETECTING SHALE (18)

No generally applicable method for the determination of shale, other than a petrologic examination, has been developed A number of different flotation tests have been outlined and used successfully in localities where the specific gravity of the shale differs considerably from that of the sound aggregate, liquids of high specific gravity, such as lead acetate, acetylene tetrabromide, bromoform, zinc chloride, etc , have been used These methods are most applicable to coarse aggregate, since, in many cases, the surface tension of the liquid is sufficient to support even the heavier particles of fine aggregate Even examinations by geologists do not agree, the authors have in mind one sample, examined by three geologists, for which percentages of shale ranging from something of the order of 10 to 30 per cent were reported

#### TESTS ON BEHAVIOR OF SOFT AND NON-DURABLE PARTICLES

The unsatisfactoriness of specification limits on shale, per se, or on similar substances, is obvious from a consideration of the wide range in characteristics and of the difficulty of identifying different types of particles Specification writers have realized these difficulties and it has been their goal to develop methods which will permit of basing limitations on some measurable characteristics of the materials The action of freezing and thawing and of various salts, used in such a way as to simulate freezing and thawing, are being investigated Studies are being made to determine the relationship between the results of such tests on the aggregate and the resistance of concrete and mortar to the action of the weather and to laboratory tests of durability

Work of this nature has not been carried to a point where specification limits can be based on it with definite assurance of establishing an accurate line of demarcation between satisfactory and unsatisfactory materials, although certain organizations have incorporated in their specifications limitations on the disintegration of the aggregates when tested in various ways An example of this trend is the specification of the Division of Highways of New York, which requires both fine and coarse aggregates to pass a sodium sulfate test Consideration is now

TABLE VI

## SODIUM SULFATE SOUNDNESS TESTS OF FINE AGGREGATES

Data from tests carried out by the National Sand and Gravel Association Tests made in accordance with "Tentative Method of Test for Soundness of Fine Aggregate by Use of Sodium Sulfate," (Ser Desig C88-31T) of the American Society for Testing Materials, except that the sodium sulfate solution was maintained at a temperature of 80 deg F

Each result is the weighted average loss determined from independent tests of different sizes of the sample

Lot No	Source	Principal mineral constituent	Weighted average per cent loss in 5 cycles	
			Test no 1	Test no 2
283 a	Iowa	Quartz and granitic minerals	4 1	3 8
283 b	Iowa	Quartz, quartzite and granite	2 5	2 7
283 c	Iowa	Quartz, quartzite, limestone, sandstone and granite	2 9	4 0
426	N Y	Sandstone, limestone, quartz	9 9	
428	N Y	Sandstone, limestone, quartz	8 4	
434	N Y	Sandstone, limestone, quartz	5 3	
437	N Y	Quartz, quartzite, limestone and sandstone	5 4	
438	Pa	Sandstone, quartz, shale	19 1	21 0
444	Pa	Sandstone, limestone, quartz	4 2	4 1
445	N Y	Sandstone, limestone, quartz	9 8	9 2
446	N Y	Limestone screenings	3 9	3 8
447	N Y	Sandstone, limestone, quartz	11 9	12 0
451	N Y	Quartz, limestone, sandstone, shale	14 5	14 7
453	Pa	Quartz, quartzite, sandstone	4 7	4 1
454	N Y	Quartz, quartzite, granite	4 0	4 4
455	Pa	Sandstone, limestone, quartz	10 1	9 7
458	N Y	Quartz, quartzite, granite	1 3	1 4
468	N Y	Sandstone, limestone, quartz	10 5	11 0
473	Ohio	Sandstone, limestone, quartz, feldspar, etc	3 7	3 1
474	Ohio	Sandstone, limestone, quartz, feldspar, etc	3 5	3 6
490	N Y	Quartz, quartzite, granite, limestone	1 2	1 5
495	N Y	Quartz, chert, quartzite, sandstone, limestone	4 2	4 2
501	N Y	Sandstone, limestone, quartz	6 1	5 9
505	N Y	Sandstone, limestone, quartz	4 8	4 8
518	N Y	Limestone, sandstone, quartz	4 3	4 1
528	N Y	Sandstone, limestone, quartz	7 5	7 4
531	N Y	Sandstone, limestone, quartz	7 5	7 7
542	D C	Quartz, quartzite, feldspar, gneiss	2 6	1 8
565	Pa	Sandstone, quartz	3 8	4 0
566	Pa	Sandstone, quartz	10 0	8 8
571	Pa	Sandstone, quartz	5 1	4 3
572	Pa	Sandstone, quartz	4 9	7 1
607	N Y	Quartz, quartzite, sandstone, limestone	4 3	5 2
612	N Y	Sandstone, quartz, limestone	5 1	6 8
613	N Y	Granite, quartz, feldspar	3 6	3 2
614	N Y	Quartz, granite, feldspar	2 9	1 6

being given by that state to the substitution of magnesium sulfate for sodium sulfate. The tentative methods of test for soundness of fine and coarse aggregate by use of sodium sulfate (Serial Designation. C88-31T and C89-31T) of the American Society for Testing Materials are further examples of this trend.

While specifications such as these appear to provide a more logical basis for judging the quality of an aggregate than the usual method of identification of specific materials, there is still much information to be developed before such a procedure can be considered as a satisfactory basis for acceptance. Such data as are available do not show a definite relationship between the results of tests of this kind and the behavior of

TABLE VII  
ACCELERATED SODIUM SULFATE TESTS OF GRAVELS

Data from tests carried out by the National Sand and Gravel Association. Tests made in accordance with "Tentative Method of Test for Soundness of Coarse Aggregate by Use of Sodium Sulfate" (Serial Designation C89-31T) of the American Society for Testing Materials, except that the solution was maintained at 80 deg F, unless otherwise noted.

Lot No	Source	Principal mineral constituents	Weighted average per cent loss in 5 cycles
389	N Y	Limestone, sandstone, shale, shaley sandstone	5 8
390	N Y	Limestone, sandstone, shale, shaley sandstone	4 1
391	N Y	Limestone, sandstone, igneous particles	6 8
393	N Y	Sedimentary and metamorphic particles	3 4
395	N Y	Igneous and sedimentary particles	0 2
427	N Y	Limestone, trap rock particles	5 3
452	N Y	Limestone, sandstone, quartz	30 0
527	Okla	Limestone, dolomite, conglomerate	8 3*
569	Pa	Sandstone, quartz, quartzite	2 4
570	Pa	Sandstone, quartz, quartzite	4 7

\* Test made with sodium sulfate solution maintained at 70 deg F

the materials in service, and warn against the too arbitrary use of such methods.

A discussion of this phase of the problem goes considerably beyond the scope of this paper, but it will be of interest to refer briefly to some of the work which is being directed along these lines. An adequate summary of this work should be made the subject of an independent report to supplement information such as is included in this and similar papers.

The freezing and thawing test appears to represent most nearly the action of the weather on aggregates and concrete. Investigations of freezing and thawing as a method of test are being carried out by several different laboratories. Notable among them are the U. S. Bureau of

Public Roads, the U S Bureau of Standards, the Engineering Experiment Station of the Kansas State College, the University of Minnesota, the Portland Cement Association, the National Crushed Stone Association and several others. So far no standardized procedure has been developed, and results of tests by different investigators vary over a considerable range. Until a standard procedure is developed, which will insure different laboratories obtaining the same results on the same materials, freezing and thawing test methods cannot be considered as suitable acceptance tests. Preliminary work in the development of a

TABLE VIII

## ACCELERATED SODIUM SULFATE TESTS OF SIX SAMPLES OF SAND FROM SAME SOURCE

Data from tests carried out by the National Sand and Gravel Association

Two tests made on independent samples from the same lot of sand, duplicate tests were carried out at the same time

Tests made in accordance with "Tentative Method of Test for Soundness of Fine Aggregate by Use of Sodium Sulfate" (Serial Desig C88-31T) of the American Society for Testing Materials, except that the sodium sulfate solution was maintained at a temperature of 80 deg F

Samples selected and tested at various times over a period of ten months

Test No	Per cent loss in 5 cycles of treatment of each size						Weighted average per cent loss*
	100-50	50-30	30-16	16-8	8-4	4-3	
1	3.3	10.6	9.3	9.8	9.4	18.6	9.4
2	2.2	11.0	8.3	9.0	7.8	12.0	8.5
3	5.4	7.2	11.4	9.0	11.4	24.4	9.8
4	2.4	4.0	9.9	15.8	20.0	26.8	11.8
5	4.9	7.6	8.6	10.9	14.6	20.6	10.1
6†	1.2	1.6	5.0	10.0	10.4	‡	6.5

\* Weighted according to average sieve analysis of all six samples

† Test made of material sampled after certain changes in production method designed to reduce sodium sulfate loss

‡ Sample did not contain any of this size. For purpose of computing weighted average loss shown in this tabulation an average of the previous 5 tests of this size was taken (20.5 per cent)

standardized procedure is represented by a Proposed Method of Making Freezing-and-Thawing Test of Concrete and Concrete Aggregates presented before the last meeting of the American Society for Testing Materials (39)

The use of salts, which, in solution, are absorbed by the aggregate and then crystallized during the soaking and drying process to simulate freezing and thawing, are being investigated by several laboratories, including most of those listed above and some additional ones. Most attention has been paid to the use of sodium sulfate, adapting the fundamentals of a procedure developed years ago in tests of building

stone (1) The sodium sulfate test has been fairly well standardized, as outlined in the tentative methods of the American Society for Testing Materials referred to previously. This test, however, leaves much to be desired because of a variety of reasons. No satisfactory correlation has been found between its results and other durability tests on aggregates and concrete made from them.

The test is difficult to control, the solubility of sodium sulfate varies greatly with temperature and, unless the most minute care is exercised in controlling the conditions of the tests, erratic results are obtained. Recently, considerable thought has been given to the substitution of magnesium sulfate for the sodium sulfate. This salt recommends itself because its solubility is not so sensitive to temperature changes as in the case of sodium sulfate, and because there is a greater constancy in the nature of the crystals which are formed. Such work as has been done with magnesium sulfate has, for the most part, followed the procedure outlined for sodium sulfate. Other salts are being considered and several of them investigated. While, as stated previously, this paper cannot be expected to attempt anything approximating a complete account of such investigations, it should be of interest to summarize some typical results.

#### PORTLAND CEMENT ASSOCIATION'S TESTS

The Portland Cement Association (32) has carried out one of the most comprehensive of the investigations comparing soundness tests of aggregates with the resistance of concrete and mortar to freezing and thawing. The work included petrological examination of the aggregates in addition to sodium sulfate and freezing and thawing tests. Many of the sands were suspected of containing relatively large amounts of non-durable particles. Figure 5 shows a comparison between the results of sodium sulfate tests on sands and the amounts of various types of non-durable particles. Figure 6 summarizes freezing and thawing tests on mortar of different water-ratios made with the same sands as shown in Figure 5.

The outstanding feature indicated by these tests was the very marked influence of the quality of the protecting cement paste on the resistance of the aggregates to freezing and thawing in mortar and concrete. When incorporated in a paste of high quality, even those aggregates which showed relatively poor performance in the soundness tests, exhibited a high degree of resistance in 2 inch mortar cubes which withstood as many as 200 cycles of freezing and thawing without showing an excessive amount of failure. On the other hand, when a paste of poor quality was used, mortars made with the best of the aggregates showed relatively poor performance.

The authors of the report point out that the materials which appear to be least resistant to direct soundness tests are shale, chert, slate,

argillaceous sandstone and argillaceous limestone Of these they felt the shale and chert particles to be the most detrimental to mortar and concrete They point out, however, that it is not possible, with our present knowledge, to predict the probable behavior of aggregate in concrete and mortar solely on its behavior in freezing and thawing

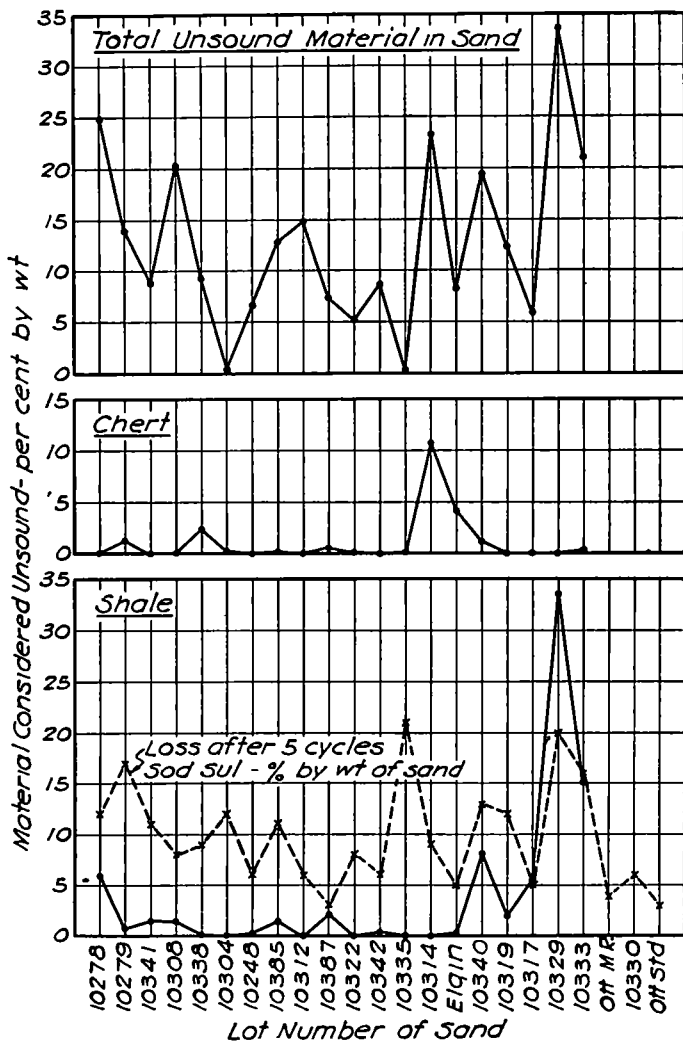
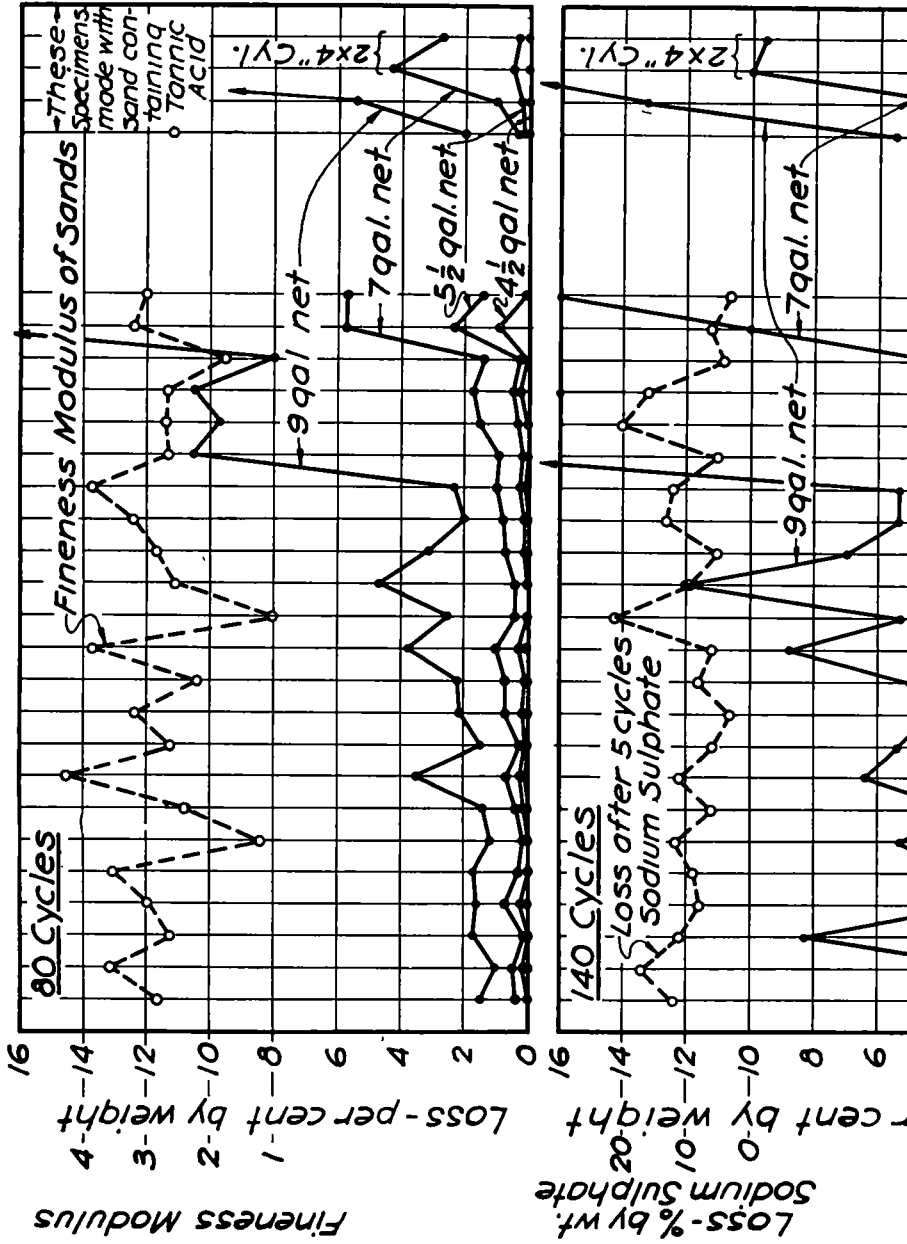


Figure 5. Relation between Sodium Sulphate Test and Amount of Unsound Materials

From tests carried out by the Portland Cement Association and reported in a paper on "Durability Studies of Aggregates and Concrete," by H. F. Gonnerman and G. W. Ward, before the Seventh Annual Convention of the Association of Highway Officials of North Atlantic States, and published in Proceedings of that Association, in 1931, and in the May, 1931 issue of the National Sand and Gravel Bulletin.



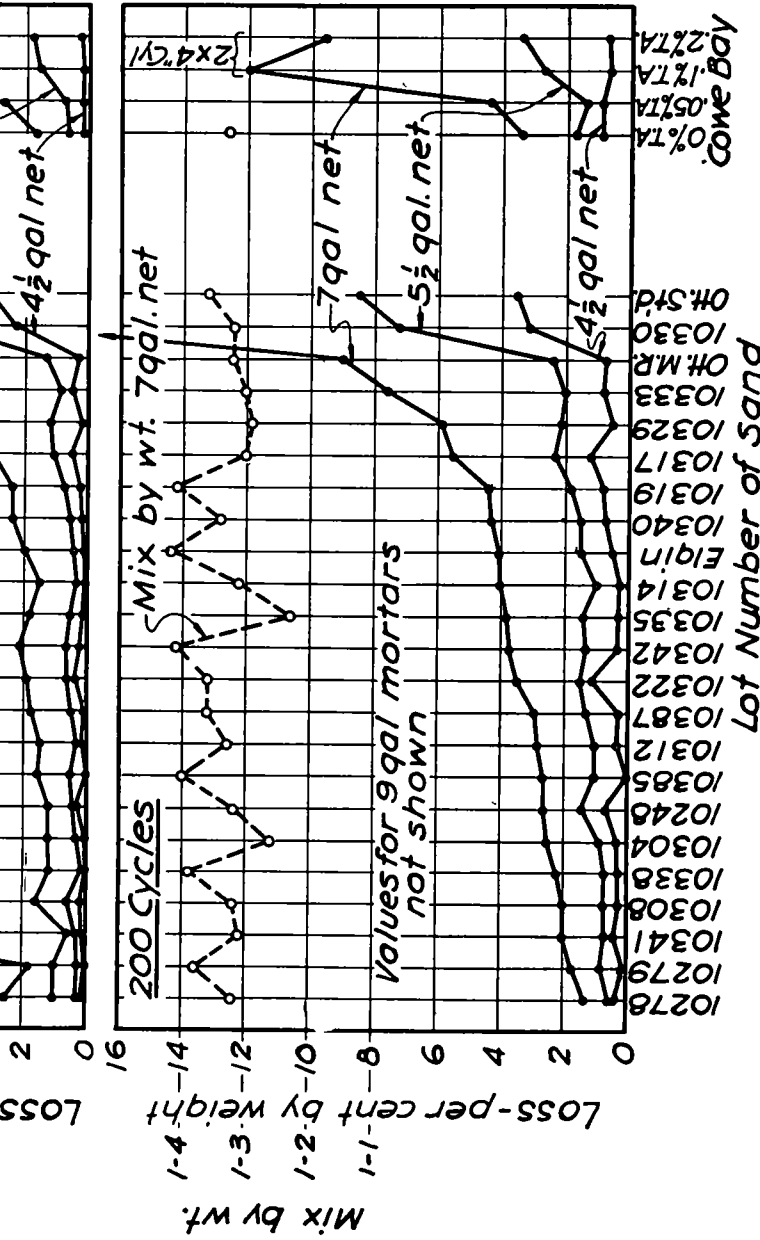


Figure 6 Losses in Weight of 2 inch Mortar Cubes at 80, 140, and 200 Cycles of Freezing and Thawing Sands arranged in ascending order of losses in weight of 7-gallon cubes at 200 cycles.

From tests carried out by the Portland Cement Association and reported in a paper on "Durability Studies of Aggregates and Concrete," by H. F. Gonnerman and G. W. Ward, before the Seventh Annual Conventon of the Association of Highway Officials of North Atlantic States, published in Proceedings of that Association, in 1931, and in the May, 1931, issue of the National Sand and Gravel Bulletin.

tests Nevertheless, it is conservative to look with suspicion on those aggregates showing relatively poor results in freezing and thawing tests until such time as it is proved that they are suitable for use.

#### NATIONAL CRUSHED STONE ASSOCIATION'S TESTS

Tests of the behavior of sound and unsound aggregate in concrete and mortar subjected to freezing and thawing, made by the National Crushed Stone Association, are reported by A T Goldbeck in the April 1931 issue of the Crushed Stone Journal (27) That investigation and those which have been carried out by the same laboratory more recently have failed to develop a satisfactory correlation between soundness tests on the aggregate and soundness tests on concrete and mortar In fact, in certain cases, greater disintegration was found for mortar made with a sand which would be considered durable from tests made on it and from its record of service than was found for a sand which was generally considered to be unsound and which gave poor results in the usual tests Mr Goldbeck found that tests of a coarse aggregate, unsound by the usual tests, did not necessarily make for unsoundness in concrete The unsound stone tested did not crack the concrete nor did it leave the concrete or cause pitting, it was only after the mortar had disintegrated that the stone failed by continuous chipping

#### NATIONAL SAND AND GRAVEL ASSOCIATION'S TESTS

The Laboratory of the National Sand and Gravel Association has directed a great deal of attention to the development of the technique of carrying out accelerated soundness tests using sodium sulfate and magnesium sulfate A reasonably satisfactory duplication of results has been obtained Comparisons with other laboratories have shown fairly good checks with those having proper control apparatus and sufficient experience with the test to have developed accurate technique Certain of the data of that laboratory are summarized here in order to furnish information on the order of magnitude of results of sodium sulfate and magnesium sulfate tests, and on their uniformity when the tests are made by the same operator, on different samples from the same source, and by different laboratories

In Table VI sodium sulfate tests on several different sands are summarized together with a rough mineral classification of the samples The duplicate tests were made by the same operator and illustrate the degree of uniformity which can reasonably be expected under these conditions Table VII gives sodium sulfate tests on different samples of gravel, the durability of which had, in general, been questioned Table VIII gives the results for six samples of sand collected from the same source over a period of about a year Table IX compares the results of tests of several laboratories on separate portions of the same samples of sand In Table X tests made with magnesium sulfate and

TABLE IX

## COMPARISON OF SOUNDNESS TESTS MADE BY DIFFERENT LABORATORIES

Data from tests carried out by several laboratories on separate portions of the same samples of sand

In general, soundness tests were made in accordance with "Tentative Method of Test for Soundness of Fine Aggregate by Use of Sodium Sulfate," (Serial Designation C88-31T) of the American Society for Testing Materials.

Samples submitted to the laboratories were obtained by carefully quartering a well mixed sample

Laboratory	Nominal temperatures of solution, Fahrenheit	Per cent loss in 5 cycles					Weighted average per cent loss
		100-50	50-30	30-16	16-8	8-4	
Sodium sulfate soundness tests of Lot 505							
A	70°		2 0	3 9	6 2	6 4	3 7
B	70°*		2 6	3 2	4 3	8 6	3 71
"	80°		5 6	12 5	16 1	16 7	11 22
C	80°	4 0	8 7	6 3	4 7	9 5	6 9
D	80°	2 0	3 0	8 0	16 0	26 0	8 6
E	80°	1 3	1 6	5 0	9 9	10 5	4 6
Sodium sulfate soundness tests of Lot 531							
A			4 4	6 9	8 7	16 9	7 3
"			5 3	7 5	9 9	27 2	8 9
D		1 0	2 0	7 5	16 0	17 0	7 3
E		2 6	5 2	5 8	13 1	11 8	7 5
Magnesium sulfate soundness tests of Lot 505							
A							
B	80°		6 3	12 2	17 8	24 9	12 4
C	80°	7 7	23 5	19 8	15 2	15 2	18 7
D	80°	10 0	19 0	30 0	30 0	40 0	24 5
E	80°	7 5	17 4	26 3	27 1	22 4	20 9
Magnesium sulfate soundness tests of Lot 531							
A			17 8	32 0	29 9	36 9	26 8
"			17 3	27 0	27 3	26 9	23 5
D		8 5	20 0	27 0	29 0	26 0	22 6
E		7 0	14 0	19 7	20 3	17 1	16 7

\* Average of two tests

TABLE X  
COMPARISON OF EFFECT OF SODIUM SULFATE AND MAGNESIUM SULFATE IN  
ACCELERATED SOUNDNESS TESTS

Data from tests carried out by the National Sand and Gravel Association

Two tests made with each salt on independent samples from the same lot of sand; comparative tests made at the same time and in duplicate, in accordance with the "Tentative Method of Test for Soundness of Fine Aggregate by Use of Sodium Sulfate" (Ser Desig C88-31T) of the American Society for Testing Materials, except that the sulfate solution was maintained at a temperature of 80 deg F

Sample	Sulfate solution	Per cent loss in 5 cycles for each size						Weighted average per cent loss
		100-50	50-30	30-16	16-8	8-4	4-3	
505	Sodium	1 2	1 6	5 0	10 0	10 4		4 6
505	Magnesium	7 6	17 4	26 3	27 0	22 4		20 9
518	Sodium	2 5	2 0	2 8	5 4	7 2	7 1	4 2
518	Magnesium	6 5	11 8	15 8	15 8	10 8	7 5	12 2
528	Sodium	3 8	3 9	6 8	10 2	13 2		7 4
528	Magnesium	6 3	10 5	13 1	13 6	11 7		11 4
529	Sodium	4 5	7 3	9 0	8 6	6 7		6 5
529	Magnesium	11 6	16 6	18 2	15 3	11 4		13 4
530	Sodium	5 4	6 4	7 8	5 7	4 4		5 9
530	Magnesium	11 8	14 6	16 8	6 5	2 8		12 2
531	Sodium	2 6	5 2	5 8	13 1	11 8		7 6
531	Magnesium	7 0	14 0	19 7	20 3	17 1		16 7
565	Sodium	2 1	2 8	3 6	5 7	6 4	6 2	3 9
565	Magnesium	6 7	9 0	12 3	14 6	14 4	12 3	10 7
566	Sodium	2 7	5 4	10 0	11 6	19 6	25 4	9 4
566	Magnesium	8 2	19 2	49 4	64 3	63 2	63 6	32 2
542	Sodium	2 2	1 8	2 6	1 8	2 7	3 7	2 2
542	Magnesium	7 6	6 8	8 2	12 0	9 4	12 0	8 0

sodium sulfate using the same procedure as for sodium sulfate are shown Table IX also includes information along those lines

#### ELIMINATION OF SHALE AND SOFT STONE FROM AGGREGATES (40)

As specification limits have become more rigid and as the aggregate producer has developed less satisfactory sources, considerable attention has been paid to methods for the elimination of shale and similar materials. This problem has been studied for several years and satisfactory results have been obtained in some cases. The range in quality of the materials which it is desired to eliminate has made the problem a different one for each source.

Discussions of methods of eliminating undesirable particles have been published from time to time. A recent paper in *Rock Products* (40) reviews the several methods which have been tried. Jigs, log washers and hydraulic separation devices of one sort or another have been used. Recently most attention has been paid to devices which break up the soft particles by throwing the aggregate against plates or by grinding it in a type of ball mill. According to Mr. Huntington, in the *Rock Products* article referred to, experiments are now being carried out on the use of selective crushers.

These methods have not proven uniformly successful on account of the wide variety of conditions to be met. All of them, however, have been used with success in specific cases. In one case, recently called to the attention of the writer, sufficient soft stone was broken up to make a gravel meet specification requirements for abrasion which it had previously failed to pass.

#### CONCLUSION

A review of the foregoing discussion leads to the following observations:

1. Soft, friable and non-durable particles are detrimental to concrete aggregates. Shale is one of the several types of particles occurring in natural aggregates which meets this description.

2. Due to the wide range in quality of shales and similar materials, it is difficult to place logical specification limits on them which are applicable beyond the limits of a fairly small territory.

3. Investigations of the effects of shale and similar substances in concrete aggregates have yielded valuable information, but have not provided a conclusive basis for fixing specification limits. Most present day specification limits are based on engineering judgment formed from a consideration of the service records of the aggregates and from a consideration of the economics of the problem in a given locality.

4. It is desirable to develop testing procedure which will permit of basing specification limits on the resistance of the aggregate particles in a suitable test, without reference to mineral composition.

5 Soundness tests of aggregates are being subjected to intensive study, but, thus far, a satisfactory correlation has not been found between the results of such tests and the behavior of aggregate in concrete subjected to destructive agencies

As was emphasized in the body of this discussion, no attempt has been made to give a complete summary of the more recent investigations of the general problem of durability of aggregates. Reference has been made to many investigators, whose work has been discussed briefly in this paper and who have obtained results which have not been available to its authors at the time of its preparation. It is hoped that these investigators will supplement the information contained in this paper by including their data in discussions of it

#### REFERENCES

(November, 1932)

Many of the references, and particularly the early ones, are from an unpublished bibliography prepared by the Portland Cement Association

1828

- 1 Brard, *Annales de Chemie et de Physique*, v 38, p 160, 1828

1837

- 2 *Treatise on Calcareous Mortars and Cements*, by L. J. Vicat  
Translated from French by J. T. Smith (J. Weale, London)  
1837

Following is from Appendix to Vicat's book by Smith "Whilst we were engaged with these researches, Mr Brard (then director of the collieries of Lardin, in the department of Dordogne), tried to distinguish the stones which are injured by frost, from those which are not so, by substituting for the expansive force of congealing water, that of an easily crystallizable salt, the sulfate of soda. No sooner were we made acquainted with this happy idea, than we were eager to try it upon our mortars. In conformity with the directions of the able mineralogist whom we have just named, a hundred specimens were impregnated with a warm, saturated solution of the sulfate of soda, and then exposed in a loft to the temperature of 25° to 30° Centigrade (77° to 86° Fahrenheit, Tr), and lastly, washed from day to day with pure water. These specimens were not long in giving signs of degradation."

1895

- 3 *Relative Effects of Frost and Sulfate of Soda Tests on Building Stones*  
*Trans Am Soc Civil Eng*, v 33, p 249, 1895

Tests on western building stones by immersion in water during day and in cold storage room at night at 0 to 4°F for 12 days, loss in weight recorded

1915

- 4 Effect of Saturated Sodium Sulfate Solution upon Structure of Clay Burned to Different Temperatures, by W L Howat  
Trans Am Ceramic Soc , v 17, p 249, 1915

1916

- 5 Comparison between Sodium Sulfate and Freezing Tests for Drain Tile, by H. F. Staley.  
Trans Am Ceramic Soc , v 18, p 642, 1916.

Tests on hard and soft 8-in , 12-in , and 16-in clay drain tile from 4 Iowa factories and 8-in and 16-in concrete tile Sodium sulfate test considered practical for clay tile, but not for concrete because of chemical action.

1921

- 6 Nashville Concrete Bridges Show Serious Deterioration, by W W Southgate Engineering News-Record, December 8, 1921, p. 934.

Limestone screenings used for fine aggregate Quarry badly interspersed with shale,—one of causes of concrete disintegration

1922

- 7 Shale Removed from Gravel by Jigging.  
Engineering News-Record, v. 88, 1922, p 1034.

Describes jig prepared by Minnesota Pipe and Tile Co with aid of Profs. Lang and Davis of University of Minnesota

- 8 Effect of Shale Pebbles in Concrete and Removal of Shale from Gravel, by F C Lang  
Minnesota Techno-log, v 2, January, 1922, p 11

Description of method of separating shale from aggregate, results of included shale, etc

- 9 Simple Test for Determining Shale Content of Sand  
Concrete Highway Magazine, 1922.  
Engr. and Contr , Nov. 1922, p 94

Like in gold washing, sand settles to bottom and shale being lighter will float to top

1923

- 10 Interesting Case of Dangerous Aggregates, by Pearson and Loughlin  
Concrete, April, 1923, p 144

Unsuitability of altered lime-soda feldspar aggregate for concrete; unaltered feldspar good material for concrete aggregates

## 1924

- 11 Soundness Tests on Minnesota Rock  
Bull 20, Minnesota Highway Dept , 1924

Sodium sulphate tests on trap rock, quartzite, granite, limestone and sandstone

## 1925

- 12 Soundness Tests for Coarse Aggregates, by M O Withey  
Proc 4th Annual Meeting Highway Research Board, 1925,  
p 108

4 types of crystallization tests used for determining soundness of stone and clay products (a) freezing and thawing test, (b) sodium sulfate test, (c) sodium chloride test, and (d) alkali test  
Method of making tests and results of soundness tests on various aggregates

- 13 Shale in Sand, by P M Hogdal  
Public Roads, v 6, July, 1925, p 116  
Engr and Contr , v 64, November 4, 1925, p 64

Lead acetate solution used

## 1927

- 14 Summary of Tests on Effect of Shale in Gravel on Compressive Strength of Concrete, by F C Lang  
Appendix 3, Report of Subcommittee on Gravel, Comm E-5, A C I  
Proc Am Conc Inst , v 23, 1927, p 592  
Natl Sand and Gravel Bulletin, May, 1927, p 5  
Bull 5, National Sand and Gravel Association, March, 1930

Tests carried out by Minnesota State Highway Department  
The conclusions are that shale is detrimental especially when concrete is subjected to weathering

- 15 Qualifications of Different Kinds of Natural Stone for Concrete Aggregates, by G F Loughlin  
Proc Am Conc Inst , v 23, 1927, p 319-354

Discussion of physical and chemical properties of natural stone and weathering effects

- 16 Durability Tests of Aggregates  
Tech News Bull , Bureau of Standards, p 7, July, 1927  
Rock Products, v 30, p 51, September 17, 1927

Alkali, sodium sulfate, sodium chloride, and boiling and drying tests for soundness of aggregates

17. Relation between Sodium Sulphate Soundness Tests and Absorption of Sedimentary Rock, by D O Woolf  
Public Roads, v 8, p 225, December, 1927  
Rock Products, v 31, p 39, January 7, 1928

150 rocks tested for soundness and absorption, 43 per cent were unsound, of samples with absorption greater than 2 per cent, 82 per cent were unsound

1928

- 18 Proposed Test for Percentage of Shale in Gravel, "Standard and Tentative Methods of Sampling and Testing Highway Materials"

Bull 1216, U S Dept of Agriculture, Revised, September, 1928, p 20

Suggested method for separation of shale and other pieces having low specific gravity from concrete aggregates

- 19 Some Accelerated Freezing and Thawing Tests on Concrete, by C H Scholer  
Proc Am Soc Testing Mats, 1928, Pt II, p 473

Progress report on tests reported in Bulletin No 28 of the Kansas State College

- 20 Usefulness of Petrology in the Selection of Limestone, by G F Loughlin  
Rock Products, March 17, 1928, p 50

Roads built in Green County, Penn in 1919 with stone containing shale began to disintegrate appreciably in three years Gives results of physical tests of limestone and shale carried out by the Pittsburgs Testing Laboratory in 1920 and in 1926 Brief descriptions of unsound stones from Illinois, Iowa, and Kansas Table, giving some chemical and physical properties of argillaceous limestones classified by sodium sulfate test, includes data from above sources

1929

- 21 Influence of Coarse Aggregate on the Durability of Concrete, by F R McMillan and Geo W Ward  
Proc Am Soc Testing Mats, 1929, Pt II, p 816

Brief review of literature bearing on failure of aggregate of various types, igneous, sedimentary and certain metamorphic rocks discussed Consideration given to texture, structure and impurities that may cause failure, points to be guarded against in selection of aggregate pointed out

- 22 Some Observations on Accelerated Soundness Tests, by A T. Goldbeck  
The Crushed Stone Journal, July, 1929  
Comparison of methods of accelerated soundness tests by use of sodium sulfate and freezing and thawing
- 23 The Effect of Soft Particles of Coarse Aggregate on the Strength and Durability of Concrete, by W J Emmons  
Proc Sixteenth Annual Conference on Highway Engineering, University of Michigan, 1930  
National Sand and Gravel Bulletin, June and July, 1931  
Reprinted as Circular 6, National Sand and Gravel Association  
Abstracted—Rock Products, August 2, 1930, p 42  
  
Results of tests carried out on hard absorbent, intermediate or borderline and soft sandstones, shale, ochre, and floaters
- 24 Concrete Made from Unsound Stone, tests made by Kentucky State Highway Department  
Report of Comm on Highway Research Activities, A A S H O, 1930  
  
Weathering tests of concrete in which blue shale and blue limestone were used as aggregates. Concluded not more than 5 per cent of blue shale should be allowed in total coarse aggregate

## 1931

- 25 Accelerated Freezing and Thawing as a Quality Test for Concrete Aggregates, by F C Lang and C A. Hughes  
Proc Am Soc Testing Mats, 1931, Pt II, p 435  
  
Coarse aggregate included gravels from 18 plants, 2 crushed stones, and 9 selected materials which would be classified as deleterious, referred to as chocolate bars having soft interior, usually clay, and a hard ferruginous or manganitic shell
26. Relation Between Durability of Concrete and Durability of Aggregates, by F H Jackson  
Proc Tenth Annual Meeting, Highway Research Board, 1931, p 101  
Discussion by H F Gonnerman and G W Ward, p 113  
Discussion by F C Lang and C A Hughes, p 117  
  
Suggests outlines of research in durability of concrete with special reference to relation of aggregates to durability. Discussions include results of tests carried out by the Portland Cement Association and the Experimental Station of the University of Minnesota

- 27 Freezing Tests on Mortar and Concrete, by A T Goldbeck  
The Crushed Stone Journal, April, 1931, p 5  
Results of tests carried out in the National Crushed Stone Association laboratory using aggregates with varying percentages of unsound particles
- 28 Deleterious Substances in Concrete Aggregates, by F C Lang  
National Sand and Gravel Bulletin, April, 1931  
Reprinted—Circular 10, National Sand and Gravel Association
- 29 Allowable Percentages of Soft Materials in Coarse Aggregates, by H C Grove  
Rock Products, May 23, 1931, p 47  
Compression tests on concrete cylinders indicate that 6 per cent of soft rock could be permitted, although a limit of 4 per cent would be preferable, 4 per cent of shale could be used without serious results to strength in places where concrete would be protected from weather
- 30 Researches on the Durability of Concrete, by H F Gonnerman  
The Crushed Stone Journal, May, 1931, p 15  
Paper before 14th Annual Convention, National Crushed Stone Association, discussion of tests carried out in the Portland Cement Association's laboratory—does not include data
- 31 The Durability of Concrete, by C H Scholer  
Bull No 28, Kansas State College, Engineering Experiment Station, July, 1931  
Tests on various aggregates and effect of unsound aggregate on durability of concrete, the most destructive and common type is absorptive chert in gravel or flinty concretions in limestone
- 32 Durability Studies of Aggregates and Concrete, by H F Gonnerman and G W. Ward  
Proc Seventh Annual Convention, Association of Highway Officials of North Atlantic States, 1931  
National Sand and Gravel Bulletin, May, 1931, p 13  
Abstracted—Pit and Quarry, September 9, 1931, p 33  
Includes data of results of tests carried out in the Portland Cement Association's laboratory
- 33 The Selection of Durable Aggregate for Concrete, by M Temin, W Pigman and J Tucker, Jr  
Rock Products, August 1, 1931, p 37  
Discussion by A T Goldbeck, p 42  
Freezing and thawing tests carried out by U S Bureau of Standards on 36 crushed rocks, gravels and slags using sodium sulfate solution, sodium chloride solution, boiling and drying, freezing and thawing.

- 34 Surface Pit Survey on Concrete Pavements, by F. V. Reagel  
 Research Abstract No 2, Highway Research Board, October, 1931, p 1  
 Gives table showing chert contents, amounts of various other detrimental materials such as sticks, shale, mudballs, lignite, soft stone, etc were included in report
- 35 Unsoundness of Certain Types of Rocks, by Mark Morris  
 Proceedings Iowa Academy of Science, 1931  
 Research Abstract No 2, Highway Research Board, October, 1931, p 67  
 Abstracted—Pit and Quarry, December 2, 1931, p 67  
 Directs attention to destructive effect of artificial and natural weathering conditions upon certain kinds of rock, particularly shales, shaley limestones, iron oxides, iron-stones, cherts, and a miscellaneous class of soft, earthy rocks
- 36 The Significance of Sodium Sulfate and Freezing and Thawing Tests on Mineral Aggregates, by Verne McCown  
 The Crushed Stone Journal, December, 1931, p 5  
 Abstracts reports from Illinois, Iowa, Tennessee, Pennsylvania, New York, the Portland Cement Association Tenn Hwy Dept tests on "Effect of Shale on Strength and Durability of Concrete" showed amount of shale of 5 per cent to 10 per cent has no effect on durability in 45 cycles of freezing and thawing, did not materially influence transverse, but did cause reduction in compression strength

1932

- 37 Shale in Aggregates, by E F Bean  
 Proc Twelfth Annual Meeting, Highway Research Board, December, 1932  
 National Sand and Gravel Bulletin, January, 1932  
 Crushed Stone Journal, Jan 1932, p 7  
 Abstracted—Rock Products, May 7, 1932, p 42  
 Discussion of origin, characteristics and metamorphic equivalents of shale
- 38 The Resistance of Concrete to Frost Action, by F H Jackson and George Werner  
 Public Roads, April, 1932, p 32  
 National Sand and Gravel Bulletin, June, 1932, p 9  
 Investigation by the Bureau of Public Roads over a period of six years on resistance of concrete to frost action as affected by the character of the coarse aggregates used in mixture, using 18 different coarse aggregates of widely varying characteristics

39. Proposed Method of Making Freezing-And-Thawing Test of Concrete and Concrete Aggregates.

Appendix to 1932 Report of Committee C-9 on Concrete and Concrete Aggregates of the American Society for Testing Materials.

Suggested procedure for making tests.

40. Removal of Shale and Soft Stone from Gravel, by C. S. Huntington. Rock Products, November 5, 1932, p. 56.

Description of methods for removing shale and soft stones from gravel.

## DISCUSSION

ON

### SHALE IN AGGREGATES

MR. F. C. LANG, *Minnesota Highway Department*: From my experience with shales in Minnesota I cannot fully agree with Mr. Walker

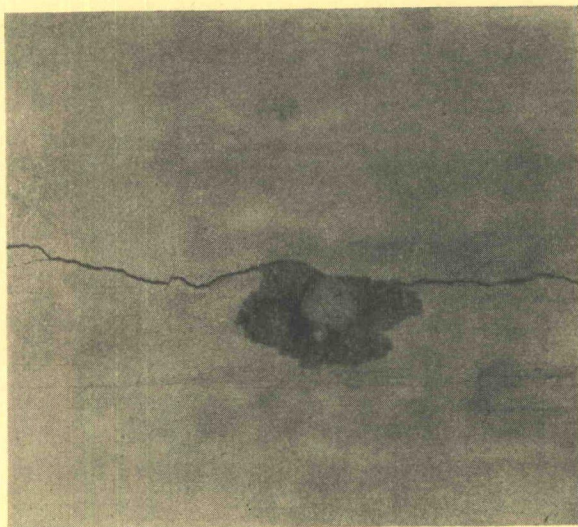


Figure 1. A Pop-out in a Bridge Pier Caused by Shale

when he says: "The most obvious effect is represented by pits in the surface of the concrete; in general no disruption of the concrete occurs, since shales and allied materials do not change in volume greatly on disintegration," and also in his conclusion when he states: "Soft, friable and non-durable particles are detrimental to concrete aggregates. Shale is one of the several types of particles occurring in natural aggregates which meets this description."

We do not classify shales with the particles which we consider structurally weak or soft but rather with those substances which are effective in acting on the concrete because of their expansive characteristics. The expansive force probably is not so great as with some cherts and

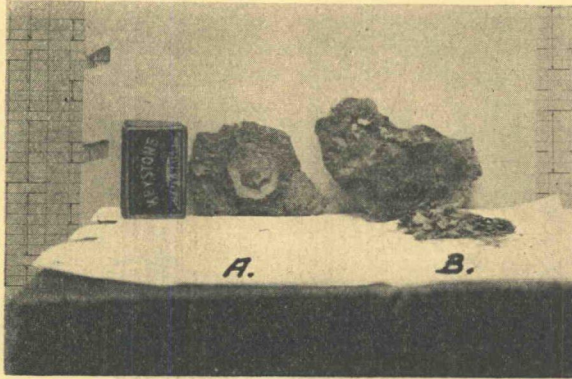


Figure 2. Pieces of Concrete Forced Out by Expansion of Shale

some other materials but I think the pop-out on the bridge pier shown in Figure 1, and the two pieces of concrete shown in Figure 2, which have been forced out on the same bridge, clearly show that the shale has an appreciable expansive force. Pop-outs of this character are quite common on concrete structures in the shale area of Minnesota.