CHERT AS A DELETERIOUS CONSTITUENT IN INDIANA AGGREGATES*

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SYNOPSIS

This paper is a progress report of a cooperative investigation between the Bureau of Tests and Materials, State Highway Commission of Indiana, and the Joint Highway Research Project of Purdue University The investigation is divided into two parts. 1, a study of Indiana limestone quarry cherts, and 2, Indiana gravel cherts This paper relates primarily to Part 1 of the study.

Representative samples of chert from practically all producers of stone and gravel aggregates in Indiana were obtained, together with some materials from surrounding states Ledge cherts were obtained from quarries and exposed stone faces, and identified geologically. A record was made of the visual appearance of each specimen, including color, luster, texture, and fracture. Performance was determined by imbedding the chert in mortar cubes and subjecting them to alternate cycles of freezing and thawing. Identification tests consisted of specific gravity, absorption, degree of saturation, dye penetration, unconfined freezing and thawing, chemical analyses, and microscopic examination of thin sections.

The results reported primarily cover Indiana stone cherts It was observed that the characteristics of cherts vary widely in different regions and consequently a study of chert should be restricted to a definite geographical area. Materials from Indiana varied widely in performance and properties. The most unsound cherts had a ratio of 0 85 or more between the absorption by one hour evacuation and 23 hours' immersion and that calculated for one hundred per cent saturation. They had an absorption of 3 per cent or more, and a bulk specific gravity, saturated surface-dry, of less than 2 50, by A.S.T M. method C 127-39. The investigation confirms, in part, the work of other investigators in regard to bulk specific gravity, absorption, and degree of saturation as means of distinguishing sound from unsound cherts. The cherts which showed disruptive tendencies also had an Eosine dye penetration of one-half inch or more after 20 hours' immersion, and were predominantly light in color The results indicated that freezing of water in the voids was the primary cause of disruption The performance of the cherts was dependent on the degree of saturation. This observation constitutes somewhat of a criticism of the accepted methods for specific gravity and absorption determination and preparation for the freezing and thawing test, because of the lack of consideration given to the degree of saturation of the materials tested.

GENERAL DISCUSSION OF CHERT

No definition of chert has yet been universally accepted. However, cherts have been variously described as "those crypto-crystalline varieties of quartz which are opaque, save on thin edges, and are white, pink, green, gray or blue-gray in color" (1)[1]; "a variety of hornstone which resembles flint but having a more splintery fracture and being more brittle" (2); "almost any rock composed of micro-crystalline or crypto-crystalline silica" (3); "any opaque natural micro-crystalline or micro-aphanitic silica whose structure and environment do not permit it to be otherwise classified" (4).

Thus, the term "chert" has been used

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[1] Figures in parentheses refer to list of references at end.

to describe almost any micro-crystalline silica rock It is often confused with other rocks such as flint, chalcedony, and opal which also fall in this class.

Chert occurs in deposits of almost every geological age. According to Tarr (1, p 22) "In essentially all their occurrences, (referring to chert and flint) they are found interbedded with limestone, dolomite and chalk; the rare occasions when they occur with shale or sandstone being under apparently exceptional conditions . . ."

Chert occurs in two general forms; either as well defined beds or as nodules within the limestone The theories as to its origin may be divided into three general classes; organic, replacement, and direct precipitation. The first theory suggests that the silica was derived from the spicules of sponges. These spicules, which consist largely of opaline silica, were partly dissolved under the influence of sea water under pressure and organic material, and reprecipitated about nuclei, such as pyrite, sand grains or organic material Prestwich (5) believed that silica was present as a chemical precipitate in the mud of the sea. This silica had a strong affinity for other forms of silica and aggregated about sponge spicules and other siliceous organisms. The irregular masses produced continued to grow as long as there was any colloidal silica within range of the attraction.

According to the replacement theory the formation of nodules resulted "from replacement of unconsolidated limestone, the silica being derived from silica in solution which was mingled with the sediment, from silica in solution in the sea water, and from solution of organic silica ." (6)

The precipitation theory as advanced by Tarr (1, p. 24) assumes that the silica is derived from chemical weathering of low lying land masses and is transported to the sea by streams Here it tends to accumulate under certain conditions but finally is precipitated rapidly. On the sea floor it tends to assume spherical or irregular shapes. After burial it is compressed by overlying sediments and undergoes successive changes to opal to chalcedony to quartz.

Each of the above theories is supported by a mass of evidence and by many investigators. Recognizing this, F. W. Clarke (7) suggests that "no one process can account for all the occurrences of amorphous or crypto-crystalline silica, and each locality must be studied in the light of its own evidence". This supports the author's contention that chert should be investigated by geographical or geological areas.

The following list from Tarr (1, p 20) shows the wide geologic and geographic distribution of chert

> "Pennsylvanian: Common in Missouri, Iowa, Kansas, Oklahoma, and some parts of the Rocky Mountains
>
> "Mississippian: Abundant in the lower part of the Mississippian in the Mississippi Valley, and to a less extent in the Appalachian region.
>
> "Devonian: Found in the Appalachian states, the central Mississippi Valley, Arizona, and California
>
> "Silurian: A little reported in Wisconsin, Iowa, Oklahoma, Texas, and in the Appalachian region (Ohio and Virginia)
>
> "Ordovician: Abundant in the Knox dolomite and Shenandoah limestone in the lower part of the Ordovician and top of the Cambrian in the Southern Appalachian region Also abundant in the Mississippi Valley and to the southwest in Texas, New Mexico, and Arizona
>
> "Cambrian. Upper Cambrian in the Appalachian region, as noted above, in the Mississippi Valley, and in the western part of the United States"

This list which is not complete indicates that the presence of chert in aggregates is not a rare phenomenon. Indeed, it is likely to occur in any section of the country which has outcrops of limestone. Scattered observations also indicate that cherts derived from the same geological system but obtained from different states, have widely varying characteristics.

It is generally recognized that some types of chert are deleterious because of their lack of durability which causes "popouts" and other forms of disintegration in concrete. The first indication of a popout is a circular crack that forms the base of a conical piece of concrete. At the apex of the cone will be found a fragment of chert with another portion of the chert imbedded in the main body of concrete. The chert piece has split with such force as to break and lift out the concrete above.

An early observation of this behavior was made by F. V. Reagel (8). After describing the popouts discovered in Missouri, he notes, "No action is apparent in connection with the flint obtained from crushing lead and zinc ore but very serious effects are found in connection with the crushed chert found in crushed limestone from any of the various limestone formations thus far investigated". Dr. Kriege (9) describes popouts appearing on a pavement between Fort Wayne and Huntington, Indiana. The coarse aggregate used in this pavement was a cherty limestone. Another concrete pavement, also containing cherty limestone as coarse aggregate, was observed by Dr. Kriege. This road had been in use ten years without any sign of pitting or cracking. From observations such as these he concludes "the disintegrating tendency of some chert is much less than in others or does not occur at all". Cantrill and Campbell (10) concluded that "the failure of concrete throughout the western part of the state (Kentucky) was due to the use of chert gravel. . . ." They report "The predominant failures take the form of progressive scale followed by disintegration of the concrete." The type of failure of which this is an example has become known as "map cracking."

Recognizing the harmful effect of some types of chert, various states have set up specifications limiting the amount of chert in concrete aggregates as shown in Table 1. It can be observed from this table that the states mostly concerned over chert are those in the Middle West, including in particular: Ohio, Michigan, Indiana, Illinois, and Kentucky (not listed).

In addition to the surface effect of popping out, chert has a deleterious influence on other properties of concrete. Kellerman (11) reported that siliceous aggregates in general gave lower flexural strength than calcareous aggregates. The map cracking observed by Cantrill and Campbell was caused by a marked reduction in strength after freezing and thawing occurred. Excessive expansion of concrete in California led to an investigation from which Stanton (12) concluded "with certain minerals (certain types of chert and shale) a high alkali cement may be a contributing factor to excessive expansion and subsequent failure of the concrete." From the standpoint of bituminous pavements, Tyler (13) found that siliceous minerals in general have low resistance to stripping of bituminous films.

From this discussion it is evident that much information about chert is required. It has been noted that not all cherts cause "popouts" or disruption of concrete. Walker (14) points out "that there are good chert gravels and bad chert gravels. . . . It is only excessive quantities of bad chert that need to be guarded against. . . ." The quantities of so-called bad chert which may be allowed will necessarily vary according to the structure in which they are incorporated. For example, bridge handrails and other decorative structures should contain much less deleterious material than pavements.

A method for distinguishing between durable and non-durable cherts is the most critical need at the present time and is the reason for conducting this investigation. In describing this need, Wuerpel (15) stated, "Practical methods of differentiating between durable and non-durable chert have not been available, and in consequence, all varieties of this material are viewed with suspicion. Some gravel aggregates have been rejected because of stringent limitations on the mineral without real knowledge of its structural soundness. In other cases, the inability to differentiate between unsound chert and other waterworn, iron-bearing pebbles has resulted in the use of gravel which contained a dangerous quantity of this undesirable material."

TABLE 1

EXISTING STATE HIGHWAY SPECIFICATIONS LIMITING CHERT IN CONCRETE AGGREGATES

State	Specification Date	Crushed Chert Limit	Total Chert Allowed	Remarks
Illinois	1940			"The use of gravels in which chert or foreign particles predominate will not be permitted."
Indiana	1939	Class A—5% Class B—10%	13% 18%	"All varieties of flint, whether crushed or uncrushed, pure or impure, regardless of color, shall be included as chert."
Iowa	1937		2%	A limit of 2% is imposed on "the total of shale, unsound chert, and other kinds of materials whose disintegration is accompanied by an increase in volume which may cause the spalling of concrete or mortar in which they are contained"
Michigan	1940		Size 4A (coarser) 3% Size 10A (finer) 5%	(Applying to gravel)
Minnesota	1938		1 0% Ret on ⅜" sieve 1 5% on total sample	These limits are placed on "Total Spall Materials (shale, bad iron oxides, unsound cherts, and other materials having similar characteristics)."
Missouri	1940		2% to 5%	"A white porous type which occurs in the Burlington limestone."
Ohio	1939		1%	"Chert which will disintegrate "
Wisconsin	1935			" . the determination of apparent specific gravity, absorption, and quantities of chert, soft or non-durable particles, thin or elongated pieces, will be done in accordance with the methods of the Commission's laboratory "

PREVIOUS INVESTIGATIONS

A laboratory investigation of the behavior of chert was begun by F. V. Reagel (8, p. 333) in 1923. His first work consisted of freezing and thawing concrete beams in which the coarse aggregate was chert. Large reductions of flexural strength were observed after only a few cycles of freezing and thawing. He also notes that "flint is not seriously affected by freezing action . . In all cases investigated the stained gravel successfully resisted attempts made to induce disintegration by freezing. The differences in resistance to freezing effects noted between crushed chert on one hand and crushed flint and stained chert gravel on the other is attributed by the writer in a large measure to the resilicification of the flint and the chert gravel." It should be noted that early investigations were handicapped by lack of data on the amount and rate of absorption. The importance of saturation ratios was unknown.

Kriege (9) tested several different cherts by freezing and thawing them in the unconfined state and by freezing and thawing concrete blocks containing the chert as coarse aggregate. He also ran sodium sulphate soundness tests on both the unconfined and confined aggregate Results of these tests indicated a wide variation in the behavior of different cherts. Heating and cooling of concrete blocks containing chert showed that these cherts were not affected by alternations of temperature from 160°C to 20°C

Following a condition survey of Kentucky pavements, Cantrill and Campbell (10) ran specific gravity and absorption tests on various aggregates including chert gravels They also made concrete beams using these aggregates and subjected them to freezing and thawing. Their conclusions in regard to chert were that the material would not produce durable pavement, and that unsatisfactory material might be eliminated by two specifications; viz ,

"(a) Coarse aggregate shall not show an absorption greater than 3 per cent when subjected to A.S T M Standard Test C 95-36

"(b) Concrete in which any aggregate is incorporated shall not show a reduction in flexural strength greater than 30 per cent when subjected to 40 cycles of freezing and thawing in the presence of water "

After reviewing available data on chert, Wuerpel (15) concluded that "practically the sole thread of accord was a general relation between apparent specific gravity, absorption, and durability." (It should be noted here that Wuerpel's "apparent specific gravity" is the same as the bulk specific gravity, saturated surface-dry basis, obtained by A.S.T.M. Method C 127-39, except that the saturation is obtained by boiling five hours, whereas saturation by the A.S.T.M method is by 24-hour immersion in water at room temperature) He devised a flotation procedure for separating pebbles of various specific gravities and performed various tests on these fractions. Microscopic examinations, absorption, magnesium sulphate soundness, and freezing and thawing of concrete containing the aggregate, all indicated that gravel with specific gravity less than 2.40 (by this flotation method) was undesirable.

Spain and Rose (16) attributed the unsoundness of chert to the porosity in some types and to incipient fracture planes in other types.

In discussing rock weathering, G. P. Merrill (17) states. "Among siliceous sedimentary rocks poor in alkalies or iron-bearing silicates, the degeneration is mainly disintegration, though a small amount of silica, existing in either crystalline or chalcedonic forms, is usually lost through solution." A different conclusion was reached by Penrose (18) in studying Arkansas chert. He observed that the disintegration was caused by the leaching of a small amount of interstitial calcium carbonate

COLLECTION AND CLASSIFICATION OF SAMPLES

The first step in the study of Indiana cherts was the collection of samples from quarries and gravel pits. This was done with the aid and cooperation of the Bureau of Materials and Tests of the State Highway Commission. Approximately four thousand pounds of chert were secured from the six State Highway Districts in Indiana, and from some sources in Illinois, Ohio, Kentucky, and Tennessee. In view of the lack of agreement as to the distinction between chert and flint, no attempt was made in gathering samples to differentiate between the different types of micro-crystalline silica and all types were gathered for laboratory examination.

Outcrops of Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian age are present in Indiana. It is possible that chert occurs in the limestones of each of these systems, but since most Indiana quarries that produce road-building materials are in Silurian, Devonian, and Mississippian outcrops, these were of most interest It was found that chert occurs in each of these systems. Samples of chert were obtained from 35 quarries and highway cuts and catalogued according to their geologic age and the geographical location of the outcrop This was done with the aid of the "Handbook of Indiana Geology" (19), and was later checked by Dr R E. Esarey, State Geologist

Most of the State is covered with a thick sheet of glacial drift. This is of Wisconsin age over most of the State with the Illinoian drift appearing on the surface in southern Indiana. This drift is composed of rock debris of all sizes. Where it has been transported by water it is assorted and stratified. The sorting may have been done by the meltwater of the glacier or by rivers flowing over the drift after glaciation ended.

Gravel deposits of commercial value are all located in deposits formed in this manner. They frequently contain much igneous and metamorphic rock which has been carried in by the glacier from upper Michigan, Wisconsin, or Canada. Other constituents of the gravel are limestone, sandstone, shale, and chert which may have been derived from outcrops of these materials in Michigan, Wisconsin, Illinois, or Indiana. This must have been the case since the direction of Wisconsin glaciation was from northwest to southeast and since present drainage originates for the most part within the state with the exception of the Ohio River. Gravels found in the Ohio River may be derived from glacial drift or from rock outcrops in Kentucky, West Virginia, Pennsylvania, Ohio, or Indiana.

Samples of gravel chert were collected from 31 deposits in all parts of Indiana. Many different types of chert were present in the gravel from each deposit.

It was planned to perform numerous physical and chemical tests on each chert type and correlate the properties with the performance in concrete. For this it was necessary to have a number of pieces of each type which were alike in their characteristics. This was possible with cherts from quarries since it is likely that a number of pieces broken from the same ledge in a quarry will be uniform in their properties. On the other hand, it was not certain that two pieces of gravel chert which had the same external appearance would have the same properties or would perform alike in concrete. Therefore, it was decided to run identification and performance tests on samples from quarries and determine if possible the characteristics which distinguish deleterious cherts from non-harmful types. These tests have been completed on 27 of the quarry samples and are reported herein. It is planned to test the gravel cherts as completely as possible to determine if the results from quarry chert tests are applicable to gravel cherts.

This plan of attack seems to be logical since the gravels are derived from rock strata. There is a possibility that in some cases their properties may be changed by the weathering and transportation they have undergone.

PERFORMANCE TESTS

In order to correlate the performance of quarry chert samples with their physical characteristics, it was necessary to determine how each type behaved in concrete.

To eliminate as many outside variables as possible, individual chert pieces were imbedded in sand-cement mortar which was cured, and then frozen and thawed. Five preliminary series of tests were conducted before a standard procedure was determined. For Series I to V, mortar blocks 12 in. long, 7 in. wide, and $4\frac{1}{2}$ in. high were made. Several strengths of mortar were used and pieces of chert which had been immersed in water for various lengths of time were imbedded at

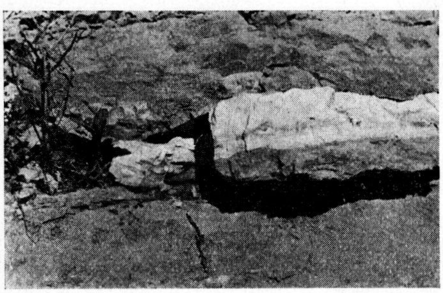

Fig. 1. Bed of Chert

different depths. Two-inch cubes of mortar alone were made for each of the series and were tested in compression at seven-day intervals. All of the blocks were cured seven days. After this time, they were placed in a pan which was filled with water to a depth of $1\frac{1}{2}$ in. and frozen for 21 hours at $-10°$F. They were then immersed in water at 75°–80°F. for three hours. This procedure was repeated until 40 cycles had been reached, when the blocks were removed from the test.

Freezing was done in the frost action cabinet of the Joint Highway Research Project described by H. F. Winn (20). To adapt them for this purpose, the drawers were filled with 4 in. of dry sand and 4 in. of cork as bottom insulation. The blocks were thawed in a large concrete tank in which the temperature of the water could be regulated by the admission of steam.

Popouts in a Series V block are shown in Fig. 5. Other blocks in the preliminary series had no popouts.

The procedure devised for testing the relative disruptive tendencies was as follows:

Two-inch mortar cubes containing individual chert pieces of various sizes were

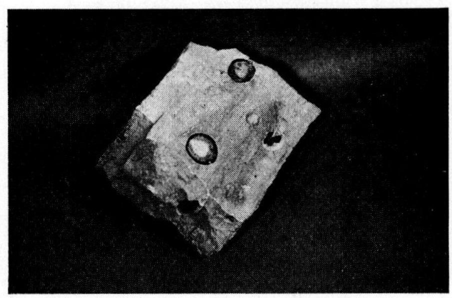

Fig. 2. Chert Nodules

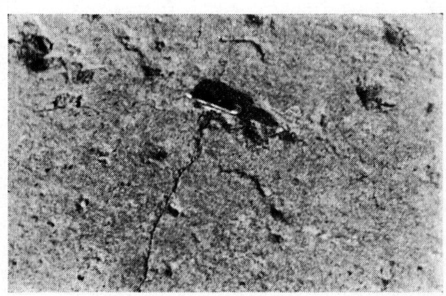

Fig. 3. Chert Popouts

frozen and thawed until failure or until 40 cycles had been completed. A mortar of portland cement and a well-graded sand in the proportions 1:5 by weight were used. These materials were mixed dry in a large pan, and a weight of water equal to 0.75 times the weight of cement was added. After thorough mixing the mortar was placed in the cube molds in two layers and was tamped 32 times for each layer. The chert pieces were evacuated for one hour under a pressure of two mm. of mercury and then saturated with water while under the vacuum. Before being placed in the forms, the chert pieces were thoroughly coated with mortar to insure the absence of any air cushion surrounding them. The chert was inserted in the cubes and the mortar was tamped and puddled around it. After the top surfaces of the cubes were leveled

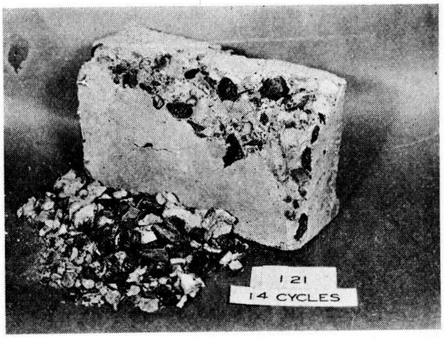

Fig. 4. Freezing and thawing disintegration of concrete block containing cherty coarse aggregate.

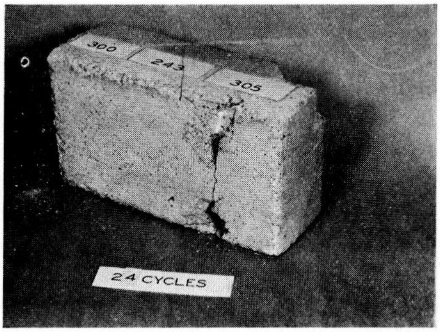

Fig. 5. Popouts in a Mortar Block

with a steel straight edge, they were placed in a moist room for 48 hours. The molds were then removed and the cubes were immersed in a water bath. After a total of seven days' curing, the cubes were placed in the freezing cabinet in pans containing a one-inch depth of water. After ten hours' freezing at $-10°F$. they were removed to the bath and thawed for two hours at 75°–80°F. Two-inch cubes and briquettes of mortar alone were made at the same time as the test cubes. Some of these were left in the curing bath and their strength determined by breaking at seven-day intervals while others were cured seven days and then subjected to freezing and thawing and broken after various lengths of time.

At intervals the cubes were examined for signs of cracking. When a crack appeared which extended across more than two sides, the cube could be pulled apart by gentle pressure of the hands. The cycle at which this occurred was recorded, and the cube was removed from the test. Fig. 6 shows some typical failures in the mortar cubes.

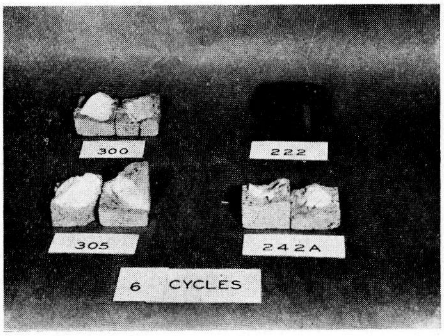

Fig. 6. Typical Failures in Mortar Cubes

Most of the cubes split on a plane parallel to one of the sides. In some cases, a corner of the cube was forced away, but in most failures the mortar failed in direct tension due to a force exerted within the chert particle which split the particle and disrupted the mortar. The area of mortar which tended to prevent disruption was measured in each failure. The product of this area of mortar and the unit tensile strength of the mortar is something less than the disruptive force exerted by the chert. To evaluate this force, it was necessary to imbed the deleterious cherts in mortars with greater strength. A mortar whose tensile strength was 500 lb. per sq. in. was not strong enough to resist disruption from some types. It is planned to mix mortars of greater strength to determine, if possible, the magnitude of these forces.

On the basis of behavior, the quarry chert samples were divided into two groups: those which disrupted the cubes 51 to 100 per cent of the time in less than 40 cycles; and those which failed 0 to 50 per cent of the time in 40 cycles. These results, which are shown in Table 2, give a comparison between the degree of unsoundness of different samples, since the exact relation of 40 cycles of freezing and thawing to natural weathering is unknown. A wide variation in resistance to freezing and thawing by different chert types is shown. The data on disruptive force indicates that a force of at least 1000 pounds is exerted by some types of chert The force may be much greater than this, since a resisting strength of mortar of 1000 pounds was not enough to prevent disruption of pieces of one inch diameter.

TABLE 2

PERFORMANCE TESTS

Group	Sample No	No of Cubes Made	No of cubes that failed (less than 40 cycles)	Percentage of cubes failed in 40 cycles	Ave No cycles at failure (including only failures at less than 40 cycles)
A (51–100% Failures)	302	13	13	100	8
	305	13	13	100	10
	245	10	10	100	13
	331	6	6	100	16
	333	6	6	100	16
	242A	8	7	87	25
	332	6	5	83	10
	334	6	5	83	12
	222	16	13	81	28
	306	5	4	80	21
	350	9	7	77	31
	301	10	7	70	25
	300	13	9	69	21
	243	16	10	62	27
B (0–50% Failures)	307	6	3	50	22
	351	3	1	33	8
	221	4	1	25	40
	303	4	1	25	40
	244	10	1	10	6
	200	4	0	0	
	200A	4	0	0	
	200B	4	0	0	
	200C	4	0	0	
	201	4	0	0	
	220	4	0	0	
	242	4	0	0	
	304	4	0	0	

In addition to the series of mortar tests which were performed on all samples, two series of cubes were made using a blended cement composed of one part natural to five parts portland cement. In half of these, oven-dried chert was imbedded, and in the other half chert which had been saturated and treated in the regular way. The chert which had been oven-dried failed just as soon as that which had been saturated. However, since the cubes were immersed in water during curing and while thawing after the cycles had begun, it is certain that the oven-dried chert absorbed considerable water.

In another series oven-dry chert was coated with paraffin and imbedded in mortar. These cubes failed also, but it is believed that the paraffin did not keep water out of the chert. The paraffin seal was broken in placing the chert in the cubes.

In a fourth series oven-dry chert was imbedded in mortar and after seven days' curing the cubes were oven-dried. They were then frozen dry at −10°F. and thawed in an oven which maintained a constant temperature of 140°F At 40 cycles these cubes showed no sign of disruption Other cubes were made using oven-dried chert and after seven days' curing subjected to alternate heating to 140°F. and immersion in water at 50°F. These cubes likewise showed no sign of disruption after 40 cycles of this treatment. In all of the above mortar tests, chert from group A, 51 to 100 per cent failure in 40 cycles, was used. Results of these tests indicate that the disruption probably is due to the freezing of water in the pores of the chert, since chert which was frozen and thawed dry or heated and cooled above freezing did not break open the mortar in which it was imbedded.

IDENTIFICATION TESTS

Identification tests were performed on quarry samples to secure information on the characteristics of the various types of chert and to attempt a correlation of these data with performance. The properties examined were: color, texture, luster, fracture, hardness, dye penetration, freezing and thawing of the unconfined aggregate, A.S.T.M. specific gravity and absorption, specific gravity of the powdered material, porosity, chemical analyses, and microscopic study of thin sections.

Color, Texture, Luster, Hardness, and Fracture

Indiana quarry cherts fall into seven divisions on the basis of color and texture. These are.

1. Light tan to white; dense or porous; occasionally with small dark spots.
2. Light tan to white, surrounding a dark center; white predominates.
3. Light grey to white, with darker bands; light color predominates.
4. Light tannish grey; fossiliferous.
5. Mottled dark grey, brown, and white; dark color predominates.
6. Dark brown granular.
7. Dark blue or grey and white; dark color predominates.

With only slight exceptions, those cherts in Divisions 1 to 4, inclusive, were in performance Group A, and those in 5 to 7 and the non-cherts · limestone, shale, ocher, quartzite, etc Div. 8, in Group B.

The descriptions of each sample are given in Table 3. It will be noted that several of them have more than one designation. This is necessary because the dark color predominated in some of the pieces which had a dark center with a white border and in those which had blue and white bands.

The luster of a mineral according to Sosman (4, p. 716) "is determined by the character of the reflected light and by the visible patterns which reflection makes evident on the surface of the mineral." Terms used in describing luster are: metallic, adamantine, vitreous, resinous, pearly, greasy, waxy, silky, dull, and earthy. The luster of the various chert samples is given in Table 3.

The fracture of a rock or mineral is the way it breaks when it does not show plane surfaces. The following terms are used to describe different types of fracture (21):

a. Conchoidal. The fracture has smooth, curved surfaces like the interior surface of a shell.
b. Fibrous or splintery. The fracture shows splinters or fibers.
c. Hackly. The fracture has a jagged, irregular surface with sharp edges.
d. Irregular. The fracture has roughened irregular surfaces.

Sosman (4, p. 795) suggests a correlation between the fracture and the micro-characteristics of a substance. He states, "If the fibers are long and are arranged in a regular manner, the fracture will be fibrous. But if the fibers are very short and arranged heterogeneously, the fracture is likely to be conchoidal. . . . A distinction sometimes made is that the fracture of chert is more splintery than that of flint."

The types of fracture of the various cherts found in Indiana are shown in Table 3.

The relative hardness of a mineral can be determined by comparing it with a standard scale. This scale consists of the following minerals, each being harder than those preceding it in the scale:

1. Talc	6. Orthoclase
2. Gypsum	7. Quartz
3. Calcite	8. Topaz
4. Fluorite	9. Corundum
5. Apatite	10. Diamond

All of the cherts tested showed a hardness of 6 to 7. They were harder than a knife blade or orthoclase, but they were softer than quartz. Some types appeared to be softer because of their powdery granular structure.

TABLE 3

GEOLOGICAL AGE AND DESCRIPTIONS OF QUARRY CHERTS

Performance Group	Sample No.	Geological Formation	Color*	Texture	Luster	Fracture
A (51–100% failure)	302	Geneva—Silurian	4	Porous	Earthy	Conchoidal
	305	Liston Creek—Silurian	1	Porous	Earthy	Conchoidal
	245	Huntington—Silurian	4	Porous	Earthy	Conchoidal
	331	Niagaran—Silurian	1	Smooth	Dull	Hackly
	333	Niagaran—Silurian	1	Smooth	Dull	Irregular
	242A	Huntington—Silurian	2 & 7	Smooth	Dull	Conchoidal
	332	Niagaran—Silurian	1	Smooth	Dull	Conchoidal
	334	Niagaran—Silurian	1	Porous	Earthy	Hackly
	222	New Prov.—Mississippian	1	Smooth & porous	Dull	Conchoidal
	306	Liston Creek—Silurian	1	Porous	Earthy	Conchoidal
	301	Laurel—Silurian	3 & 7	Smooth	Resinous	Conchoidal
	300	Laurel—Silurian	2 & 7	Smooth & porous	Resinous	Hackly
	243	Huntington—Silurian	2 & 7	Smooth	Resinous	Conchoidal
B (0–50% failure)	307	Liston Creek—Silurian	3 & 7	Smooth	Dull	Conchoidal
	221	Kenneth—Devonian	5	Dense	Resinous	Conchoidal
	303	Jeffersonville—Devonian	7	Dense	Dull	Irregular
	244	Liston Creek—Silurian	7	Dense	Silky	Conchoidal
	200	St. Louis—Mississippian	7	Dense	Silky	Conchoidal
	200A	St Louis—Mississippian	5	Dense	Dull	Conchoidal
	200B	St Louis—Mississippian	5	Dense	Vitreous	Hackly
	200C	St Louis—Mississippian	8	Granular	Earthy	Irregular
	201	St. Louis—Mississippian	7	Dense	Silky	Conchoidal
	220	Kenneth—Devonian	5	Dense	Resinous	Conchoidal
	242	Huntington—Silurian	6	Granular	Earthy	Conchoidal
	304	Liston Creek—Silurian	6	Granular	Earthy	Conchoidal
Out of State	350	Columbus—Devonian	3	Dense	Earthy	Conchoidal
	351	(Mexico City Caliche)	8	Porous	Earthy	Irregular

* Key to description of color under Identification Tests.

A.S.T.M. Specific Gravity and Absorption

A.S.T.M. Method C 127-39 (22) was used to determine the specific gravity and absorption of all of the quarry samples. This method gives a value for absorption after 24 hours immersion in water at room temperature. Definitions of the different kinds of specific gravity as given by A.S.T M. designation E 12-27 (22, p 874) are as follows

"*Specific Gravity* (*of solids and liquids*). The ratio of the weight in air of a given volume of the material at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature.

"*Apparent Specific Gravity* (*of solids*). The ratio of the weight in air of a given volume of the impermeable portion of a permeable material (that is, the solid matter including its impermeable pores or voids) at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature

"*Bulk Specific Gravity* (*of solids*). The ratio of the weight in air of a given volume of a permeable material (including both permeable and impermeable voids normal to the material) at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature"

Table 4 gives the results of the determinations of specific gravity and absorption by the A S T.M. methods It will be noted that cherts in group A had an average bulk specific gravity, saturated surface-dry, of 2 40 with a maximum of 2 46. They had an average absorption of 5.67 and a minimum of 3.91. Those in group B had an average bulk specific gravity of 2 59, and a minimum of 2 48. Absorptions of cherts in this group averaged 1.83, with a maximum of 3.02.

It should be noted that some of the apparent specific gravities were higher than that of quartz, specific gravity 2.65 This was caused partly by incomplete separation of the chert from the limestone in which it occurred, since the specific gravity of limestone may run as high as 2 85 Pyrite and calcite contained in the chert itself would also tend to increase the specific gravity. Impermeable voids would have a buoyant effect which would cause a decrease in the apparent specific gravity.

The factors affecting bulk specific gravity, saturated surface-dry, are the amount of absorption and the apparent specific gravity, which is, in turn, affected by the true specific gravity and the amount of impermeable voids of the material. Thus, a material with low absorption but large amount of impermeable voids would have a low apparent specific gravity and consequently a low bulk specific gravity On the other extreme, a material with a high apparent specific gravity and a high absorption would also show a low bulk specific gravity.

In one case of an Ohio chert obtained from the Devonian System (located on the eastern side of the Cincinnati Arch) the test results were not reported in Table 4. However, the material was outstanding in that it showed poor performance even though it had a relatively high bulk specific gravity of 2 51 This further emphasizes the necessity for investigating cherts in restricted localities.

True Specific Gravity

In the A S T.M. method, the values for apparent specific gravity were somewhat less than the true specific gravity of the material since small voids and sealed voids are not filled with water and give a buoyant effect. To determine the true specific gravity, a modification of the test for specific gravity of fine aggregates, A.A S.H O. method T-84 (23), was used. Representative pieces from several samples were selected. These were pulverized under water in an agate mortar and pestle. To facilitate grinding, the pestle was clamped in the chuck of an electric drill press which was geared to run at low speed. This worked very well and aided considerably in grinding A hydrometer analysis was run on two of the samples to determine the gradation. This showed that the grain size distribution approximated a Fuller's maximum density curve with 80 per cent of the material smaller than 0.30 mm., and 20 per cent smaller than 0 012 mm.

The chert was ground under water to minimize the change in specific gravity of the quartz due to heat expended in grinding. This change in density was investigated by Dale (24) who found a reduction in density due to grinding of approximately 0.01. He considered this change to be due to an inversion of part of the quartz to vitreous silica which has a lower density

TABLE 4

A S.T.M. Specific Gravity and Absorption, Dye Penetration, and Unconfined Freezing and Thawing Tests on Indiana Quarry Cherts

Performance Group	Sample No.	A. S. T. M.			20-hour dye penetration	Loss after 50 cycles unconfined freezing and thawing
		Bulk Sp. Gr. (Sat Surf. Dry)	Apparent Sp. Gr	Absorption		
				%	in.	%
A (51–100% Failure)	302	2 398	2 623	6 141	Complete	89 2
	305	2 363	2 640	7 703	"	74 7
	245	2 353	2 554	5 887	"	
	331	2 427	2 657	5 791	"	
	333	2 355	2 625	7 036	"	
	242A	2 356	2 548	5 406	0 40	19 9
	332	2 368	2 608	6 714	Complete	
	334	2 401	2 619	5 855	"	
	222	2 416	2 600	5 172	"	53 6
	306	2 383	2 599	6 049	0 58	
	301	2 458	2 643	3 907	0 60	51 9
	300	2 455	2 610	4 070	Complete	39 0
	243	2 463	2 615	3 942	"	47 0
Aver.		2 400	2 611	5 667	0 70	56 9
Max.		2 463	2 657	7 703	Complete	89 2
Min		2 353	2 548	3 907	0 40	19 9
B (0–50% Failure)	307	2 600	2 691	2 124	0 60	
	221	2 482	2 591	2 841	0 27	40 2
	303	2 560	2 686	3 017	0 44	
	244	2 575	2 648	1 749	0 20	38 5
	200	2 612	2 651	0 927	0 10	8 8
	200A	2 528	2 607	2 022	0 00	3 2
	200B	2 610	2 618	0 893	0 20	9 6
	200C	2 672	2 733	1 334	0 00	8 2
	201	2 580	2 643	1 500	0 22	16 0
	220	2 517	2 611	2 378	0 25	
	242	2 647	2 722	1 673	0 10	19 9
	304	2 663	2 732	1 517	0.05	5 7
Aver.		2 587	2 661	1 831	0 20	16 7
Max.		2 672	2 732	3 017	0 60	40 2
Min.		2 482	2 591	0 893	0 00	3 2

The specific gravity of this powdered material was determined by the method for specific gravity measurement of non-cohesive soils (25).

A pycnometer bottle of 100 ml. capacity was accurately calibrated for temperature change in volume The powdered chert was introduced into the bottle and covered with distilled water. The bottle was evacuated for 30 min under a pressure of 0.3 cm. of mercury. After this time, the bottle was filled with water so that it coincided with the mark on the neck of the bottle. The weight of the bottle plus water plus rock was determined and recorded as W_s. The temperature of the water was recorded. Then the water and powdered chert were poured into an evaporating dish and placed in an oven regulated at 105°–110°C. After drying to constant weight, the weight of chert was determined and recorded as W_o. From these data and using the weight of bottle plus water, W_w, at the recorded temperature (determined from the calibration curve), the specific gravity was computed from the equation

$$S = \frac{W_0}{W_0 + W_w - W_s}.$$

True specific gravity values for 12 samples tested by this method are shown in Table 5. These and other data are necessary for calculating the absorption for 100 per cent saturation.

Degree of Saturation

In order to compute the degree of saturation after 24 hours' immersion, the total porosity or the absorption of the material if it were completely saturated must be determined. This can be computed if the apparent specific gravity, the corresponding absorption, and the true specific gravity are known.

If A = oven-dry weight of solid material,
V_v = total volume of voids,
1 = specific gravity of water;

Then absorption at 100% saturation = $\frac{V_v \times 1}{A} \times 100$.

Let V_s = volume of solid material,
B = wt. of solid material plus absorbed water,
C = wt. of material in water,
w = wt. of absorbed water (24-hour immersion),

$$\text{percentage absorption} = \frac{w}{A} \times 100$$

$$\text{Apparent specific gravity} = S = \frac{A}{A - C}$$

$$\text{True specific gravity} = G = \frac{A}{V_s}$$

$$A = G\,V_s$$

$$B = A + w = G\,V_s + w$$

$$C = (G\,V_s + w) - (V_s + V_v) = G\,V_s + w - V_s - V_v$$

$$S = \frac{GV_s}{GV_s - (GV_s + w - V_s - Vv)}$$

$$= \frac{GV_s}{V_s + Vv - w}$$

$$\frac{GV_s}{S} = V_s + Vv - w$$

$$Vv = \frac{GV_s}{S} - V_s + w = \frac{A}{S} - V_s + w$$

Absorption at 100% saturation

$$= \frac{Vv}{A} \times 100 = \frac{100}{S} - \frac{100\,V_s}{A} + \frac{100\,w}{A}$$

Absorption at 100% saturation

$$= \frac{100}{S} - \frac{100}{G} + (\text{24-hour absorption})$$

It can be seen then that the degree of saturation after 24 hours' immersion is the ratio of the 24-hour absorption to the computed absorption at 100 per cent saturation.

Representative pieces of twelve chert types weighing approximately 50 g. were selected and immersed in water. After 24 hours' immersion, the specific gravity and absorption of each piece was determined, using an analytical balance.

After oven-drying, the same pieces were evacuated for one hour and saturated while under the vacuum. They were soaked 23 hours and then apparent specific gravity and absorption were determined. These twelve pieces were pulverized as described above and their true specific gravities determined. From these data the values in Table 5 were computed.

nary pressures would not break down under weathering Scholer, in discussing durability of aggregates, shows that "as the pressure rises due to the formation of ice, the water may flow over into these still available air spaces and only very low internal pressure be developed." It might be inferred from this that those materials with large well connected voids would disintegrate under frost action because of lack of any remaining air space to take care of the ice expansion.

TABLE 5

RELATION OF RESISTANCE TO FREEZING AND THAWING TO DEGREE OF SATURATION

Performance Group (Percentage Failures)	Sample No	True Specific Gravity	Calculated Percentage Absorption with 100% Saturation	24-hour Immersion		Unconfined Freezing and Thawing Loss	1-hour Evacuation		Failed in Mortar Cubes
				Absorption	Degree of Saturation		Absorption	Degree of Saturation	
				%	%	%	%	%	%
A	302	2 634	4 727	4 727	100 0	89 2	4 727	100 0	100
51–100	305	2 655	7 420	7 163	96 5	74 7	7 383	99 5	100
	245	2 660	8 354				7 501	89 8	100
	242A	2 647	5 215	3 762	72 2	19 9	4 566	87 5	87
	301	2 660	4 130	3 831	92 8	51 9	3 866	93 6	70
	243	2 660	4 529	3 940	87 0	47 0	4 063	89 7	62
B	221	2 654	3 578	2 840	79 4	40 2	2 862	80 0	25
0–50	244	2 655	1 912	1 467	76 7	38 5	1 522	79 6	10
	200	2 655	1 051	0 606	57 6	8 8	0 755	71 8	0
	200B	2 649	1 125	0 924	82 1	9 6	0 954	84 8	0
	201	2 642	0 805			16 0	0 560	69 6	0
	220	2 655	2 150				1 603	74 5	0

Dye Penetration

The function of the dye penetration test is to measure the depth and rate of water absorption in materials The depth of penetration of dye for any time interval can be measured. This depth shows the extent of water penetration since the dye serves merely to trace the path of the water The test indicates the size and conjunctivity of the pore spaces. This is important according to Kreuger (26) and Scholer (27). Kreuger found that those materials which do not absorb a volume of water greater than 80 per cent of the total void space have a high resistance to frost action. If this is true, a material with voids and void openings too small to admit water under ordi-

Pieces of chert approximately 1½ in in size were dried to constant weight, then partially immersed in a one per cent solution of water soluble eosine dye After 20 hours the pieces were removed, broken open, and the depth of dye penetration was measured. Several determinations for each sample gave the average values shown in Table 4. Some cherts showed a variation in depth of penetration in a single piece. This occurred in those types which were banded, mottled, or light in color surrounding a dark center. In all cases the dye penetrated much farther in the white or light colored portion.

Freezing and Thawing Tests

Freezing and thawing tests have been used extensively for judging the soundness or durability of aggregates. However, the American Society for Testing Materials (28) emphasizes the fact that "principle dependence should be placed on service records of the materials when exposed to actual weathering conditions."

In this investigation, the freezing and thawing test was intended as an identification test only, since there may be some question of the correlation between the performance of an aggregate confined in concrete and its performance in an unconfined state. The freezing cabinet and thawing tank previously described were used Each sample consisted of 1500 g. passing the 1½-in. sieve and retained on a ¾-in. sieve. The samples were covered with water for 24 hours before the start of the test. The water was then drained off and replaced with enough water at 32°F to cover the stone. This was done in an attempt to speed up the freezing action The aggregate was frozen for 6 hours at −10°F. and thawed for 30 min. at 75°–80°F. At the end of ten cycles it was oven-dried and sieved. It was then immersed for 24 hours before freezing. This procedure was repeated until 50 cycles was reached. Table 4 shows the loss after 50 cycles which was considered to be the percentage passing the ¾-in. sieve upon which all of the material was retained at the beginning of the test.

The relation between degree of saturation and freezing and thawing loss is shown in Table 5. These data indicate that the durability is greatly affected by the ratio of the absorption to the total void volume. This ratio is a fairly accurate index to the soundness or unsoundness of the cherts in this investigation.

TABLE 6

CHEMICAL ANALYSES

Performance Group		A		B	
Sample No		302	305	200	244
Percentage Composition	SiO_2	97 85	98 10	92 06	68 42
	TiO_2	0 00	0 00	0 00	Trace
	R_2O_3[a]	0 89	1 79	1 22	2 82
	CaO	1 00	0 32	4 37	15 50
	MgO	0 35	0 15	0 09	0 84
	H_2O	Trace	0 04	Trace	0 65
	CO_2	0 77	0 02	2 64	11 81
	Organic C	0 09	0 00	0 04	0 12
	P_2O_5	Trace	0 00	Trace	0 00
	S	0 02	0 00	0 00	0 00
	SO_3	0 00	0 00	0 00	0 00
Total[b]		100 97	100 42	100 42	100 16

[a] R_2O_3 includes TiO_2, Al_2O_3, Fe_2O_3, FeO, P_2O_5, and MnO

[b] In all operations, care was taken so that any necessary errors would lie in the amount of SiO_2 determined and not in the less abundant constituents. Therefore, this error is probably mainly in the amount of SiO_2

Chemical Analyses

Chemical analyses are being run as a part of the identification tests to determine if any correlation exists between the chemical composition and the performance Procedures given by Hillebrand (29) and Mellon (30) are used. No con-

TABLE 7

PRELIMINARY MICROSCOPIC ANALYSES

Performance Group	Sample No	Microscopic Description
A (51–100% failures)	302	Non-uniform texture, fossils replaced by quartz, very little calcite
	305	Non-uniform coarse texture, visible voids, small amount calcite lining voids
	245	Fine texture, many pores, calcite uniformly distributed, but not sufficient to fill voids
	331	Fine texture, some small calcite crystals distributed throughout
	333	Uniform texture, visible voids, very little disseminated calcite.
	242A	Very fine-grained texture, no visible pores.
	332	Fine texture, no calcite, chalcedony spherulites line cavities which are filled in with coarse quartz crystals
	334	Non-uniform texture, many voids, some disseminated calcite
	222	Non-uniform coarse texture, many large connected voids, no calcite.
	350	Uniform texture, much uniformly distributed calcite, some visible voids
	301	Fine texture with spherulites of chalcedony, some calcite
	300	Fine texture with large area of chalcedony spherulites, very little calcite
	243	Non-uniform fine texture, fine-grained calcite uniformly distributed
B (0–50% failures)	307	Predominantly medium-grained calcite, cavities filled with chalcedony
	244	Abundant calcite on one side separated from fine-grained no-calcite area by winding fissure filled with quartz and calcite
	200	Abundant calcite present in large crystals; fine texture
	200B	Non-uniform texture; calcite present in fine disseminated particles

clusions can be drawn as yet since only four analyses are complete. These are shown in Table 6.

Microscopic Analyses

Thin sections of chert are being studied microscopically to determine the mineralogical composition and structure of the various types. Preliminary observations on seventeen thin sections are shown in Table 7. Figure 7 shows sample 244 magnified 40 times, under crossed nicols. The dividing line between the upper calcitic area and the lower calcite-free area is marked. Figure 8 shows sample 305 magnified 40 times under crossed nicols. The coarse uneven texture and open voids may be noted.

The most striking characteristic of the thin sections in general was the correlation of the amount and distribution of calcite with the macroscopic color. The cherts whose macroscopic color was white or light had very little calcite present. Those that were gray to blue had considerable calcite distributed throughout. This darker color may be caused by the denser texture from the presence of the calcite in the pores of the chert, rather than to the color of the calcite itself.

The presence or absence of calcite is insufficient to account for all the variations in color of cherts since carbon, iron oxide, and other minerals probably cause wide variations in color. The effect of calcite is probably confined to the light grey and blue varieties of chert.

PRELIMINARY TESTS ON GRAVEL CHERT

The performance of a number of gravel chert particles has been tested following the same procedure as was used with quarry cherts. These particles were picked at random from samples from all parts of Indiana and were evacuated, saturated, and imbedded in mortar cubes which were frozen and thawed for 40 cycles.

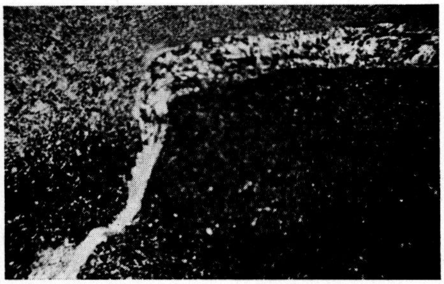

Fig. 7. Photomicrograph of Sample 244 Magnified 40 Times. Crossed Nicols

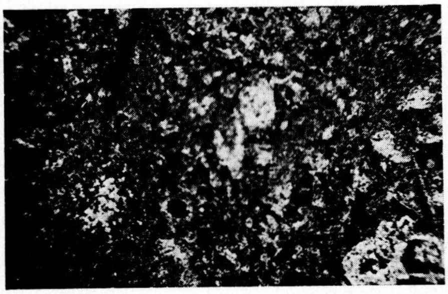

Fig. 8. Photomicrograph of Sample 305 Magnified 40 Times. Crossed Nicols

No attempt at classification of the cherts was made before imbedding them in mortar since the external appearance of a rounded piece may be much different from the appearance of a freshly fractured face. Since it was possible that breaking them open before freezing and thawing might change their resistance to disruption, they were not examined until they had disrupted the mortar cubes or had undergone 40 cycles of freezing and thawing. After a cube had been disrupted the chert piece was examined and described according to the same classification as was used for quarry cherts. The cubes which resisted 40 cycles of freezing and thawing were broken open with a chisel and examined. The results of these tests are shown in Table 8. The key to the description is given below:

TABLE 8

PRELIMINARY PERFORMANCE TESTS OF GRAVEL CHERTS

Color[a]	No. of cubes tested	No. of cubes failed in 40 cycles	Failed in 40 cycles	Not failing in 40 cycles
			%	%
1	137	124	91	9
1 Stained	12	7	57	43
2	25	24	96	4
2 Stained	6	6	100	0
3	15	14	93	7
3 Stained	0	...	...	...
4	5	5	100	0
4 Stained	0	...	...	...
1–4	200	180	90	10
5	10	1	10	90
5 Partially Stained	1	0	0	100
6	14	1	7	93
6 Partially Stained	9	0	0	100
7	58	2	3	97
7 Partially Stained	16	0	0	100
8 (non-chert)	28	7	25	75
8 Partially Stained	4	0	0	100
5–8	140	11	8	92

[a] Key to color classification given below.

1. Light tan to white, dense or porous, occasionally with small dark spots.

2. Light tan to white, surrounding a dark center; white predominates.
3. Light grey to white, with darker bands; light color predominates.
4. Light tannish grey; fossiliferous.
5. Mottled dark grey, brown, and white; dark color predominates.
6. Dark brown granular.
7. Dark blue or grey and white; dark color predominates.
8. Non-chert (limestone, shale, ocher, quartzite, etc.)

It will be noted that the color and performance of the gravel cherts check almost perfectly these characteristics in the quarry cherts. Further identification tests will be conducted on these same chert pieces which have been tested in mortar.

DISCUSSION OF RESULTS

From the performance tests it is evident that the Indiana quarry cherts vary widely in their soundness. These tests give a method of comparing the durability of the chert types. It is probable that some of the cherts in group B would disrupt the mortar if freezing and thawing were continued after 40 cycles, but the results indicate that group A cherts have a much greater degree of unsoundness.

It was possible to correlate certain major characteristics with performance The degree of saturation of chert is probably the most important characteristic in determining its resistance to freezing and thawing as shown in Table 5. This table shows a decided relationship between the degree of saturation and the resistance to freezing and thawing whether confined in mortar cubes or frozen unconfined. The samples for the unconfined freezing and thawing test were partially saturated by 24-hour immersion, and the degree of saturation by 24-hour immersion correlates with the unconfined freezing and thawing loss. It does not correlate with the results of the mortar tests since the samples for mortar tests were prepared by evacuation and saturation. This explains the lack of agreement between the results of the unconfined freezing and thawing tests and the performance tests. The relation of degree of saturation to performance confirms the work of Kreuger and Hirschwald who are referred to by Lang and Hughes (31). Similar conclusions were reached by Wray and Lichtefeld in their study of the effect of moisture absorption on resistance to freezing and thawing.

The data show that the percentage of absorption is another very important factor in performance The cherts in group A all had an absorption greater than 3.0 per cent. It is possible that absorption values lower than 3.0 per cent with a high degree of saturation might cause disruption after a longer period of exposure to weathering. For rapid failure it is necessary that the chert have a high degree of saturation and a high absorption.

The bulk specific gravities by A.S.T.M. method C 127-39 for Group A Indiana cherts were all less than 2 50. The bulk specific gravity is directly affected by the amount of absorption, since the presence of water in the pores of the material causes a decrease in the average specific gravity of the whole piece.

The dye penetration test correlated very well with the performance of the cherts. The cherts in group A showed dye penetration greater than one-half inch in 20 hours This test is another measure of the rate of absorption of a material since the depth of dye penetration indicates the depth to which water has penetrated in any given time interval

A summary of the test results is given in Table 9.

Examination of the cherts which disrupted the cubes showed that they were predominantly light in color. The resistance of the dark colored cherts to disruption might be due in part to the presence of calcite in the pores, which in turn would cause a lower absorption and a lower rate of absorption. Conversely the light colored porous cherts may have well-connected pore spaces giving a high absorption and a high degree of saturation because of the absence of calcite in the pores. It was observed that pyrite inclusions and structural irregularities such as carbon partings had a marked influence on the behavior of the chert in mortar.

In some cases the standard methods of specific gravity and absorption determination and of preparation for freezing and thawing do not provide entirely satisfactory results because of the lack of consideration of the degree of saturation of a material. For example, gravel which is used in a stream wet condition has a degree of saturation which is very close to 100 per cent. Material in this condition would offer much lower resistance to freezing and thawing than it would when tested by the A.S.T.M. method which calls for oven drying followed by immersion for 24 hours.

TABLE 9

SUMMARY OF TEST RESULTS

Performance Group (Percentage Failures)		Degree of Saturation (Evacuated)	A S T.M Bulk Specific Gravity (Sat. Surf -Dry)	A S T M. Absorption	20-hour Dye Penetration	Degree of Saturation (24-hour Immersion)	Unconfined Freezing and Thawing Loss
		%		%	in.	%	%
A 51–100 (137 cubes, 13 samples)	Average	93 3	2.40	5 67	0.70	89.7	56 9
	Range	87 5–100 0	2 35–2 46	3 91–7 70	0 40–Comp.	72 2–100 0	19 9–89 2
B 0–50 (59 cubes, 12 samples)	Average	76 5	2 59	1 83	0 20	73 9	16 7
	Range	69 2–84 8	2 48–2 67	0·89–3 02	0 00–0 60	57 5–82 5	3 2–40 2

SUMMARY OF RESULTS

Since this paper presents only Part I of the investigation, the results primarily cover Indiana stone cherts. However, preliminary tests on gravel cherts, consisting of performance tests, indicate that they are performing in a similar fashion to the quarry cherts. The appearance of the specimens which disrupted mortar cubes was very similar to that of the disruptive quarry cherts. It should also be mentioned that the outstanding exceptions to the correlating results listed below are two cherts not found in Indiana. From the data obtained, the following observations were made:

1. The study of chert should be restricted to a definite geographical area. The characteristics of cherts vary widely in different regions.

2. A wide variation in performance of material from Indiana exists.

3. It is possible to correlate certain major characteristics with performance. The most unsound Indiana chert can be identified by the following characteristics:

a. A ratio of 0.85 or above between the absorption by one hour evacuation and 23 hours' immersion and that calculated for 100 per cent saturation.

b. A 24-hour absorption by A.S.T.M. method C 127-39 of 3 per cent or more.

c. A bulk specific gravity, saturated surface-dry (A.S.T.M. method C 127-39) of less than 2.50.

d. Eosine dye penetration of one-half inch or more in 20 hours.

e. Predominantly light in color.

4. Freezing of water in the voids of the chert was the cause of disruption.

5 It was further observed that pyrite inclusions and structural irregularities, when present, marked the plane of failure of the chert. Interstitial calcite apparently reduced the unsoundness.

6 The performance of chert is dependent on the method of saturation. The results constitute a criticism of the accepted standard methods for specific gravity and absorption determination, and preparation for freezing and thawing because of lack of consideration of the degree of saturation of the materials tested.

7 The work confirms generally that of Wuerpel whereby a bulk specific gravity may be used to distinguish between various degrees of resistance to freezing and thawing in cherts. The limit of 3 per cent on absorption is close to that determined by Cantrill and Campbell, who used A S T M method C 95-36. The importance of the degree of saturation on the resistance to freezing and thawing which is indicated agrees with the conclusions of Kreuger, Hirschwald, Lang, Wray and Lichtefeld.

8 Calculations of the total strength of the mortar area in the disrupted cubes indicate that the force exerted by an individual ¾-in to 1-in chert piece exceeds 1000 lb.

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