material taken from the cut. In other words, some of the soils will be loaded in their undisturbed states, and some of the soils will be disturbed and recompacted before being loaded.

The compaction characteristics of the soil or soils in the fill determine the density to which the material will be placed. Capillarity, permeability, and consolidation tests should indicate the probable moisture contents and rate of settlement, if any, that will occur after the fill has been made. The results of the tests, if they are to be practicable, must, of course, be modified by information concerning underlying materials, ground-water table, floods, and similar conditions. Strength tests, and possibly tests for expansion and shrinkage, on the recompacted soil at the condition it will likely attain in the field will indicate in advance whether the material is desirable fill for the location. Eventually, the strength-test data should be an important factor in the design of the pavement for this condition.

The tests may show also that it is desirable that the materials in the cuts or near ground elevations be recompacted in order to improve their strengths and drainage properties. In sections where poor soil must be replaced with better material, it may be that suitable borrow can be found nearby if the soil map is available and the characteristics of the mapped soils are known. These, of course, are but a few of the many factors that may be involved in such a field situation.

Knowing that topography is a major influence on the formation of soils, we can predict the condition in which the soil will probably be used for highway construction. A thorough record of the engineering characteristics of many soils combined with pedology and maps that locate the soil types in the field provides a good basis for analysis of our soil problem. In fact, it appears that these factors form a natural combination. To make this combination more complete and more workable is one goal for future highway research.

CHERT AS A DELETERIOUS CONSTITUENT OF INDIANA AGGREGATES

Harold S. Sweet,

Research Engineer, Joint Highway Research Project, Purdue University

The term "chert" has been applied to many types of rock. However, it is now usually restricted to rocks composed predominantly of micro-crystalline silica that are opaque except in thin sections. The distinction between chert, flint, opal, and chalcedony is not clear-cut; but the term "flint" is usually applied to black varieties of micro-crystalline silica; opal is a hydrous, amorphous form of silica; and chalcedony is a translucent, microscopically-fibrous variety of quartz.

Chert occurs in deposits of almost every geological age. It is usually found either as well-defined beds or as nodules within limestone. According to Tarr[1], "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 sandstones being under apparently exceptional conditions. . . ."

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.

Recognizing the harmful effect of some types of chert, various states have set up specifications limiting the amount of chert in concrete aggregates. The states particularly concerned about chert are those in the Middle West, including the glaciated states of Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin. Missouri and Kentucky also restrict the amount of certain kinds of chert that may be present in aggregate.

It has been noted that not all cherts cause "popouts" or disruption of concrete. Walker[2] 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 . . . ." A method for distinguishing between durable and non-durable cherts is needed.

In the fall of 1939, the Joint Highway Research Project, in co-operation with the Bureau of Materials and Tests of the State Highway Commission of Indiana, undertook a comprehensive study of Indiana cherts. The first part of this study covered an investigation of quarry cherts, which has already been published,[3] while the second part covered gravels. This paper covers briefly some of the more important phases of this investigation.

The first step in the study of Indiana cherts was the collection of samples from quarries and gravel pits. Samples of chert were obtained from quarries in outcrops of Silurian, Devonian, Mississippian, and Pennsylvanian rocks in Indiana and adjoining states. In addition, chert samples from gravel deposits throughout the state were secured.

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[1] Tarr, W. A. "Origin of Chert and Flint," *University of Missouri Studies*, Vol 1, No. 2, 1926, p. 22.

[2] Walker, Stanton. "Discussion of Cantrill and Campbell's Paper on Selection of Aggregates for Concrete Pavements," *Proceedings, American Society for Testing Materials*, Vol. 39, 1939.

[3] Sweet, Harold S. "Chert as a Deleterious Constituent in Indiana Aggregates," *Proceedings, Highway Research Board*, Vol. 20, 1940, pp. 599-620.

Part I. Quarry Cherts

It was planned to perform numerous physical and chemical tests on each chert type and to correlate the properties with the performance in concrete. For this it was necessary to have a number of pieces of each type that 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 reasonably uniform in their properties. On the other hand, it was not certain that two pieces of gravel chert that 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 to determine, if possible, the characteristics that distinguish the deleterious cherts from non-harmful types.

Performance of the samples was determined by alternately freezing and thawing two-inch mortar cubes with one-inch chert pieces imbedded in their centers. Identification tests consisted of color, luster, texture, fracture, specific gravity, absorption, degree of saturation, dye penetration, unconfined freezing and thawing, chemical analyses, and microscopic examination of thin sections.

It was observed that quarry cherts 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 followed by 23 hours' immersion and that calculated for one hundred per cent saturation. They had an absorption of three 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 quarry cherts that showed disruptive tendencies also had an eosine dye penetration of one-half inch or more after twenty hours' immersion, and were predominantly light in color.

After tests on the quarry samples had been completed, the gravel cherts were tested to determine if the characteristics of both materials were the same. This plan of attack seems to be logical since the gravels are derived from rock strata.

Part II. Gravel Cherts

The performance of gravel chert was determined by the same procedure as was used with the quarry cherts. Pieces ¾″ to 1″ in size were picked at random from samples of gravel chert from Indiana and other states. These were evacuated for one hour, saturated, and immersed for 24 hours. They were then imbedded in two-inch mortar cubes. The cubes were cured for seven days and then frozen and thawed. Table I shows the number of specimens tested in this manner. The cubes made with 1:5 mortar (one part portland cement to five parts of sand by weight) were frozen immersed in water, while the cubes made with 1:3 mortar were frozen in air.

The 1:5 cubes that did not fail were removed from the test after 40 cycles of freezing and thawing. The 1:3 cubes were frozen and thawed for 160 cycles before being removed.

TABLE I

SUMMARY OF MORTAR TESTS

Mortar	1:5			1:3			
Material Tested and Treatment	No. Cubes Made	Fail. in 40 Cycles	Pctg. Fail.	No. Cubes Made	Fail. in 160 Cycles	Pctg. Fail.	Total Cubes Made
Evacuated One Hour and Saturated:							
Quarry Chert	218	122	56.0	39	31	79.5	257
Gravel Chert	320	183	57.3	382*	178	46.6	702
Limestone	8	1	12.5	42	5	11.9	50
Soft Oolitic Limestone and Caliche	9	6	66.7	18	7	38.9	27
Sandstone	1	0	0	11	2	18.2	12
Shale	10	5	50.0	4	3	75.0	14
Iron Concretions or Ocher	5	5	100.0	19	16	84.3	24
Igneous and Metamorphic	2	0	0	4	0	0	6
Quartzite	14	1	7.1	7	0	0	21
Special Treatment	107	39	36.4	192	89	46.4	299
Cubes Still Under Test				323			323
Total Cubes	695			1,041			1,735

* Twenty-five cubes containing gravel chert are being frozen and thawed more than 160 cycles.

No attempt at classification of the chert pieces was made before imbedding them in mortar, since the external appearance of a rounded (and sometimes stained) gravel particle may be far different from the appearance of a freshly-fractured face. After a cube failed, the chert piece was examined and classified as to appearance. The mortar was then broken away from the gravel particle. The bulk specific gravities of all the specimens were determined by using the flotation procedure described later. Dye-penetration tests were then performed on some of the pieces. The absorptions of other pieces are being determined. The cubes that did not fail were broken open with a chisel, and the chert pieces were removed. They were then tested by following the same procedure as was used on the failures.

Bulk Specific Gravity. The flotation method of determining the bulk specific gravity of gravel particles was used by Wuerpel and Rexford[4] in separating chert samples into different fractions on the basis of bulk specific gravity. A modification of their procedure was used in testing the gravel cherts. The method determines the average specific gravity of the solid material plus water and air contained in the voids of the specimen.

Carbon tetrachloride, specific gravity 1.58, and acetylene tetrabromide, specific gravity 2.97, were mixed together to give liquids with specific gravities of 2.60, 2.55, 2.50, 2.45, 2.40, 2.35, and 2.30. These specific gravities were tested with a hydrometer that had been accurately calibrated.

A gravel specimen that had been broken out of the mortar cubes was immersed in water. After it had soaked for 24 hours, it was surface-dried and placed in the heaviest liquid (2.60). If it sank in this liquid, it was removed and the specific gravity was recorded as 2.60+. If it floated on the 2.60 liquid, it was removed and placed in the 2.55 liquid. This process was repeated, putting it in liquids with successively lower specific gravities until it sank in some liquid. If it floated in the lightest liquid (2.30), its specific gravity was recorded as 2.30—.

Many of the samples tested were broken in several pieces during the process of removing them from the cubes and also by the freezing and thawing they had undergone. Furthermore, in many cases the bulk specific gravities of portions of the same gravel particle were different. This was particularly true of the banded types. The darker-colored portions showed a higher specific gravity than the lighter portions. When several portions of a gravel piece varied in specific gravity, an average value for the whole piece was calculated, based on the relative size and specific gravity of the different fractions.

The results of the specific gravity tests have been plotted according to the percentage of samples in any group with a flotation specific gravity less than a given value. Fig. 1 shows the range in values for failed Indiana gravel chert imbedded in 1:5 mortar. Out of the 123 failures, 93.5% were lower than 2.50 in specific gravity. Fig. 2 shows the values for failures and non-failures in Indiana gravel cherts tested in 1:3 mortar. The percentages for these curves are based on the number of failures or non-failures.

The number of cycles at failure of a specimen might be considered an index of its durability. The samples failing before 40 cycles are less durable than those failing after a

[4] Wuerpel, C. E., and Rexford, E. P. "The Soundness of Chert as Measured by Bulk Specific Gravity and Absorption," *Proceedings, American Society for Testing Materials,* Vol. 40, 1940, pp. 1021-1043.

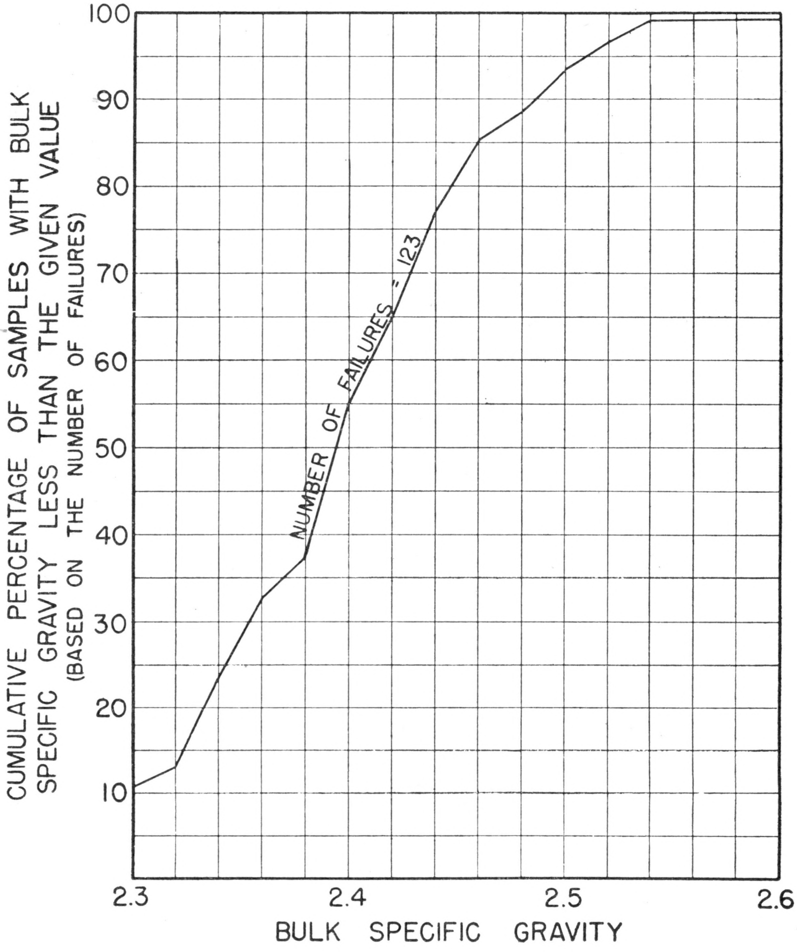

Fig. 1. Bulk specific gravities of failures in Indiana gravel chert imbedded in 1:5 mortar (samples failed in 40 cycles).

greater number of cycles. Examination of the curve in Fig. 2 for failures in less than 40 cycles shows that 95% of them were below 2.50 in bulk specific gravity. However, 40% of the samples that had not failed in 40 cycles were also below 2.50. Seventy-two per cent of the failures were below 2.45, with 19% of the non-failures also below 2.45. In the group of specimens which failed before 160 cycles, 55 per cent were lower than 2.45; while only 16% of the samples that did not fail in 160 cycles were below 2.45. Similarly, it may be seen that 84% of all samples failing in less than 160 cycles were below 2.50, and 31% of the non-failures at 160 cycles were below 2.50. These curves indicate that if the specific gravity limit is raised, the accuracy in detecting non-durable chert is increased. How-

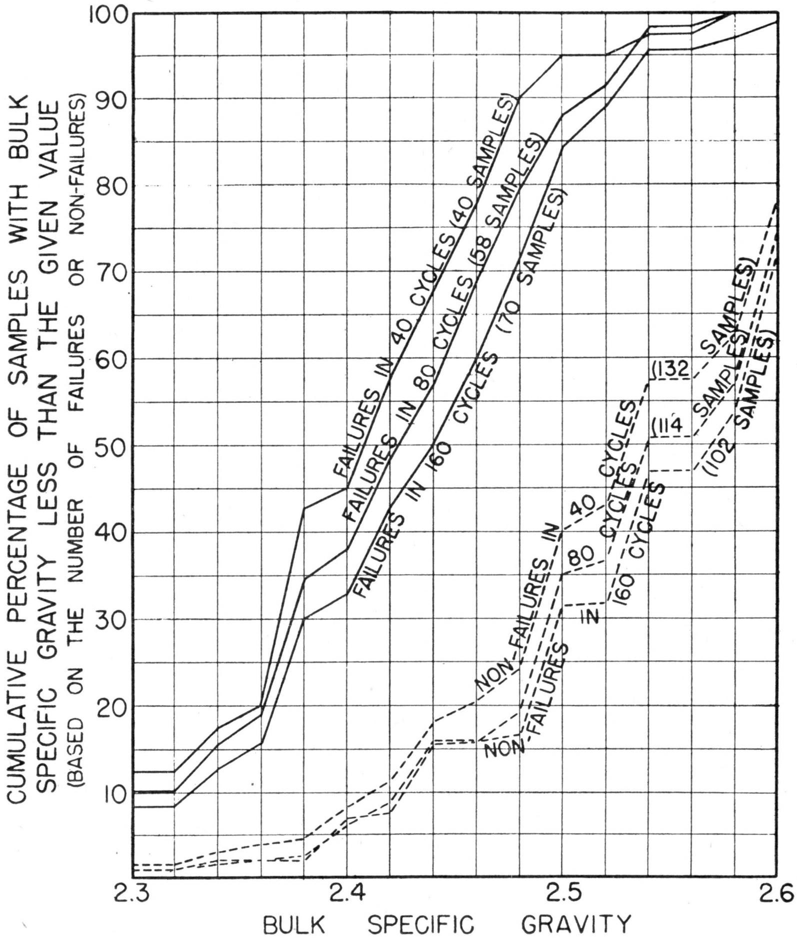

Fig. 2. Comparison of bulk specific gravities of failures and non-failures at 40, 80, and 160 cycles. (1:3 mortar specimens).

ever, the amount of relatively-durable material included is also increased. Thus, a limit of 2.45 detects the very harmful types and includes little durable material. A limit of 2.50 includes almost all the non-durable material and also a larger amount of durable particles than does the 2.45 limit.

It should be noted that the specific-gravity values obtained by testing the chert pieces after they had been broken by freezing and thawing may be somewhat higher than the original specific gravity of the whole piece. The chert piece when intact probably had systems of voids, such as incipient fracture planes. These voids would have a buoyant effect and cause a lower value for specific gravity than the value after they had been destroyed.

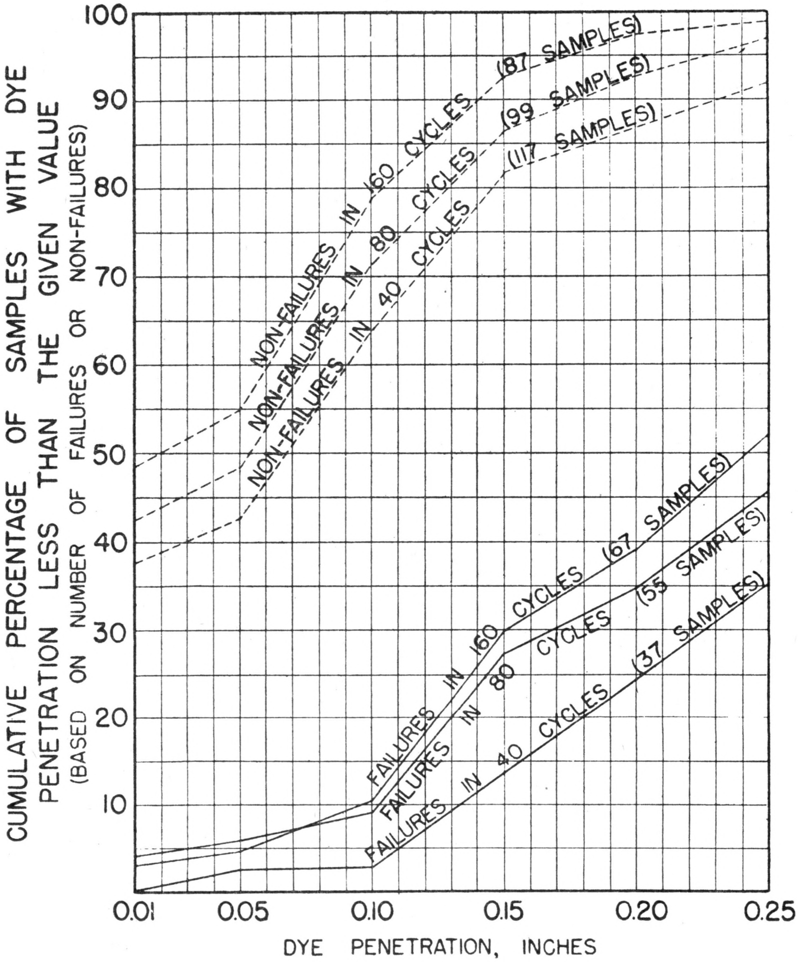

Fig. 3. Comparison of dye penetration of failures and non-failures at 40, 80, and 160 cycles (Indiana gravel chert imbedded in 1:3 mortar).

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 gravel chert specimens from the 1:3 mortar cubes were partially immersed in a one-per-cent solution of water-soluble eosine dye. After one hour, the specimens were removed and broken open, and the depth of dye penetration was measured. These results were plotted in Fig. 3 as the cumulative percentage of failures or non-failures with dye penetration less than the given value. These curves indicate that the cherts with a higher dye penetration are the first to fail. It may be noted that 13% of the failures in 40 cycles showed a dye penetration of less than 0.15 inches, while 82% of the non-failures were less than 0.15 inches in penetration. Ten per cent of the failures and 80% of the non-failures in 160 cycles had less than 0.10 inches dye penetration.

Some of the overlapping of the test results on failures and non-failures is probably due to inaccuracy in the mortar test. It was observed that, when the cubes that did not fail were broken open, some of the chert pieces were split into several pieces. Since they had not disrupted the cubes, it is probable that there existed a cushion of air around them that allowed expansion to take place. This probably occurs in only a small percentage of the cubes, since the majority of the non-failing specimens were removed intact from the mortar. Another source of error is in the samples with a hard, dense outer crust. These specimens would not absorb water as readily when this crust was intact as they would after it had been broken in removing the specimen from the cube. Thus, they would show higher dye penetration and higher bulk specific gravity than would a sample with the crust unbroken.

Summary of Results

The characteristics of Indiana gravel cherts coincide, in general, with those of the quarry cherts. The non-durable types that failed in less than 160 cycles of freezing and thawing had the following characteristics:

1. Predominantly light in color except when stained.
2. Bulk specific gravity less than 2.50.
3. Eosine dye penetration of 0.10 inches or more in one hour.

The specific-gravity test showed considerable overlapping of values for failures and non-failures. Eighty-four per cent of the failures and 31% of the non-failures in 160 cycles were less than 2.50 in bulk specific gravity. The dye-penetration test also showed overlapping, but it was slightly less. Ninety per cent of the failures and 21% of the non-failures in 160 cycles showed greater than 0.10 inches of dye penetration.

It was observed that samples failing in the first 40 cycles had higher dye penetration and lower bulk specific gravity than the more durable types. Eighty-seven per cent of these specimens showed greater than 0.15 inches of dye penetration, and 72% were less than 2.45 in bulk specific gravity.