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Properties of Five Iowa Fine Sands

By W. W. WILLIAMS, D. T. DAVIDSON, AND T. Y. CHU

INTRODUCTION

Today a major problem in the State of Iowa is the development of substitute materials which can be used in place of the rapidly diminishing supplies of readily available gravel and rock surfacing materials for roads and streets. The materials now available are not evenly distributed throughout the state, and the rate at which they are being used indicates that it will soon be necessary to turn to materials which are not now considered suitable. One such material is fine sand, commonly discarded by gravel plants as waste. Fine sand is readily available in almost every section of the state. It forms a portion of the flood plain deposits of many of the major rivers and streams and is found in a variety of occurrences related to the glacial drift sheets of the state.

The Iowa State Highway Commission has inaugurated a research program to find ways of utilizing fine sands as highway surfacing materials. The portion of this problem dealing with the determination of fundamental properties of the sands was assigned to the Iowa Engineering Experiment Station, Iowa State College. This report presents the results of the Station's study of five samples of fine sand.

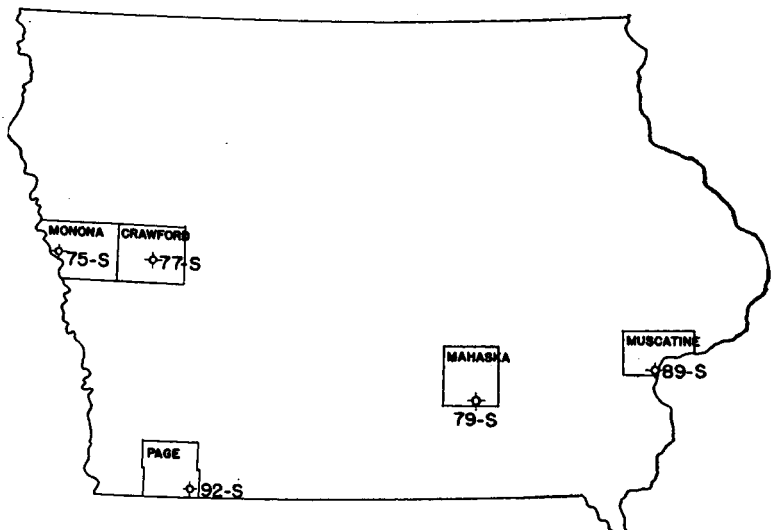


Figure 1. Distribution of the five Iowa fine sand sampling locations.

Five sand deposits (Figure 1) were sampled by personnel of the Highway Commission under the supervision of a geologist. Approximately one ton samples were taken, and a 60 pound portion of each was submitted to the Soil Research Laboratory of the Iowa Engineering Experiment Station for determination of fundamental properties. Information of the sampling locations is given in Table I. The five sand samples are identified by the numbering system of the Highway Commission.

The fundamental properties of the fine sands are presented under three headings:

1. Occurrence and origin.
2. Composition.
3. Behavior characteristics.

As used in this report *occurrence and origin* includes information as to the source, areal extent and uniformity of a deposit wherever determined. The term *composition* is broadly interpreted to cover factual information on the components of a sand. *Behavior characteristics*, sometime called engineering properties, are those characteristics, such as shearing strength, plasticity, permeability, capillarity, and compactability, which may be used to predict the performance of a sand as a highway construction material.

OCCURRENCE AND ORIGIN

An attempt has been made to determine the occurrence and origin of the fine sand deposits by a review of the pertinent literature and by field studies, augmented wherever possible by maps and aerial photographs.

Monona County Deposit

The deposit in Monona County was studied by using maps and aerial photographs before field observations were made. Figure 2 shows where sample 75-S was taken and also some of the prominent alluvial features related to the deposit sampled. The area is described by Shimek (1) in a report on the geology of Monona County. He states that Blue Lake was the main channel of the Missouri River at the time of the Lewis and Clark expedition in 1804 and points out that the lake must have been cut off between this time and the time of his study. He describes the sand lying to the east of the lake as having been reworked by the wind.

The Missouri River in Monona County meanders in a relatively wide valley which narrows to the south near Council Bluffs and to the north near Sargents Bluff. In the process of meandering, a river such as the Missouri river is constantly changing its course by lateral mi-

Table 1
Sampling Locations of the Five Iowa Fine Sands.

Sample No.	County	Section	Township North	Range West	Remarks
75-S	Monona	SE $\frac{1}{4}$,NE $\frac{1}{4}$,S-2	83	46	Sampled from the eastern edge of Blue Lake.
77-S	Crawford	SW $\frac{1}{4}$,NW $\frac{1}{4}$,S-14	83	39	Sampled from an abandoned gravel pit at the south edge of Denison.
79-S	Mahaska	NE $\frac{1}{4}$,SE $\frac{1}{4}$,S-25	74	16	Sampled from the north side of the gravel road leading to the Concrete Materials and Construction Company's gravel plant.
89-S	Muscatine	SW $\frac{1}{4}$,NW $\frac{1}{4}$,S-15	76	2	Sampled from a waste pile on the west side of Stewart Road.
92-S	Page	SE $\frac{1}{4}$,NW $\frac{1}{4}$,S-22	69	36	Sampled from a pit locally called the Walker Pit.

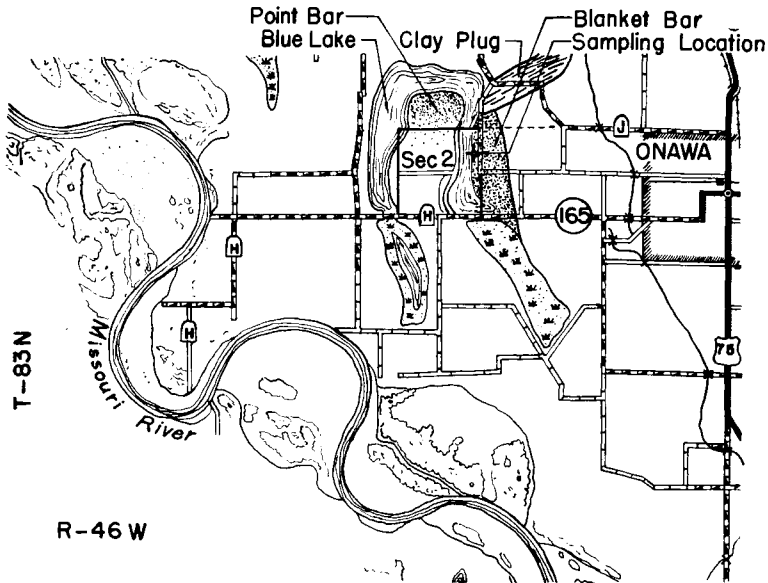


Figure 2. Sampling location of Sample 75-S and prominent alluvial features related to the blanket bar sampled.

gration due to removal of material on the concave bank in the meander loops and by abandoning entire meander loops by a process of neck or chute cut-offs. A neck cut-off occurs when the opposite limbs of the stream in a meander have migrated so close together that flood waters spill over the divide separating them and erodes it away. This shortens the stream in this area and so increases the gradient that the stream will remain in the cut-off. After the cut-off, the river migrates laterally away from the abandoned loop, which becomes an ox-bow lake. The ox-bow lake is rapidly filled with fine grained sediments, usually of silt and clay sizes. This cohesive fine-grained material forms a deposit, or *clay-plug*, in the abandoned channel (2). The clay-plug is difficult to erode and tends to limit the migration of the meander belt and to cause numerous reverse curves in the stream channel such as the east bend of Blue Lake.

Although neck cut-offs occur in the Missouri River, the chute type of cut-off appears to be more common. This type of cut-off occurs when the river cuts across a point bar through one of the sloughs. In this type cut-off the abandoned channel is filled with coarser sized material which offers little resistance to erosion, and the stream continues to migrate in the same direction as before. In time it regains the original position before the cut-off. The flood-plain east of Blue Lake as far as Onawa is a complex of these old

meander loops which may be readily identified on aerial photographs of the area.

There are four types of sand deposits commonly associated with meandering streams: point bars, blanket bars, natural levee systems, and channel fillings. All four types of deposits are found in the area around Blue Lake.

A point bar is found on the inside bank of curves and is commonly composed of a series of arcuate ridges parallel to the curvature of the meander. The point bar is made up of sand or silty sand in the ridges which are separated by sloughs underlain by silty sand or silty clay. A point bar is shown in Figure 2.

Blanket bars and natural levees are related to each other genetically and are found along the margins of the stream. A blanket bar is deposited below some feature along the river which serves to deflect the main current when the river is in flood stage. A natural levee is deposited from the sediment laden overflow when the stream is in flood stage and is a low, nearly continuous ridge parallel to the stream bank. Blanket bars and natural levees usually consist of silty sand or fine sand which is somewhat finer than the material in a point bar. The blanket bar from which sample 75-S was taken occurs on the downstream side of the clay-plug shown in Figure 2.

Channel fillings are generally more variable than either of the other types of deposits and may be of all particle sizes from coarse gravel through clay. They are usually a complex of interbedded gravel and sand intermixed with the finer grained alluvium.

A part of the field investigation was the collection of samples of material from the ridges of the point bar and from the clay-plug. The gradations of samples representing the point bar, the clay-plug, and the blanket bar sampled by the Highway Commission are compared in Figure 3. As would be expected from the above discussion, the cumulative curves in Figure 3 show the material of the point bar to be coarsest and that of the clay-plug finest.

The blanket bar shown in Figure 2 is limited on the north by the clay-plug, to the west by the channel fillings under the present lake, and on the east and south by material which becomes progressively finer textured away from the blanket bar.

The sand represented by sample 75-S was deposited by the river during the Recent epoch and is in part derived from sedimentaries of Cretaceous age, as shown by the presence of Cretaceous microfossils. This material also is probably in part derived from the till plains to the east and north by erosion and selective transportation.

The sands found in the vicinity of Blue Lake should not be con-

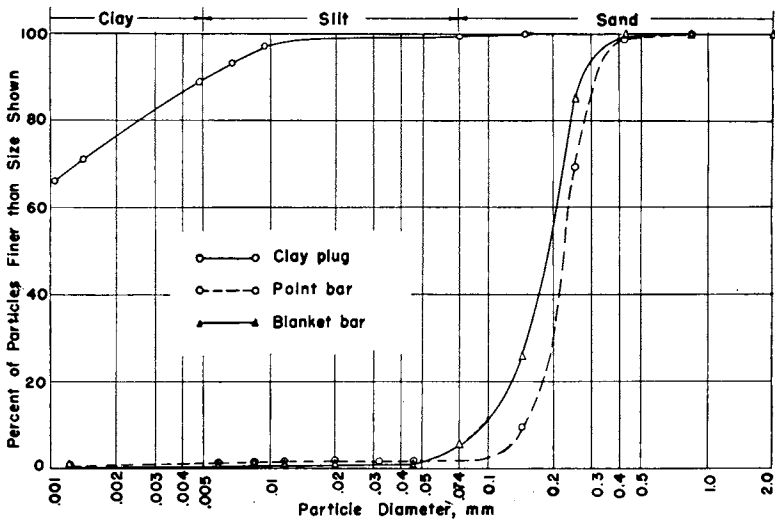


Figure 3. Particle-size accumulation curves showing gradation of clay plug, point bar, and blanket bar materials from Blue Lake deposits in Monona County.

sidered characteristic of the sands found either upstream or downstream from this area. In any alluvial valley the materials carried and deposited by the stream vary from place to place due to the influence of tributaries as well as to local hydrologic and geologic factors. The effect of a major tributary is often great enough to cause the material deposited along the main stream below it to be quite different from that deposited above.

Crawford County Deposit

Sample 77-S from Crawford County, near Denison, (Table I) was taken from an abandoned gravel pit lying to the south of the West Boyer River and at a somewhat higher elevation than the present floodplain.

Lees calls this location the Old Mill Pit (3). He identified the material in the pit as fine yellow and gray sand with interbedded gravel approximately 50 feet in thickness. Lees was unable with the knowledge at hand to date the deposit, but Kay and Miller (4) describe other, probably similar, deposits in Crawford County as Loveland in age.

The areal extent of the deposit, which represents a portion of an old river terrace built up by glacial melt waters, was not determined in the present investigation. If it proves to be a terrace deposit, it may extend both upstream and downstream parallel to the West Boyer River.

The field investigation showed the gravel pit to be much as Lees

described it. The color of the sand appears to depend upon the state of reduction of the iron, grading from gray at the bottom to a brownish yellow at the top. Three to four feet of gray loess overlays the deposit.

Mahaska County Deposit

Sample 79-S from Mahaska County (Table I) was taken from a narrow lineal hill bordering the flood plain on the east side of the Des Moines River in a northwest to southeast direction in the vicinity of Eddyville. The deposit is limited to the hill which has a relief of about 50 to 75 feet, a width of 300 to 500 feet, and a length of about two miles.

Bain (5) designates other fine sand of the county as aeolian, but does not specifically mention this deposit, which is sometimes identified as a wind-deposited sand derived from the flood plain of the river. Examination of the area on aerial photographs and in the field suggests that the sand may have been deposited by water overflowing a low ridge of glacial till which formed the east side of a conspicuously narrow segment of the valley in this area. This narrow segment of the valley is essentially co-extensive with the length of the sand ridge. The age of the deposit is unknown.

Muscatine County Deposit

Sample 89-S from Muscatine County (Table I) was collected from a waste pile discarded by a material producer engaged in the production of gravel. The waste pile was deposited by a flume carrying the water and fine sediments that passed through the screens of the gravel producing plant. The flume outlet was moved frequently as the waste pile accumulated, and as a result the deposit is complex to sample since the material is texturally coarser near the flume outlets and grades radially into finer sizes.

Page County Deposit

The geological origin of the deposit from which sample 92-S from Page County was taken is different from that of the other deposits. This deposit is a type of alluvial fan and is located (Table I) in the valley of the Nodaway River. It appears to have been derived from erosion of the Kansan till uplands by small tributaries of the Nodaway River, which deposited the sand and gravel as their gradients were decreased when they reached the floodplain of the Nodaway.

COMPOSITION

The preceding discussion of occurrence and origin refers to the sand deposits as a whole. In the rest of this paper the properties

of five sand samples taken from these deposits by Highway Commission personnel are discussed. Additional field work is needed to determine whether the five samples are representative of the deposits from which they were taken.

Mechanical Composition

Mechanical composition covers such information as the size, specific gravity, shape (sphericity), surface texture, and aggregation characteristics of the sand particles.

Size

Particle-size determinations were made by A.S.T.M.* standard method D422-51, as modified by Davidson and Chu (6). The particle-size data for the five sand samples are shown as cumulative curves in Figure 4. The percentages of sand, silt, and clay-size material in each sample are given in Table II. Although all samples were classified texturally by the U. S. Bureau of Public Roads system (7) as sand, their gradation differed considerably; and some of the samples contained appreciable amounts of silt and clay-size material.

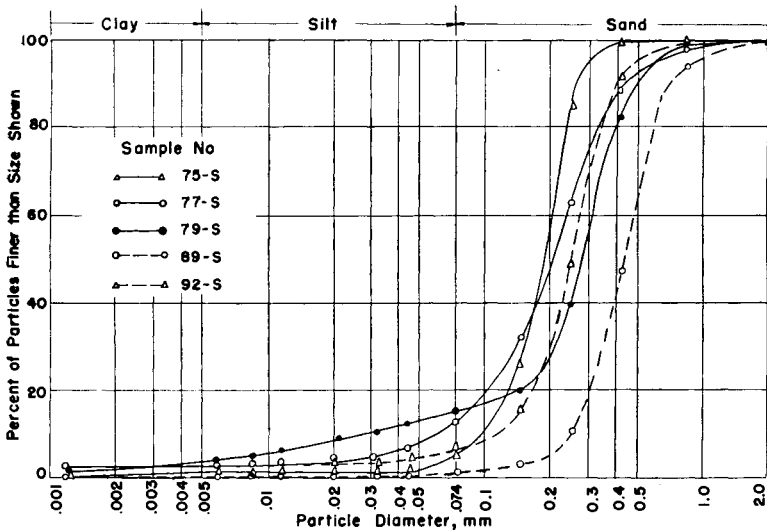


Figure 4. Particle-size accumulation curves for the five Iowa fine sands.

Specific Gravity

The specific gravity of each sand sample was determined by A.S.T. M. method D854-45T (8). The data are given in Table II. The specific gravity of each sample was close to that of quartz, which is 2.66.

*American Society for Testing Materials.

Shape

The shape or sphericity of sand particles is directly related to their occurrence and origin and should have an important effect on their behavior characteristics. While various methods have been devised for estimating the average sphericity of a sample (9, 10, 11, 12), there is need for a more exact method.

The Rittenhouse (13) chart shown in Figure 5 was used for estimating particle sphericity. The sand particles were viewed through either a petrographic or a binocular microscope, depending upon the particle sizes being studied; and their sphericities were estimated by comparing sand particle outlines with the outlines in the chart of particles of known sphericity.

The Rittenhouse chart is based on Krumbein's (14) formula:

$$\text{Sphericity} = \frac{\text{Intermediate particle diameter}}{\text{Maximum particle diameter}}$$

The meaning of *intermediate particle diameter* and *maximum particle diameter* is shown in Figure 5. In using the chart for estimating sphericity, it is assumed that the minimum particle diameter is normal to the line of sight and that the outline of the particle as viewed on the slide shows the maximum and intermediate diameters.

The selection of particles from the whole sand sample that would represent the average sphericity of the sample was difficult, since the tendency was to choose only the larger particles. To avoid doing this, the following particle-size ranges, which bracket the median* particle diameters and are thought to be representative of the sand and silt portion of the samples, were used for the shape determinations:

Sample No.	Particle-Size Range
75-S	0.250 to 0.074 mm.
77-S	0.250 to 0.074 mm.
79-S	0.420 to 0.250 mm.
89-S	0.420 to 0.250 mm.
92-S	0.250 to 0.074 mm.

The Jeffries method (15) was used to remove clay and iron coatings from samples used in the shape study.

The results of the shape study are given in Table II. Sample 89-S from Muscatine County had the highest average sphericity, and sample 92-S from Page County had the lowest. In general, it was found that in all samples the larger particles showed the greatest degree of sphericity.

Texture

Surface texture as used herein covers both the markings and the

*The median diameter is the particle diameter associated with the 50 percent line of the cumulative curve.

Table 2
Mechanical Composition of the Five Iowa Fine Sands.

Sample		Textural Composition ^a			Sp.G. (25°C)	Ave. Spher- icity ^b	Surface Texture ^c		Aggregation Characteristics		
No.	Location	Sand,%	Silt,%	Clay,%			Markings	Coatings	Amount	Size,mm	Cement
75-S	Monona Co.	96.3	2.9	0.8	2.67	0.65	Dull and smooth	Partially coated by calcareous clay	Rare	1-1½	Calcareous clay
77-S	Crawford Co.	87.6	9.6	2.8	2.66	0.71	Dull and rough (faceted)	Partially coated by calcareous clay	Common	1-3	Calcareous clay
79-S	Mahaska Co.	84.7	11.0	4.3	2.65	0.73	Dull and smooth	Partially coated by ferruginous clay	Abundant	½-1½	Ferruginous clay
89-S	Muscatine Co.	98.1	1.6	0.3	2.67	0.75	Dull and rough (pitted)	Partially coated by iron oxide	Absent
92-S	Page Co.	92.9	4.3	2.8	2.68	0.61	Dull and rough (pitted)	Completely coated by slightly calcareous clay	Common	1-2	Slightly calcareous clay

^aSand—2 to 0.074 mm, silt—0.074 to 0.005 mm, clay—less than 0.005 mm.

^bSee Rittenhouse chart—Figure 5.

^cDescriptions apply to most sand particles in the sample.

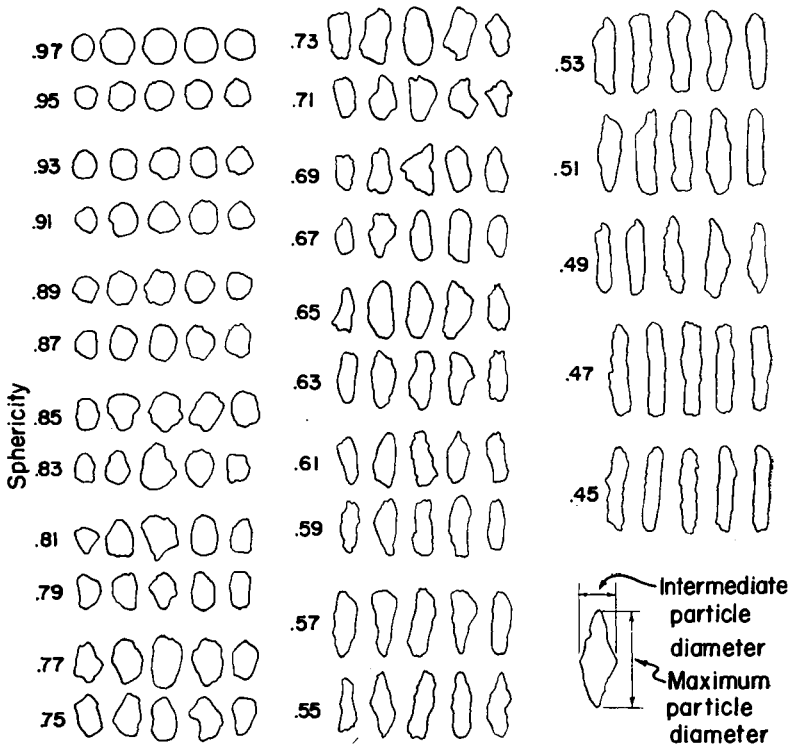


Figure 5. Rittenhouse chart for determining visually the sphericity of sands.

coatings on the surface of particles. Markings on particles result from the effects of transportation and of diagenesis. Like particle shape, surface markings vary with the size of the particles. Unlike particle shape, however, the kind of markings rather than the amount varies with the size. At the present time there is no well defined procedure for evaluating surface markings. Krumbein and Pettijohn (16, p. 307) have suggested a two word system of describing markings. The first word refers to luster, and the second to the surface relief of the sand particle. This system was used in the present study. Coatings on particles may be especially significant in stabilization studies, since they may have an important effect on the interaction between the mineral particles and chemical additives. Clay, lime, and iron oxide are perhaps the most common coatings found on the surface of sand-size particles. These coatings may completely coat the particle, or they may occur only in the surface depressions. Important factors in connection with coatings are: type and amount, reactivity, ease of removal, and effect on aggregation. Coatings are seldom determined quantitatively, rather their

appearance is described (Table II).

Markings and coatings on the sand-size material of the five Iowa fine sands were determined with a binocular microscope. Samples representative of the whole, uncleaned sands were used for studying coating; similar samples cleaned by Jeffries method (15) were used for determining markings. The results of the surface texture studies are presented in Table II.

Aggregation

Aggregation is the cementation of two or more sand-size particles to form a larger unit. It is closely related to coatings on the particles in that coatings of clay, lime, iron oxide, or organic matter (humus) alone or intermixed provide the cementation necessary for aggregation.

Aggregation in the five Iowa sands was determined with a binocular microscope. The samples used for this purpose were representative of the whole, uncleaned sands. The water-stability of aggregates in the samples was estimated by placing a drop of water on the aggregate and noting any resulting disintegration.

The relative amount of aggregation, the aggregate sizes, and the principal cementing agent responsible for aggregation in each sample are given in Table II. Aggregation of the smaller sand particles was found in all samples except sample 89-S. The aggregates in samples 75-S and 77-S were most water-stable, probably because of the flocculated state of the clay coatings. The clay coatings in samples 79-S and 92-S appeared to be dispersed.

MINERALOGICAL COMPOSITION

The mineralogy of the five fine sands was determined by both petrographic and differential thermal analyses. The primary minerals and calcite in each sand were identified by petrographic methods. The predominant kind of clay mineral in each sand was estimated by the differential thermal analysis method.

Petrographic Analysis

For the purposes of the petrographic studies, representative portions of sand were separated into the particle-size ranges shown in Figure 6. Following the size separations, each size range was further separated into light and heavy mineral fractions by a heavy liquid (bromoform) fractionation procedure patterned after the method outlined by Krumbein and Pettijohn (16, p. 340). Particles representative of each of the light and heavy fractions were mounted on glass slides for microscopic examination. Details of the petrograph-

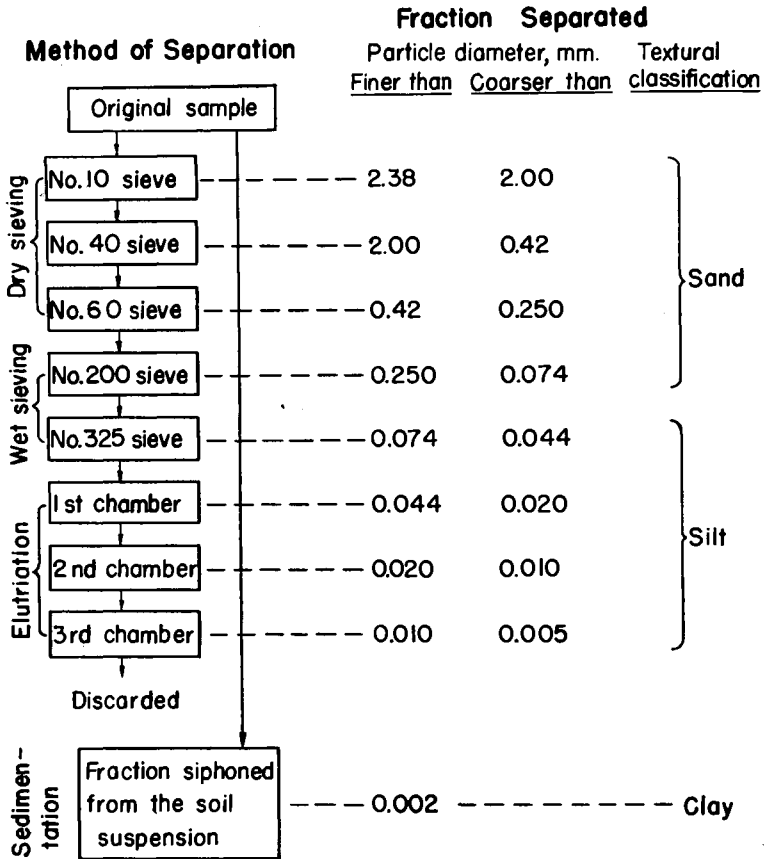


Figure 6. Separation of sand samples into different fractions for determination of their mineralogical composition.

ic analysis procedure are given by Krumbein and Pettijohn. Commercially prepared thin sections mounted in bakelite proved unsatisfactory because of the high refractive index of bakelite.

The results of the petrographic analyses are given in Table III. The data show that light minerals predominate in all sands, with quartz being most abundant. The percentage of heavy minerals present in each of the sands was relatively small and, as shown in Figure 7, they were not evenly distributed among the different size ranges. *Rock fragments* are the particles composed of more than one mineral. The average composition of the rock fragments would probably be similar to that of granite. Calcite or calcium carbonate is a secondary mineral, but since it can be identified microscopically, it is included in the petrographic analysis.

The large percentage of light minerals, especially quartz, in all the

Table 3
Light and Heavy Mineral Composition of the Five Iowa Fine Sands.

Kind of Mineral	Sample				
	75-S Monona Co.	77-S Crawford Co.	79-S Mahaska Co.	89-S Muscatine Co.	92-S Page Co.
LIGHT MINERALS, %	93.8	98.2	98.8	96.5	98.6
Quartz, %	62.0	75.0	76.4	68.7	72.6
Potash Feldspar, %	8.6	9.6	10.6	7.9	4.6
Plagioclase Feldspar, %	5.3	1.6	1.6	2.1	2.6
Rock Fragments, %	13.4	5.7	9.2	13.8	15.6
Calcite, %	3.0	5.0	0.5	3.0	0.5
Other, %	1.5	1.3	0.5	1.0	2.7
HEAVY MINERALS, %	6.2	1.8	1.2	3.5	1.4
Opaque Minerals, %	4.0	0.1	0.7	2.4	0.7
Amphibole, %	1.0	1.0	0.3	0.8	0.2
Pyroxene, %	1.0	0.5	0.1	0.2	0.2
Zircon, %	0.1	0.1	Trace	Trace	0.1
Tourmaline, %	Trace	0.1	Trace	Absent	Absent
Garnet, %	Trace	Absent	Absent	Absent	0.1
Mica, %	Trace	Absent	Absent	Absent	Trace

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FINE SANDS

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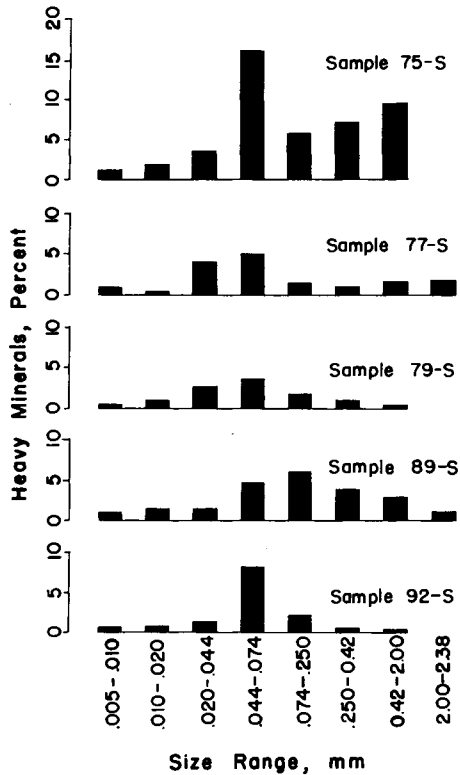


Figure 7. Variation of amount of heavy minerals in different size ranges of the five Iowa fine sands.

fine sand samples, is in agreement with the Bowen (17) reaction (stability) series, which shows the light minerals to be relatively more stable in nature than the heavy minerals and quartz to be the most stable of all primary minerals. Goldrich (18) has more recently substantiated Bowen's series, listing the primary minerals in the order of increasing stability as:

Ferro-Magnesian (heavy minerals) \cong plagioclase feldspar $<$ potash feldspar $<$ quartz

Calcite being a secondary mineral is not included in the series. In a humid environment calcite is considered unstable due to its solubility. The stability of the primary minerals may decrease in the presence of certain chemical additives used in soil stabilization work but, in general, their order of stability should remain the same.

Differential Thermal Analysis

The minus 0.002 mm fractions of the five sands obtained by sedimentation (Figure 6) were used for the differential thermal

analyses because most of the clay minerals occur in this particle-size range. While small amounts of non-clay materials may occur in this size range, their presence in inorganic soils would not be expected to mask clay mineral thermal reactions. Differential thermal analysis experiments with the minus 0.074 mm fractions of the sands showed that quartz and carbonates did mask clay mineral reactions in most cases. This is shown by the data in Table IV.

The differential thermal analysis apparatus and procedure used were similar to that described by Lambe (19). Interpretations of thermal curves were based on the relatively pure clay mineral reference curves of Grim and Rowland (20) and of the American Petroleum Institute (21). Preece (22) and Johnson and Davidson (23) have discussed the engineering significance of the clay mineral

Table 4
Interpretations from Thermal Curves of Two Particle-Size Ranges of Each of the Five Iowa Fine Sands.

Sample		Predominant Kinds of Clay Minerals		
No. and Location	Size Range Analyzed, mm	of Clay Minerals	Carbonates	Quartz
75-S Monona Co.	-0.074	Illite	Present	Present
	-0.002	Illite and Montmorillonite	Absent	Absent
77-S Crawford Co.	-0.074	Illite (?)	Present	Present
	-0.002	Illite	Absent	Absent
79-S Mahaska Co.	-0.074	Masked	Present (?)	Present
	-0.002	Illite	Trace (?)	Absent
89-S Muscatine Co.	-0.074	Masked	Present	Present
	-0.002	Illite	Trace (?)	Absent
92-S Page Co.	-0.074	Masked	Absent	Present
	-0.002	Illite	Absent	Absent

content of soils. The predominant kind of clay mineral in each of the sands is given in Table IV. Illite was present in all sands, and sample 75-S contained montmorillonite in addition to illite.

CHEMICAL COMPOSITION

Only a limited amount of information is available on the influence of chemical composition and related characteristics on those

properties of soil of interest to the highway engineer. Clare (24) briefly discusses the engineering significance of soil water pH and of the presence in soils of constituents such as carbonates, organic matter, and sulfates. Davidson and Sheeler (25) present relationships between whole soil cation exchange capacity and engineering properties. The presence of free iron oxide in soils has not received much attention from engineers, but where present it should be an important factor in some kinds of soil stabilization work.

In the fine sand investigation, the following quantitative tests were employed to estimate the proportions of the above mentioned constituents in each of the sands, as well as to determine their acidity or alkalinity (pH value) and their cation exchange capacity:

1. Organic matter—Dichromate oxidation method (24).
2. Carbonates (CaCO_3)—Acid decomposition method (25).
3. Sulfate (SO_4)—Water soluble sulfate determination (24).
4. Free iron oxide—Jeffries method (15).
5. pH value—Electrometric determination, 15g soil in 30 ml water.
6. Cation exchange capacity (whole sand)—Ammonium acetate method (26).

Table V presents test results. The organic matter content of all sands was low, and no sulfate salts were found to be present. Carbonates were present in all sands, and those containing the greater amounts had a corresponding higher pH value; the pH values varied from slightly alkaline to alkaline. Free iron oxide occurred as particle coatings or as individual grains. In organic soils such as the five fine sands, cation exchange capacity is mainly dependent on the amount and kind of clay minerals present. Sample 75-S had the highest cation exchange capacity despite the fact (Table II) that it had next to the lowest clay content. This is probably due to the presence of montmorillonite in this sample.

BEHAVIOR CHARACTERISTICS

The quality of fine sands as construction material can in general be rated on the basis of their composition. However the rating of sands is sometimes difficult because the relationship between composition and performance is not fully established. Laboratory tests to determine behavior characteristics of sands are therefore necessary to more fully evaluate sands as engineering materials.

The behavior characteristics needed for rating the suitability of sands depends upon the use which will be made of them. For example, the behavior characteristics which are significant for sands to be stabilized with Portland cement may not be significant for sands to be stabilized with bituminous materials. Since the specific

Table 5
Some Chemical Constituents and Related Characteristics of the Five Iowa Fine Sands.

No.	Sample	Organic Matter, %	Carbonates, % CaCO ₃	Sulfate, % SO ₃	Free Iron Oxide, %	pH	Cat. Ex. Cap., m.e./100 g
	Location						
75-S	Monona Co.	0.16	3.8	Absent	0.26	8.2	2.3
77-S	Crawford Co.	0.07	3.0	Absent	0.15	8.6	2.0
79-S	Mahaska Co.	0.17	1.4	Absent	0.17	7.4	1.5
89-S	Muscatine Co.	0.09	3.5	Absent	0.24	8.0	1.0
92-S	Page Co.	0.12	1.5	Absent	0.13	7.1	2.1

use which will be made of the five fine sands has not been determined, experiments were performed to determine their general behavior characteristics only.

TEST METHODS

The behavior characteristics of the five sand samples which were determined by four different tests are shown in Table VI.

Standard Proctor Density Test

The standard A.S.T.M. test D698-42T (8) was used to determine the maximum dry density and the optimum moisture content. The porosity of the sands at maximum dry density was also computed.

Permeability Test

The test procedure was similar to that of the Barber method (27) with the following exceptions:

1. All samples were tested in a loose state for permeability. Their density was approximately the same as the unit weight determined by the standard A.S.T.M. test C29-42. The porosity of each sample was computed.
2. All samples were immersed in water for 24 hours before being tested for permeability.

Capillarity Test

The test procedure was similar to Herman's method (29) except that test samples were immersed for 24 hours before being tested for capillary rise.

Direct Shear Test

The procedure for this test was patterned after the Bureau of Public Roads method (29) with the following modifications:

1. The sands were tested for direct shearing strength at maximum standard Proctor density and at optimum moisture content.
2. The diameter of test specimens was $2\frac{1}{2}$ inches and the height $\frac{1}{2}$ inch.
3. The rate of shear displacement was 0.02 inches per minute.
4. Normal loads of 1, 2, and 3 tons per square foot were used in the determination of the maximum shearing stresses. The cohesion and the angle of internal friction were determined on the basis of these stresses.

TEST RESULTS

Behavior characteristics of the five Iowa fine sands are given in Table VI. All sands were non-plastic according to the Atterburg limits data obtained by the Iowa State Highway Commission, and all were classified by the B.P.R. system (30, p. 29) as Group A-3 soils.

Table 6
Some Behavior Characteristics of the Five Iowa Fine Sands.

Sample		Standard Proctor Density Test			Permeability Test (sample in loose state)		Capillary Rise, in.	Direct Shear Test	
No.	Location	Max. Dry Density,* g/cc	Opt. Moist. Content,* Percent	Porosity at Max. Density, Percent	Porosity, Percent	Coefficient of Permeability, ft./day		Cohesion, psi.	Angle of Internal Friction
75-S	Monona Co.	1.61	16.3	39.6	42.4	48.4	13	1.7	36° 4'
77-S	Crawford Co.	1.74	12.4	34.5	43.4	24.3	14	1.6	35° 38'
79-S	Mahaska Co.	1.89	10.0	28.6	39.4	7.3	13	1.6	37° 6'
89-S	Muscatine Co.	1.72	15.0	35.5	37.4	208.5	9	2.4	34° 15'
92-S	Page Co.	1.72	14.4	35.7	45.9	70.7	11	2.9	35° 29'

*Data furnished by the Iowa State Highway Commission.

Table VI shows that sample 79-S had the highest maximum dry density. This sample had a better gradation than the other samples as is shown in Figure 4, and this is believed to be the principal reason for its higher density.

The porosity of the five sands at maximum density and in the loose state are also given in the table. The difference between these two porosity values is a measure of the compactibility of each sand. The greater the difference the more effectively the sand can be compacted.

Data in Table VI show that, for samples 89-S and 75-S, the maximum density porosity was only about 2 and 3 percent lower respectively than the loose state porosity. For the other samples the maximum density porosity was near or over 9 percent lower than the loose state porosity. In other words, the compactibility of samples 75-S and 89-S was significantly lower than the others. This is probably due mainly to their relatively low clay contents (see Table II), since moist clay will help to lubricate the sand particles and facilitate their reorientation during compaction.

Sample 89-S had the highest coefficient of permeability, but its porosity in the loose state was the lowest. This can possibly be explained by its coarse texture and absence of aggregation (see Table II).

As compared with the differences in permeability values, the variation in capillary rise was relatively small in the five samples. Sample 89-S, which had the highest permeability, had the lowest capillary rise, as would be expected.

The cohesion and angle of internal friction determined by the direct shear tests showed only slight differences in the five samples. No apparent correlation of shearing strength with other properties of the sands was found.

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