

# Studies on Soil-Aggregate-Sodium Chloride-Stabilized Roads in Franklin County, Iowa

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Sodium chloride-stabilized roads in Franklin County, Iowa, were studied to gain a better insight into the time rate of material loss from the surface. The roads were located in the same general area and constructed of materials from the same sources so that the main variable was duration of service. The thickness of the soil-aggregate-sodium chloride surface courses and the amount of float material on the surface of the road were determined. The float material was tested in the laboratory to study any gradation changes that might have occurred following displacement from the intact surface course. The component materials of the soil-aggregate mix were tested in the laboratory to determine what changes in physical properties could be attributed to the addition of sodium chloride.

The results of these investigations show that the thickness of the surface course decreases and the amount of float material increases as the period of use increases. These tests also show that the silt-clay content of the float material is less than in the soil-aggregate surface course. The addition of sodium chloride to the soil-aggregate mix caused no noticeable changes in the Atterberg limits of the mix, whereas significant changes in the Atterberg limits of the soil component were noted after the addition of sodium chloride.

• THIS STUDY was conducted to examine the performance characteristics of low-cost roadway surfaces of soil-aggregate-sodium chloride mixtures. Many roads have been successfully stabilized with sodium chloride. However, little information is available on either the properties of the road materials or the effects of sodium chloride on the materials.

The performance of some of the sodium chloride-stabilized roads in Franklin County, Iowa, and the performance of some nearby non-chemically treated roads have been studied. The study of sodium chloride-stabilized roads was restricted to those in which the binder soil used in construction came from the same source. The effects of sodium chloride on some of the engineering properties of the soil and soil-aggregate mixtures used were studied in the laboratory.

## LITERATURE REVIEW

Sodium chloride has no cementing properties, and its use as a soil stabilizer is restricted to soils that are mechanically stable themselves. Such soils are soil-aggregate mixtures used as subbase courses, base courses, and low-cost roadway surface courses.

Strahan (18) made the first systematic study of soil-aggregate surface courses during the 1920's, although the art of soil-aggregate stabilization had been practiced by the Romans.

The theory of soil-aggregate stabilization has been stated, and the design and construction of soil-aggregate mixtures has been surveyed (7, 24). Standard specifications for the design of soil-aggregate mixtures have been published (1).

Sodium chloride has never been widely used as a dust control because it is only slightly hygroscopic (23) and also because considerable corrosion potential was attributed to it (8). Its use as a soil-stabilizing agent has been reported in widely varying geographical locations in the United States (13).

Possible factors in the mechanism of sodium chloride stabilization have been set forth by several authors (12, 16, 23). Some of these are increased density of soil-aggregate, low permeability due to clay expansion, moisture retention, lowered freezing point of the solution of sodium chloride in water, recrystallization of sodium chloride, increase in cohesion of clay due to sodium ions, increase in surface tension of water, and increase in solubility of carbonate minerals.

The relative effects of these mechanisms have never been fully evaluated. However, investigation of the effects in general of sodium chloride on the physical properties of soil-aggregate mixtures were made at Iowa State University (5). The addition of sodium chloride was found to increase the maximum Proctor density of the mix at a lower optimum moisture content. No other significant changes in the physical properties of the mixtures were found.

## LOCATION OF ROADS AND MATERIALS STUDIED

The roads studied are located in Franklin County, Iowa, in the north central part of the State (Fig. 1). According to the Iowa Geological Survey (9), the county is divided into two areas of glacial drift. The western five-eighths of the county is covered by Cary glacial drift, and the eastern three-eighths by Iowan glacial drift.

Location of Roads

Sodium chloride-stabilized roads were constructed in Franklin County in 1956, 1957, 1958, and 1959. One road was chosen for investigation for each year of construction (Fig. 2):

1. Road S-4 1956.—Starting at the northeast corner of section 10 in Oakland township going west to the northwest corner of the northeast quarter of section 7 (NE cor NE  $\frac{1}{4}$  90-22-10 to the NW cor NE  $\frac{1}{4}$  90-22-7). This section of road is 3.5 mi long.
2. Road S-3 1957.—Starting at the northeast corner of section 12 in Lee township going west to the northwest corner of section 11 in Oakland township (NE cor NE  $\frac{1}{4}$  90-21-12 to the NW cor NW  $\frac{1}{4}$  90-22-11). This section of road is 8 mi long.
3. Road S-2 1958.—Starting at the northeast corner of section 10 in Oakland township going south of the southeast corner of the northeast quarter of section 22 (NE cor NW  $\frac{1}{4}$  90-22-10 to the SE cor NE  $\frac{1}{4}$  90-22-22). This section of road is 2.5 mi long.
4. Road S-1 1959.—Starting at the southeast corner of section 3 in Oakland township going north to the northwest corner of section 35 in Morgan township and then east to the northeast corner of section 35 and then north to the northeast corner of section 25 in Morgan township (SE cor SE  $\frac{1}{4}$  90-22-3 to the NW cor NW  $\frac{1}{4}$  91-22-35 to the NE cor NE  $\frac{1}{4}$  91-22-35 to the NE cor NE  $\frac{1}{4}$  91-22-25). This section of road is 4 mi long.

Roads that had no sodium chloride or binder soil mixed with the aggregate of the surface course were also investigated. These nonstabilized roads surfaced with gravel only were also constructed in 1956, 1957, 1958, and 1959 (Fig. 3):

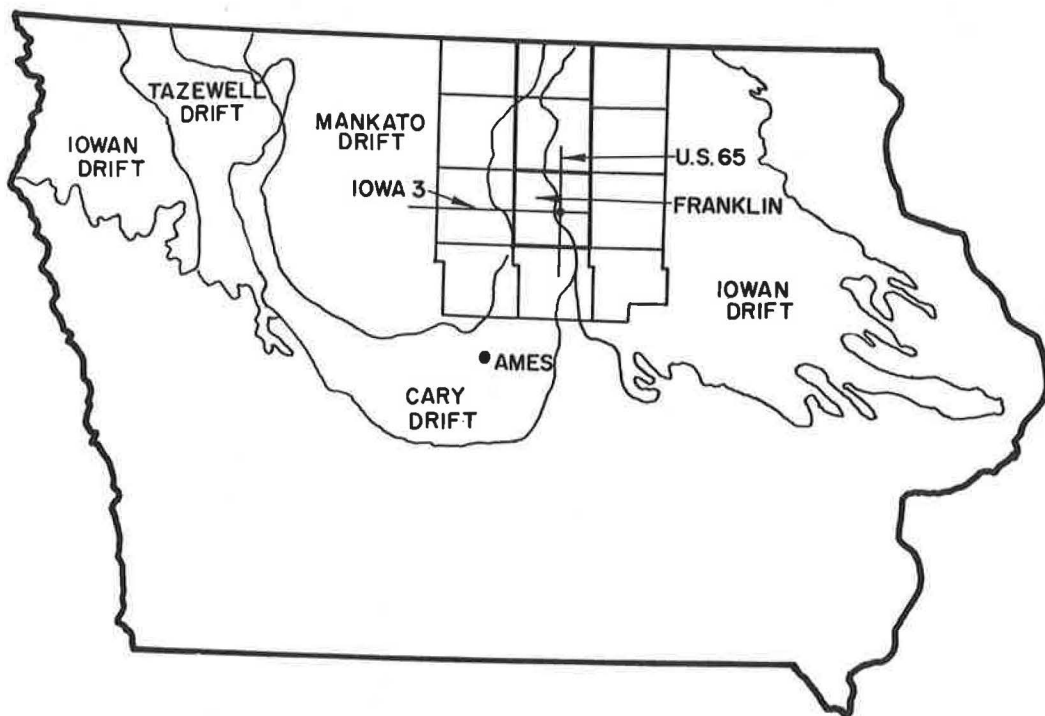


Figure 1. Map of Iowa showing Franklin County and Wisconsin glacial drift borders.

1. Road G-4 1956. —Starting at the northwest corner of section 8 in Oakland township going south to the southwest corner of section 17 and then east to the southeast corner of section 17 (NW cor NW  $\frac{1}{4}$  90-22-8 to the SW cor SW  $\frac{1}{4}$  90-22-17 to the SE cor SE  $\frac{1}{4}$  90-22-17). This section of road is 3 mi long.

2. Road G-3 1957. —Starting at the northeast corner of section 12 in Oakland township going south to the southeast corner of section 25 (NE cor NE  $\frac{1}{4}$  90-22-12 to the SE cor SE  $\frac{1}{4}$  90-22-25). This section of road is 4 mi long.

3. Road G-2 1958. —Starting at the northeast corner of section 4 in Oakland township going south to the southeast corner of section 4. Also starting at the northwest corner of section 4 and going to the southwest corner of section 4. (NE cor NE  $\frac{1}{4}$  90-22-4 to the SE cor SE  $\frac{1}{4}$  90-22-4 also NW cor NW  $\frac{1}{4}$  90-22-4 to the SW cor SW  $\frac{1}{4}$  90-22-4). The total length of these two sections of road is 2 mi.

4. Road G-1 1959. —Starting at the northeast corner of section 2 in Oakland

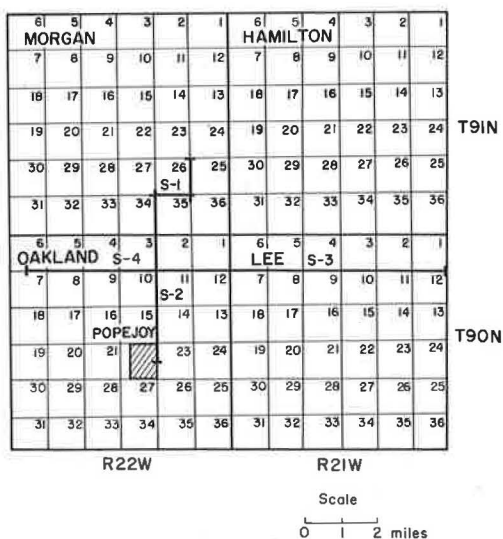


Figure 2. Map of four townships in southwestern Franklin County locating soil-aggregate-sodium chloride-stabilized roads studied.

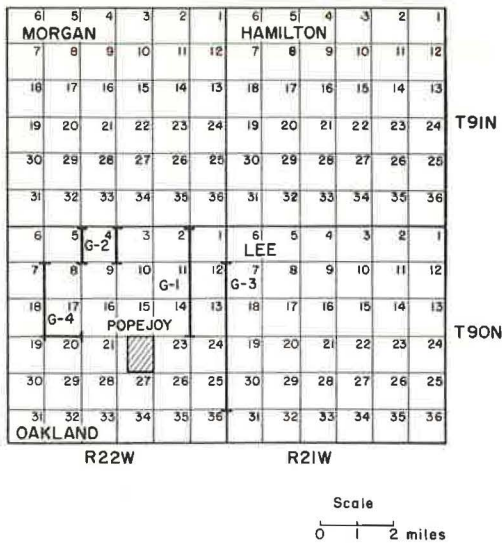


Figure 3. Map of four townships in southwestern Franklin County showing non-chemically treated roads studied.

also used on the western 3 mi of stabilized road S-3 (from the NW cor NW  $\frac{1}{4}$  90-21-7) to the NW cor NW  $\frac{1}{4}$  90-21-12). Aggregate A-1 was used for the eastern 5 mi of stabilized road S-3 (from the NE cor NE  $\frac{1}{4}$  90-21-12 to the NW cor NW  $\frac{1}{4}$  90-21-8).

Geological and Climatological Considerations

The area in which the roads are located is covered by Cary glacial drift. The principal soil association is the Clarion-Webster association (19). The aggregate sources also lie within the area covered with Cary drift, and the source of the binder soil is in a part of the county covered with Iowan drift.

The mean annual rainfall in Franklin County is 31 in. , and the mean annual

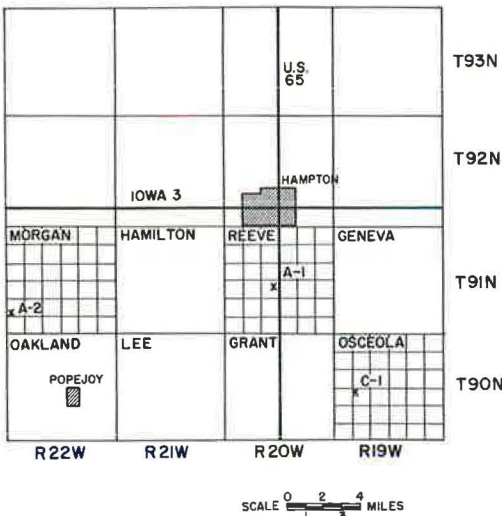


Figure 4. Map of Franklin County showing sources of materials used in construction of roads studied.

township going south to the southwest corner of section 14 (NE cor NE  $\frac{1}{4}$  90-22-2 to the SE cor SE  $\frac{1}{4}$  90-22-14). The length of this section of road is 3 mi.

Sources of Materials

The materials used to surface these roads were locally available gravels and glacial clay. The sodium chloride mixed with the soil materials was a crushed rock salt imported from St. Louis, Mo. The gravel came from two sources located within Franklin County. All the binder soil used came from one source (Fig. 4).

The first aggregate source (A-1) is located in Reeve Township in the northwest quarter of section 21 (NW  $\frac{1}{4}$  91-20-21). The second source of aggregate (A-2) is located in Morgan Township in the southwest quarter of section 30 (SW  $\frac{1}{4}$  91-22-30). The binder soil (C-1) is located in Osceola township in the northwest corner of section 20 (NW cor NW  $\frac{1}{4}$  90-19-20).

Aggregate A-2 was used on all the non-stabilized roads investigated and on stabilized roads S-1, S-2, and S-4. It was

TABLE 1

RAINFALL AND EXTREME TEMPERATURES RECORDED AT HAMPTON, IOWA, IN THE PERIOD 1956-1959<sup>a</sup>

| Year | Temperature (°F) |                 |                   | Rainfall (in.) |
|------|------------------|-----------------|-------------------|----------------|
|      | Highest Recorded | Lowest Recorded | Max. Annual Diff. |                |
| 1956 | 96               | -23             | 119               | 24.6           |
| 1957 | 95               | -18             | 113               | 31.8           |
| 1958 | 92               | -20             | 112               | 22.2           |
| 1959 | 93               | -21             | 114               | 30.7           |

<sup>a</sup>From records of U.S. Weather Bureau (20, 21, 22).

temperature is 45 F. Rainfall and temperature data recorded in the period 1956-1959 at Hampton, Iowa, the county seat of Franklin County, are given in Table 1.

## DESIGN, CONSTRUCTION AND MAINTENANCE OF ROADS

### Design of Stabilized Roads

The soil-aggregate-sodium chloride-stabilized surfaces were designed to meet the gradation and plasticity requirements of the Iowa State Highway Commission standard specifications (11). The thickness of the stabilized surface was designed to be 4 in. and the width 24 ft. The road had a maximum crown of 6 in. in 12 ft and a minimum crown of 4 in. in 12 ft. Aggregate A-1 was mixed with 20 percent soil C-1 by dry weight of the aggregate. Aggregate A-2 was mixed with 12.5 percent soil C-1 by dry weight of the aggregate. These proportions of soil and aggregate produced mixtures that meet the gradation and plasticity specifications. The specifications require a plasticity index for the soil aggregate mixture of between 5 and 12 percent.

A surface course 4 in. thick, 24 ft wide, and 1 mi long contained 1,564 cu yd of soil-aggregate. At the specified rate of 12 lb per cu yd of compacted mixture, 9.39 tons of sodium chloride would be required per mile. The application rate was 10 tons of sodium chloride, which was slightly in excess of the specified minimum for a surface course. Compacted to a density of 130 pcf, the total weight of the material in such a surface course would be 2,746 tons. Based on the dry weight of the soil-aggregate 0.36 percent of sodium was added. An addition of 0.5 percent has been found to be the optimum addition for reducing the optimum moisture content and increasing the maximum density (5).

### Construction of Stabilized Roads

A road mix type of construction was used. The aggregate and binder soils were first spread on the road, then dry sodium chloride was distributed with a mechanical spreader. The soil, aggregate, and sodium chloride were mixed in place. Sufficient water was added to bring the mixture to the optimum moisture content, and the materials were given a final mixing with a single rotor-type rotary mixer.

The materials were then spread, shaped, and compacted. The crown was shaped just before the final compaction of a section. The specifications required that the mix be compacted to 95 percent of the standard Proctor density for the mix.

### Maintenance of Stabilized Roads

In the regularly scheduled maintenance program of Franklin County, further chemical surface treatment and blading is required. Three tons of calcium chloride pellets (75 to 80 percent pure) per mile were added. This serves as a dust control. The calcium chloride is spread with a mechanical spreader.

Blading is carried out only when indicated by the surface condition of the road and then only after a rainfall. Blading after a rainfall prevents the surface of the road from being unduly disturbed and also insures that the loose material which is bladed to the heavily traveled area of the road will have sufficient moisture for recompaction (13).

The chemical surface treatment maintenance program was actually carried out on roads S-3 and S-4 in 1958 and on roads S-1, S-2, and S-4 in 1959. In other years, the chemical surface treatment was omitted because of insufficient county maintenance funds.

### Construction and Maintenance of Nonstabilized Roads

Construction and maintenance procedures of non-chemically treated surface courses were not as closely controlled as those on stabilized surface courses. The surfacing materials were hauled from the source, placed on the grade, and spread with a blade grader. Compaction was left to the action of traffic, with no moisture, density, or thickness controls exercised.

No chemical was applied for dust control, and the roads were bladed whenever necessary, without regard to moisture.

## INVESTIGATIONS

### Field

Two types of data were obtained directly from measurements in the field: the thickness of the soil-aggregate surface, and the amount of loose or float material on the surface.

A trench sample was dug one-half the width of the surface course (3). The depth of the surface course was measured at 1-ft intervals from the shoulder to the centerline of the road. The thickness of the surface course was measured at 1-mi intervals, and the side of the road on which the trench was cut was alternated at each sample location. The average thickness of the surface course at a trench sample location is given by

$$t_a = \frac{\frac{1}{2} t_1 + t_2 + t_3 + \dots + \frac{1}{2} t_n}{n-1} \quad (1)$$

in which  $t$  is the thickness of the surface, the subscripts refer to the position of the thickness measurement (transverse to the centerline of the road), and  $n$  is the number of points at which the surface course thickness was measured.

The amount of float material on the surface of the road was measured by collecting the loose material within the area of a wooden template with a soft broom. The template facilitated the gathering of data by providing a constant sampling area. A broom with soft bristles was used to minimize any loosening of firmly held material. The rectangular 3- by 6-ft template was constructed of 1- by 2-in. lumber with corner braces to prevent distortion. The float material was swept into containers and weighed in the field. A representative sample was taken for laboratory testing, and the rest of the material returned to the surface of the road.

Other field work included the gathering of samples of aggregate and binder soil for laboratory determinations of Atterberg limits, mechanical analyses, and other tests.

### Laboratory

The float material, the aggregates, the binder soil, and the soil-aggregate mix were investigated in the laboratory. The laboratory tests on the float material from the soil-aggregate-sodium chloride surface courses included a mechanical analysis of the material from each sample location.

Various soil classification and identification tests were conducted on the binder soil. These tests were performed in accordance with the standard ASTM procedures and included mechanical analysis, Atterberg limit tests, pH determination, organic matter determination, and X-ray diffraction analysis to determine the predominant minerals (1, 2).

The tests run on the gravels included mechanical analyses, abrasion tests, and soundness tests. These tests were performed in accordance with ASTM procedures. The abrasive resistance of the aggregates was determined by the use of the Los Angeles machine and the soundness of the aggregates was determined by the use of a saturated solution of sodium sulfate. Tests on the soil-aggregate mixtures were performed on the mixtures combined in the proportions for which they had been designed. Tests on these mixtures included mechanical analyses, Atterberg limit tests, and moisture-density relationships with and without the addition of 0.5 percent sodium chloride.

To determine the effect of sodium chloride on the engineering properties of the binder soil C-1, varying percentages of sodium chloride and water were added and the mixture was tested. Atterberg limit tests and X-ray diffraction analyses were performed on these mixtures. The X-ray diffraction analyses were run on dry soil-sodium chloride mixtures, on mixtures containing water, and on mixtures containing ethylene glycol.

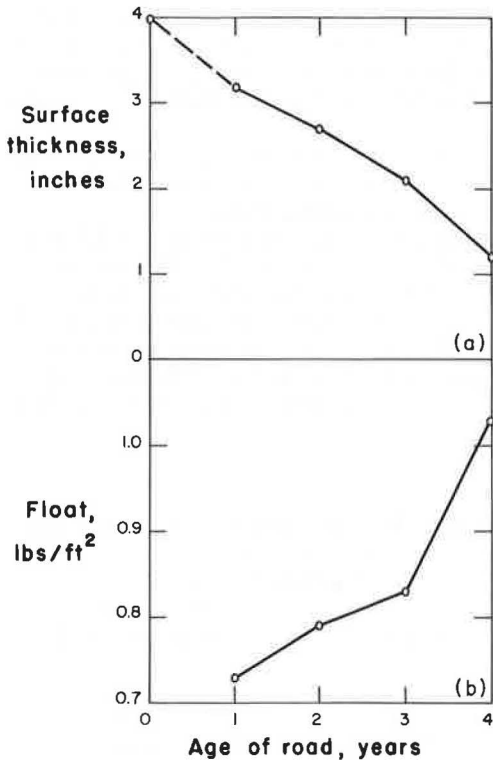


Figure 5. Field data: (a) thickness of surface course vs age of road; (b) amount of float material vs age of road.

## RESULTS

### Field Investigations

The data collected in the field are plotted in Figure 5. Figure 5a shows the thickness of the surface course vs the age of the road; Figure 5b shows the amount of float material vs the age of the road. These curves show that the thickness of the stabilized surface course decreases with time, and the amount of float material per square foot of roadway surface increases with time.

The data show that the float material on non-chemically treated roads increased for three years and then decreased. Figure 6 shows the amount of float material vs the age of the road. The upper curve is for the non-chemically treated surfaces and the lower curve is for the soil-aggregate-sodium chloride stabilized surfaces. These curves indicate that the soil-aggregate-sodium chloride surfaces have less float material than the non-chemically treated surfaces.

The curves in Figures 5 and 6 do not include data from that portion of road S-3 in which aggregate A-1 was used. Thus these curves include only the data from roads on which the same aggregate was used.

Table 2 compares surface thickness and float material on road S-3 for the different soil-aggregate.

### Laboratory Investigations

The various size fractions of the float material are plotted vs road age in Figure 7, which does not include the data from the portion of road S-3 where aggregate A-1 was used.

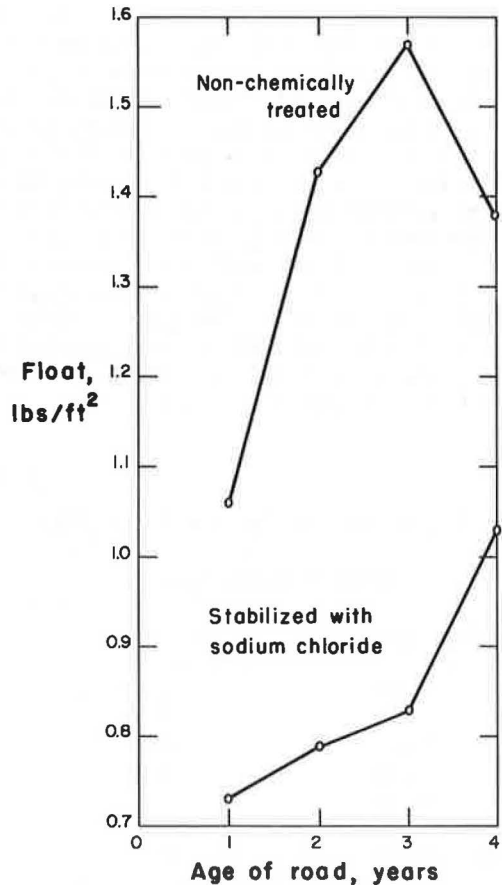


Figure 6. Amount of float material vs age of road.

These curves show that after the road has been used for one year the fine fraction (the silt and clay) in the float material is about 60 percent of what it was in the original mix. After the first year, the fine fraction of the float material remains nearly constant. This should be expected, because the fine fraction in the float material is readily transported by the wind and is quickly blown away.

The sand and gravel contents of the float material seem not to have a direct relationship to the age of the road. However, the percentage of gravel tends to increase and the percentage of sand to decrease with the increasing age of the road.

The results of the laboratory tests performed on the soil C-1 are shown in Table 4. X-ray diffraction analysis of the fraction of the soil C-1 passing the No. 200 sieve showed that the predominant minerals in this material are montmorillonite, illite, quartz, and feldspars. The portion of the road constructed with aggregate A-1 and 20 percent binder soil showed both a greater surface thickness and a greater amount of float material than did the section constructed using aggregate A-2 and 12.5 percent soil C-1. The properties of aggregates A-1 and A-2 are summarized in Table 3. The

TABLE 2

## COMPARISON OF FLOAT MATERIAL AND SURFACE THICKNESS ON ROAD S-3

| Float Material (psf) |               | Thickness (in.) |               |
|----------------------|---------------|-----------------|---------------|
| Aggregate A-1        | Aggregate A-2 | Aggregate A-1   | Aggregate A-2 |
| 1.16                 | 0.34          | 2.3             | 1.8           |
| 1.04                 | 0.62          | 2.1             | 1.6           |
| 0.78                 | 0.64          | 2.2             | 1.9           |
| 0.88                 | 0.48          | 1.8             | 1.4           |
| 0.65                 | --            | 2.1             | --            |
| 0.47                 | --            | 2.4             | --            |
| Avg. 0.83            | 0.52          | 2.1             | 1.8           |

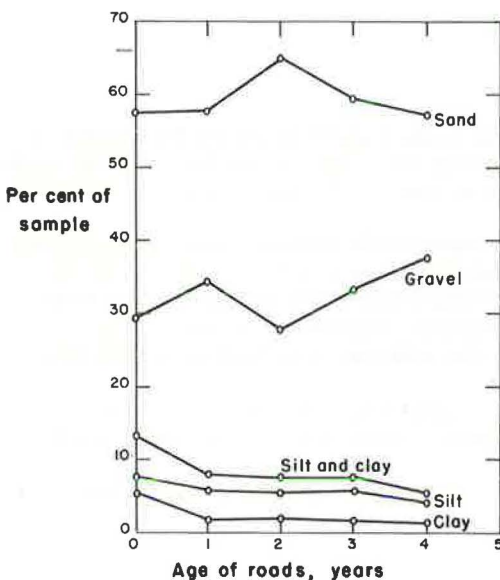


Figure 7. Various size fractions of float material vs age of road.

TABLE 3

## ENGINEERING PROPERTIES OF AGGREGATES A-1 AND A-2

| Property                                   | Value      |            |
|--|------------|------------|
|  | A-2        | A-1        |
| Gravel (%)                                 | 33         | 37         |
| Sand (%)                                   | 59         | 53         |
| Silt (%)                                   | 5          | 5          |
| Clay (%)                                   | 3          | 5          |
| Soil class.                                | A-1-b(0)   | A-1-b(0)   |
| Los Angeles abrasion loss <sup>a</sup> (%) | 48.2       | 35.7       |
| Soundness test <sup>b</sup> (%)            | 9.58       | 7.97       |
| Plasticity index <sup>c</sup>              | Nonplastic | Nonplastic |

<sup>a</sup>ASTM designation C 131-55T.

<sup>b</sup>ASTM designation C 88-59T. (loss after 5 cycles).

<sup>c</sup>Test run on that fraction passing No. 40 sieve.



engineering classification of both of these aggregates is A-1-b(0). This type of material is well graded, and except for the plasticity requirements it would meet the specifications of the Iowa State Highway Commission for soil-aggregate surface courses. Both aggregates are nonplastic. Aggregate A-1 showed a greater resistance to abrasion and more resistance to the sodium sulfate test than did aggregate A-2. Aggregate A-1 showed an abrasion loss of 35.7 percent compared with a loss of 48.2 percent for aggregate A-2. The loss after 5 cycles of immersion in a saturated solution of sodium sulfate and oven-drying was 7.97 percent for aggregate A-1 and 9.58 percent for aggregate A-2. These tests indicate that aggregate A-1 is less susceptible to being broken up by the action of traffic and is probably less susceptible to the action of freezing and thawing than is aggregate A-2.

The physical and chemical properties of soil C-1 are given in Table 4. The results of the tests performed in the soil-aggregate mix are given in Tables 5 and 6. The mechanical analysis of the soil-aggregate mix with aggregate A-1 shows that it contains 11 percent 5- $\mu$  clay (material finer than 0.005 mm) and the soil-aggregate mix with aggregate A-2 contains 6 percent clay. Both soil-aggregate mixtures contain 30 percent gravel. The plasticity index of the A-1 mix is 5 percent and of the A-2 mix 7 percent. The Atterberg limits of these soil-aggregate mixtures are unchanged by the addition of 0.5 percent sodium chloride. The addition of 0.5 percent sodium chloride caused an increase in the density of 2.5 percent for the A-1 mix and 2.8 percent for the A-2 mix.

The results of the Atterberg limit test on soil C-1 and soil-sodium chloride mixtures are given in Table 7. Figure 8 shows these results vs the percent of sodium chloride added. The addition of 0.5 percent sodium chloride by dry weight of the soil caused a slight increase in the liquid limit of the soil. The liquid limit of the soil with

the addition of 1 percent sodium chloride is nearly the same as it is with the addition of 0.5 percent sodium chloride. Additions of sodium chloride above 1 percent cause the liquid limit of the soil to decrease. The addition of sodium chloride caused the plastic limit of the soil to increase at a nearly constant rate.

TABLE 4  
PHYSICAL AND CHEMICAL  
PROPERTIES OF SOIL C-1

| Property                              | Value                   |
|---------------------------------------|-------------------------|
| Gravel (greater than 2.0 mm) (%)      | 3                       |
| Sand (2.0 mm to 0.074 mm) (%)         | 55                      |
| Silt (0.074 mm to 0.005 mm) (%)       | 21                      |
| Clay (less than 0.005 mm) (%)         | 21                      |
| Liquid limit (%)                      | 28                      |
| Plastic limit (%)                     | 14                      |
| Plasticity index (%)                  | 14                      |
| Carbonate content (%)                 | 2.35                    |
| Organic matter (%)                    | 0.11                    |
| Cation exchange capacity <sup>a</sup> | 11.5                    |
| pH                                    | 8.1                     |
| Predom. clay minerals <sup>b</sup>    | Montmorillonite, illite |
| Other predom. minerals <sup>b</sup>   | Quartz, feldspars       |
| Eng. soil class.                      | A-6(3)                  |
| Textural soil class.                  | Sandy clay loam         |

<sup>a</sup>Milliequivalents per 100 g.

<sup>b</sup>From X-ray diffraction analysis.

TABLE 5  
SOME ENGINEERING  
PROPERTIES OF AGGREGATE  
A-2 PLUS 12.5 PERCENT SOIL C-1<sup>a</sup>

| Property                       | Addition of Sodium Chloride |       |
|--------------------------------|-----------------------------|-------|
|                                | 0.0                         | 0.5   |
| Optimum moisture content (%)   | 9.5                         | 8.7   |
| Standard Proctor density (pcf) | 128.7                       | 132.3 |
| Liquid limit (%)               | 22                          | 22    |
| Plastic limit (%)              | 15                          | 15    |
| Plasticity index (%)           | 7                           | 7     |

<sup>a</sup>Size fractions in mixture: gravel, 30 percent; sand, 57 percent; silt, 7 percent; and clay, 6 percent.

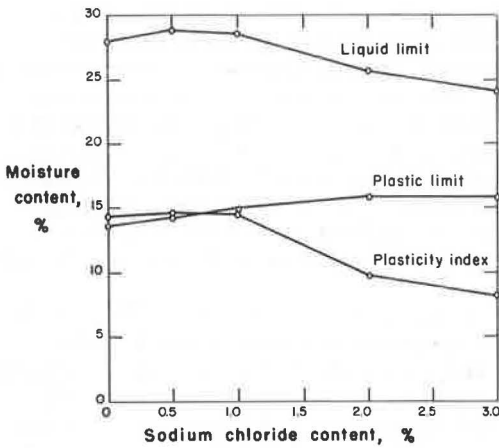


Figure 8. Atterberg limits vs percent of sodium chloride added.

The net effect on the plasticity index of the soil is that the plasticity index remains nearly constant for additions of sodium chloride up to 1 percent, due to the increase in both the liquid limit and the plastic limit. When amounts of sodium chloride above 1 percent are added, however, the plasticity index of the soil is decreased from 14 at 1 percent to 8 with the addition of 3 percent sodium chloride. This decrease in plastic limit is caused both by the decreasing liquid limit and the increasing plastic limit.

X-ray diffraction analyses of soil-sodium chloride mixtures passing the No. 200 sieve did not show any effect on the minerals due to the addition of sodium chloride, nor did these analyses show any crystalline sodium chloride in the mixtures.

#### ANALYSIS OF RESULTS

##### Field Investigations

The increase in the amount of float material on the surface of the soil-aggregate-sodium chloride-stabilized surface courses would probably continue until the surface course was worn away and only loose aggregate particles remained on the roadbed. If the surface course were completely worn away, there would be no further source for float material. Thereafter, as the float material is removed from the surface of the road by wind, water, or action of traffic, the amount of float material on the road surface would decrease. It was not possible to verify this hypothesis in the field because no soil-aggregate-sodium chloride-stabilized surface course was constructed in Franklin County before 1956.

The amount of float material on non-chemically treated roads increased for three years, and then it decreased. The decrease indicates that all the aggregate on the road surface is present as float material. As this float material is removed from the surface of the road, it is not replaced from a surface course. It was not possible to evaluate the amount of float material on non-chemically treated roads in Franklin County further, because on no roads suitable for investigation had aggregate been added more than four years

TABLE 6  
SOME ENGINEERING PROPERTIES OF  
AGGREGATE A-1 PLUS 20 PERCENT  
SOIL C-1<sup>a</sup>

| Property                       | Addition of Sodium Chloride |       |
|--------------------------------|-----------------------------|-------|
|                                | 0.0%                        | 0.5%  |
| Optimum moisture content (%)   | 11.2                        | 9.6   |
| Standard Proctor density (pcf) | 131.1                       | 134.3 |
| Liquid limit (%)               | 21                          | 21    |
| Plastic limit (%)              | 16                          | 16    |
| Plasticity index (%)           | 5                           | 5     |

<sup>a</sup> Size fractions in mixture: gravel, 30 percent; sand, 53 percent; silt, 6 percent; and clay, 11 percent.

TABLE 7  
RESULTS OF ATTERBERG LIMIT  
TESTS FOR THE FRACTION OF  
SOIL C-1 PASSING NO. 40  
SIEVE WITH VARYING  
AMOUNTS OF SODIUM  
CHLORIDE

| Percent NaCl Added | Atterberg Limit (%) |               |                  |
|--------------------|---------------------|---------------|------------------|
|                    | Liquid Limit        | Plastic Limit | Plasticity Index |
| 0.0                | 28                  | 14            | 14               |
| 0.5                | 29                  | 14            | 15               |
| 1.0                | 29                  | 15            | 14               |
| 2.0                | 26                  | 16            | 10               |
| 3.0                | 24                  | 16            | 8                |

earlier. The only aggregate on road G-4 was the float material. The thickness of the surface course on this road was virtually zero, and the surface of the road was markedly darker in color than other roads because of the exposure of the dark subgrade soil.

The reason for the increase in the amount of float material on these roads is believed to be as follows. The aggregate particles on the surface of the road are loosened from the soil matrix by the action of traffic. Eventually, these particles become completely free of the soil matrix and lie on the surface of the road. This leaves on the surface of the road a void space that was previously occupied by an aggregate particle. The fine soil surrounding this hole is then laterally unsupported, and the sides are caved in by the action of traffic. The loose fine material is picked up by the action of traffic, thrown into the air, and blown away from the road. This action leaves other aggregate particles exposed on the surface of the road and subject to the same cycle of events. Thus the thickness of the stable portion of the surface course is decreased.

The coarse aggregate particles loosened from the surface accumulate on the surface of the road; this accounts for the increase in the amount of float material. Some of these particles, however, are either thrown to the shoulders of the road or are ground into smaller particles. These smaller particles could then be blown away in the same manner as the fine soil. This would account for the reduction in the amount of float material after the source is depleted.

The fine particles in the float material are reduced in the first year, and thereafter the fine fraction of the float material is nearly constant (Fig. 7). The fine fraction of the float material is quickly removed from the surface of the road by wind action. In the non-chemically treated roads the process is probably accelerated, because there is no binder soil added to the aggregate. The surface is readily disturbed by the action of traffic, and any fine binder material is removed rather quickly, leaving the aggregate particles free to be easily thrown off the road or ground into smaller particles.

After four years of use, the stabilized road S-4 had a surface course 1 to 2 in. thick, and the non-chemically treated road G-4 had only float material remaining. These findings are in close agreement with results reported on data from Butler County, Iowa (16). Non-chemically treated roads were worn out in approximately four years, and the soil-aggregate-sodium chloride surface courses were 1 to 2 in. thick at the end of four or five years.

The portion of road S-3 constructed with aggregate A-1 had a greater surface thickness and a greater amount of float material than that constructed with aggregate A-2 after three years of use. Aggregate A-1 was mixed with a greater proportion of binder soil in construction of the surface course. The use of a greater percentage of binder soil C-1 probably increased the resistance to loosening of the aggregate particles from the soil-aggregate A-1 mix. The soil-aggregate A-1 mix contained 11 percent clay compared with 6 percent clay in the soil-aggregate A-2 mix. If this greater percentage of clay made it more difficult for the aggregate particles to be removed from the road surface, then the rate of wearing would be reduced, and this road (S-3 using aggregate A-1) would have a greater remaining thickness of surface course.

Also, after the aggregate particles had been loosened from the soil matrix, the greater resistance to abrasion exhibited by aggregate A-1 would prevent it from being ground into smaller particles as readily as aggregate A-2.

### Laboratory Investigations

A reduction of the plasticity index of the binder soil C-1 could be brought about by the addition of a sufficient amount of sodium chloride (Fig. 8). The data indicate that 1.5 to 2.0 percent sodium chloride is needed to cause an appreciable effect. The reduction of plasticity index is due both to a reduction of the liquid limit and an increase in the plastic limit. Most of the reduction in plasticity index is due to lowering the liquid limit. It is desirable in soil stabilization to reduce the plasticity index by raising the plastic limit.

The amount of sodium chloride necessary to affect noticeably the plastic properties of the soil is greater than that usually added to soil-aggregate mixtures. The addition of 0.5 percent sodium chloride had no effect on the liquid and plastic limits of the soil-

aggregate mixtures (Tables 5, 6). The percentage of sodium chloride added to the soil-aggregate mix is computed on the basis of the dry weight of the mix (5). The Atterberg limits are then run on the fraction passing the No. 40 sieve. This test procedure, which introduces sand into the soil fraction on which the test is being run, may account for the fact that the plastic properties do not change when sodium chloride is added. If the Atterberg limits were determined only for the silt and clay fraction of the soil-aggregate mix, the addition of 0.5 percent sodium chloride to the soil aggregate would most likely affect the plastic properties of this portion. A change in the basis of computation shows that 0.5 percent of the total soil-aggregate is 2.9 percent of the silt-clay fraction of the A-1 plus C-1 soil-aggregate mix and 3.8 percent of the silt-clay fraction of the A-2 plus C-1 soil-aggregate mix (Fig. 8).

The changes in the plastic properties noted in the soil-sodium chloride mixtures are probably due in part to the ion exchange which takes place when sodium chloride is added to the soil (6), but these effects have not been evaluated as a part of this investigation. Part of the reduction of the liquid limit is possibly due to the partial dispersion of the clay fraction of the soil by sodium chloride (23). The particles in such a dispersed system are able to slide over one another at a lower moisture content than is necessary in a system that is not dispersed.

The mechanism causing the rise in the plastic limit of the soil which accompanies an increase in sodium chloride content may be hypothesized through physico-chemical considerations. The plastic limit of a soil is defined as the minimum moisture content at which the soil-water system behaves as a plastic solid. In order for the material to behave in this manner, the soil particles must be bound together by interparticle forces which when totaled can be expressed as some given amount of energy per unit weight of dry soil. This energy is supplied for the most part by the surface tension of the liquid in the capillary spaces of the soil. Any change in the surface tension of the liquid causes a change in the interparticle forces, as does any change in the size of the capillary spaces. Because an increase in the sodium chloride concentration causes an increase in the plastic limit, the size of the capillary spaces must necessarily increase. An increase in the volume of water per unit weight of soil means that the space occupied by water must become larger. If an increase in volume of water per unit weight of soil is accompanied by an increase in the surface tension of the liquid, it is possible to maintain a constant total interparticle energy per unit weight. This can be done by maintaining the proper ratio of the amount and concentration of sodium chloride solution to capillary size. A soil containing a sodium chloride solution as the liquid should therefore exhibit a higher value for the plastic limit because more solution is needed to maintain a constant ratio of total surface tension per unit weight to total volume of liquid per unit weight.

X-ray diffraction analyses of the float material and of samples from the soil-aggregate-sodium chloride surface course did not show any recrystallized sodium chloride. This is probably because any crystalline sodium chloride present in these samples was in small amount and as crystals was too small to be detected by the procedures used. The same results were obtained with soil-sodium chloride mixtures prepared in the laboratory. No changes in the spacing of the clay mineral lattice were noted after the addition of sodium chloride to the binder soil in the laboratory.

The most significant contribution made by sodium chloride to the stability of soil-aggregate mixtures is probably the stabilization of the moisture content of the mixture. A soil-aggregate mix without a chemical additive is relatively impermeable; however, the addition of sodium chloride should decrease the permeability of the mix by causing greater clay expansion when wet. Sodium chloride should also prevent the moisture content of the soil-aggregate mix from falling too low during periods of dry weather. The mechanisms of this effect are the lower vapor pressure of the sodium chloride solution causing a lower rate of evaporation, the crystallization of sodium chloride in void spaces preventing evaporation of moisture from some of the void spaces, and the hygroscopicity of sodium chloride.

If the moisture content of a soil-aggregate surface course can be kept within limits so that the moisture content in the mix never becomes low enough to allow raveling or dusting on the surface, or great enough to permit the normally applied loads to rut the

surface, a conservation of material and more desirable riding qualities of the road will result.

### CONCLUSION

The durability of soil-aggregate-sodium chloride surfaces is affected by the quality of aggregate and the amount of clay-size material used in the construction of the surface course. The addition of sodium chloride causes a reduction in the liquid limit and an increase in the plastic limit of the glacial soil studied in this investigation and contributes to the stability of soil-aggregate mixtures.

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## Appendix

TABLE 8  
ABRASION OF COARSE AGGREGATE  
BY USE OF LOS ANGELES  
MACHINE<sup>a</sup>

| Aggre-<br>gate | Sample Weight (g) |       |       | Wear<br>(%) |
|----------------|-------------------|-------|-------|-------------|
|                | Original          | Final | Loss  |             |
| A-1            | 2,500             | 1,607 | 893   | 35.72       |
| A-2            | 2,500             | 1,296 | 1,204 | 48.16       |

<sup>a</sup>ASTM designation C 131-55T.

TABLE 9  
SOUNDNESS TEST OF AGGREGATE A-1 USING SATURATED SOLUTION OF  
SODIUM SULFATE<sup>a</sup>

| Sieve Size                       |                | Grading<br>of<br>Original<br>Sample<br>(%) | Wt. of Test<br>Fraction<br>Before<br>Test<br>(g) | % Passing<br>Finer Sieve<br>After Test <sup>b</sup> | Weighted<br>Avg. <sup>c</sup><br>(%) |
|----------------------------------|----------------|--|--|---|--------------------------------------|
| Passing                          | Retained<br>on |  |  |   |                                      |
| No. 100                          |                | 15.6                                       | --   | --  | --                                   |
| No. 50                           | No. 100        | 7.8  | --   | --  | --                                   |
| No. 30                           | No. 50         | 24.4                                       | 100  | 8.71  | 2.12                                 |
| No. 16                           | No. 30         | 14.4                                       | 100  | 12.53   | 1.80                                 |
| No. 8                            | No. 16         | 12.2                                       | 100  | 9.09  | 1.11                                 |
| No. 4                            | No. 8          | 15.6                                       | 100  | 11.58   | 1.81                                 |
| <sup>3</sup> / <sub>8</sub> -in. | No. 4          | 10.0                                       | 100  | 11.33   | 1.13                                 |
| <b>Total</b>                     |                | <b>100.0</b>                               | <b>500</b>                                       | <b>--</b>   | <b>7.97</b>                          |

<sup>a</sup>ASTM designation C 88-59T.

<sup>b</sup>Actual percentage loss.

<sup>c</sup>Corrected percentage loss after five cycles.

TABLE 10  
SOUNDNESS TEST OF AGGREGATE A-2 USING SATURATED SOLUTION OF  
SODIUM SULFATE

| Sieve Size |                | Grading<br>of<br>Original<br>Sample<br>(%) | Wt. of Test<br>Fraction<br>Before<br>Test<br>(g) | % Passing<br>Finer Sieve<br>After Test <sup>a</sup> | Weighted<br>Avg. <sup>b</sup><br>(%) |
|------------|----------------|--|--|---|--------------------------------------|
| Passing    | Retained<br>on |  |  |   |                                      |
| No. 100    |                | 13.5                                       | --   | --  | --                                   |
| No. 50     | No. 100        | 11.3                                       | --   | --  | --                                   |
| No. 30     | No. 50         | 22.6                                       | 100  | 11.75   | 2.66                                 |
| No. 16     | No. 30         | 18.1                                       | 100  | 11.44   | 2.07                                 |
| No. 8      | No. 16         | 13.5                                       | 100  | 13.64   | 1.84                                 |
| No. 4      | No. 8          | 12.4                                       | 100  | 13.66   | 1.69                                 |
| 3/8-in.    | No. 4          | 8.6  | 100  | 17.32   | 1.32                                 |
| Total      |                | 100.0                                      | 500  | --  | 9.58                                 |

<sup>a</sup>Actual percentage loss.

<sup>b</sup>Corrected percentage loss after five cycles.

TABLE 11  
FLOAT MATERIAL AND THICKNESS  
OF SOIL-AGGREGATE-SODIUM  
CHLORIDE-STABILIZED  
SURFACES

| Road             | Sample<br>No. | Float<br>Material<br>(psf) | Thickness<br>(in.) |
|------------------|---------------|----------------------------|--------------------|
| S-4              | 1             | 0.56                       | 1.4                |
|                  | 2             | 0.89                       | 1.3                |
|                  | 3             | 1.48                       | 0.8                |
|                  | 4             | 1.27                       | 1.2                |
|                  | 5             | 0.95                       | 1.4                |
|                  | Avg.          | 1.03                       | 1.2                |
| S-3 <sup>a</sup> | 1             | 1.16                       | 2.3                |
|                  | 2             | 1.04                       | 2.1                |
|                  | 3             | 0.78                       | 2.2                |
|                  | 4             | 0.88                       | 1.8                |
|                  | 5             | 0.65                       | 2.1                |
|                  | 6             | 0.47                       | 2.4                |
| Avg.             | 0.83          | 2.1                        |                    |
| S-2              | 1             | 0.59                       | 2.7                |
|                  | 2             | 0.93                       | 3.0                |
|                  | 3             | 0.60                       | 2.1                |
|                  | 4             | 1.03                       | 2.4                |
|                  | Avg.          | 0.79                       | 2.7                |
| S-1              | 1             | 0.46                       | 3.3                |
|                  | 2             | 0.80                       | 2.9                |
|                  | 3             | 0.74                       | 3.4                |
|                  | 4             | 1.05                       | 3.1                |
|                  | 5             | 0.59                       | 3.4                |
|                  | Avg.          | 0.73                       | 3.2                |

TABLE 12  
FLOAT MATERIAL ON NON-  
CHEMICALLY TREATED SURFACES

| Road | Sample No. | Float Material<br>(psf) |
|------|------------|-------------------------|
| G-4  | 1          | 1.64                    |
|      | 2          | 1.11                    |
|      | 3          | 1.35                    |
|      | 4          | 1.43                    |
|      | Avg.       | 1.38                    |
| G-3  | 1          | 1.67                    |
|      | 2          | 1.47                    |
|      | 3          | 1.43                    |
|      | 4          | 1.58                    |
|      | 5          | 1.69                    |
| Avg. | 1.57       |                         |
| G-2  | 1          | 1.43                    |
|      | 2          | 1.48                    |
|      | 3          | 1.35                    |
|      | 4          | 1.45                    |
|      | Avg.       | 1.43                    |
| G-1  | 1          | 1.08                    |
|      | 2          | 1.01                    |
|      | 3          | 0.97                    |
|      | 4          | 1.13                    |
|      | 5          | 1.09                    |
| Avg. | 1.06       |                         |

<sup>a</sup>Includes only that section of road S-3 on which aggregate A-2 was used for construction.

TABLE 13  
RESULTS OF MECHANICAL ANALYSES OF FLOAT MATERIAL ON  
SOIL-AGGREGATE-SODIUM CHLORIDE-STABILIZED SURFACES

| Road             | Sample No. | Float Material (%) |      |       |        |
|------------------|------------|--------------------|------|-------|--------|
|                  |            | Clay               | Silt | Sand  | Gravel |
| S-4              | 1          | 0                  | 4    | 59    | 37     |
|                  | 2          | 3                  | 9    | 60    | 28     |
|                  | 3          | 1                  | 2    | 54    | 43     |
|                  | 4          | 1                  | 1    | 46    | 52     |
|                  | 5          | 1                  | 5    | 66    | 28     |
|                  | Average    | 1.2                | 4.2  | 57.0  | 37.6   |
|                  | Range      | 0-3                | 1-9  | 46-66 | 28-52  |
| S-3 <sup>a</sup> | Max. var.  | 3                  | 8    | 20    | 16     |
|                  | 1          | 0                  | 3    | 56    | 41     |
|                  | 2          | 3                  | 6    | 70    | 21     |
|                  | 3          | 2                  | 4    | 42    | 52     |
|                  | 4          | 2                  | 10   | 70    | 18     |
|                  | Average    | 1.75               | 5.75 | 59.50 | 33.00  |
|                  | Range      | 0-3                | 3-10 | 42-70 | 18-52  |
| S-3 <sup>b</sup> | Max. var.  | 3                  | 7    | 28    | 34     |
|                  | 1          | 3                  | 8    | 42    | 47     |
|                  | 2          | 2                  | 5    | 60    | 33     |
|                  | 3          | 0                  | 4    | 45    | 51     |
|                  | Average    | 1.67               | 5.67 | 49.00 | 43.67  |
|                  | Range      | 0-3                | 4-8  | 42-60 | 33-47  |
|                  | Max. var.  | 3                  | 4    | 18    | 14     |
| S-2              | 1          | 1                  | 4    | 63    | 32     |
|                  | 2          | 2                  | 9    | 65    | 24     |
|                  | 3          | 1                  | 5    | 62    | 32     |
|                  | 4          | 4                  | 4    | 69    | 23     |
|                  | Average    | 2.0                | 5.5  | 64.75 | 27.75  |
|                  | Range      | 1-4                | 4-9  | 62-69 | 24-32  |
|                  | Max. var.  | 3                  | 5    | 7     | 8      |
| S-1              | 1          | 0                  | 3    | 51    | 46     |
|                  | 2          | 4                  | 9    | 58    | 29     |
|                  | 3          | 1                  | 5    | 62    | 32     |
|                  | 4          | 2                  | 8    | 58    | 32     |
|                  | 5          | 2                  | 5    | 60    | 33     |
|                  | Average    | 1.8                | 6.0  | 57.8  | 34.4   |
|                  | Range      | 0-4                | 3-9  | 51-62 | 29-46  |
| Max. var.        | 4          | 6                  | 11   | 17    |        |

<sup>a</sup>Portion that used aggregate A-2.

<sup>b</sup>Portion that used aggregate A-1.