Correlation of Concrete Properties With Tests for Clay Content of Aggregate

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•THE PRESENCE of clays in the fine aggregate used to make concrete is detrimental to the structural properties of the concrete. The Texas Highway Department currently uses the results of sand equivalent and loss by decantation tests as a means of detecting such clay and controlling the quality of fine aggregate used in portland cement concrete. Article 421 of the Texas Highway Department specifications states:

> The loss by decantation of fine aggregate, including mineral filler when used (Test Method Tex-406-A), shall not exceed 2.5 percent. As an alternate to this, the fine aggregate may be used if, when subjected to the Sand Equivalent test, (Test Method Tex-203-F), the sand equivalent is equal to or higher than 80.

These quality control tests were developed independently, and the relationship between the numerical results of each test was not known. Since the two tests form apparently independent bases for accepting or rejecting a material, the relationship between them is very important.

The sand equivalent test separates the finer clay particles from the coarser particles and compares them on a volume basis, which magnifies the volume of the clay in proportion to its affinity for water. (This affinity for water is referred to hereafter as the activity of the clay fraction.) This magnification of the clay volume is not accomplished by the loss by decantation test, and consequently the relationship between the two is nonlinear. The liquid limit (AASHO T80-60) of the clay fraction was chosen as the parameter to indicate activity.

Information is presented in this paper which will aid engineers in establishing limits for the quantity and activity of minus 200 mesh material allowed in concrete aggregate.

NOMENCLATURE

SE = sand equivalent value;
LD = loss by decantation given as a percentage;
P = decimal fraction of minus 200 mesh material in samples of sand;
A = sand reading in inches in sand equivalent test;
K = ratio of clay reading minus sand reading and sand reading in sand equivalent test;
C = $\frac{K}{P}$;
LL = liquid limit of minus 200 mesh fraction; and
K_1 = adherence factor, the ratio in percent between fraction decanted in loss by decantation test and fraction of minus 200 mesh material actually present in aggregate.

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STUDY OF LOSS BY DECANTATION AND SAND EQUIVALENT TESTS

Testing Program

The sand equivalent test was performed in accordance with the Texas Highway Department Test Method Tex-203-F, which is a modification of the California Test Method No. 217-C (AASHO T176-56). The loss by decantation test procedure used was in accordance with the Texas Highway Department Test Method Tex-406-A.

The sand equivalent test was developed by Hveem (4) as a rapid means of quality control of fine aggregate for bases, subbases, bituminous mixtures and portland cement concrete. The procedure developed by Hveem did not require that the samples be oven-dried before testing, and consequently results could be produced within 40 min.

The sand equivalent test method uses a calcium chloride solution to separate the clay and sand fraction. A cylinder graduated in tenths of inches is filled to the 4-in. mark with the calcium chloride solution. An oven-dried sand sample is then poured into the cylinder. Air bubbles are removed and the sample is allowed to soak for 10 min. After the soaking period, the cylinder is held horizontally and shaken vigorously by throwing the contents from end to end. The cylinder should complete 90 cycles in approximately 30 sec with a 9-in. throw. Following this operation, an agitator tube is used to flush the fine clay-like material into suspension above the coarse sand particles. The graduated cylinder and its contents are allowed to stand for 20 min. The heights of the sand

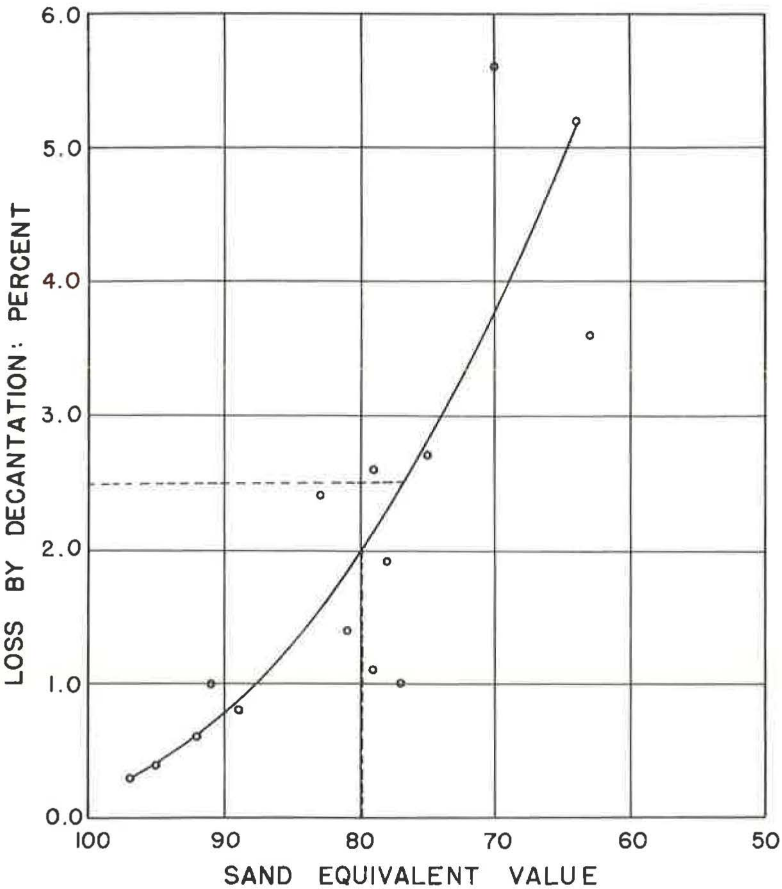

Figure 1. Relationship between loss by decantation and sand equivalent values for natural aggregate samples.

TABLE 1

MEASURED AND CALCULATED DATA FOR AGGREGATE SAMPLES

Sample No.	Loss by Decantation	Measured Sand Equiv. Value	Liquid Limit	Calculated Sand Equiv. Value
1	1.4	81	29.7	92
2	2.6	79	33.1	86
3	5.2	64	36.2	73
4	3.6	63	30.1	82
5	1.9	78	27.8	90
6	2.7	75	30.5	86
7	5.6	70	36.2	72
8	2.4	83	25.8	89
9	1.0	77	33.6	94
10	0.6	92	24.2	97
11	0.8	89	—[a]	—
12	0.4	95	—[a]	—
13	0.3	97	—[a]	—
14	1.0	91	—[a]	—
15	1.1	79	—[a]	—
101	2.2	94	0.0	96
102	2.3	87	34.0	87
103	2.1	61	200	61
104	2.4	41	400	42
105	2.3	32	640	32
106	4.4	89	0.0	93
107	4.3	81	34.0	78
108	4.5	38	200	43
109	4.2	25	400	29
110	4.1	23	640	21

[a] There was not enough minus No. 200 mesh material in this sample for a liquid limit determination.

TABLE 2

MANUFACTURED SAMPLES

Sample No.	Description
101	Washed sand with 2½ percent silica flour
102	Washed sand with 2½ percent natural clay (LL = 34%)
103	Washed sand with 2½ percent silica-montmorillonite (LL = 200%)
104	Washed sand with 2½ percent silica-montmorillonite (LL = 400%)
105	Washed sand with 2½ percent montmorillonite (LL = 640%)
106 to 110	Same as 101 through 105 but with 5 percent contaminant

and of the clay are then read and the sand equivalent value is calculated by the following formula:

$$SE = \frac{\text{sand reading}}{\text{clay reading}} \times 100$$

The loss by decantation test can be used for coarse as well as fine aggregates. The sample, no dryer than saturated surface dry (SSD), is placed in the pycnometer, and the pycnometer filled with water. After

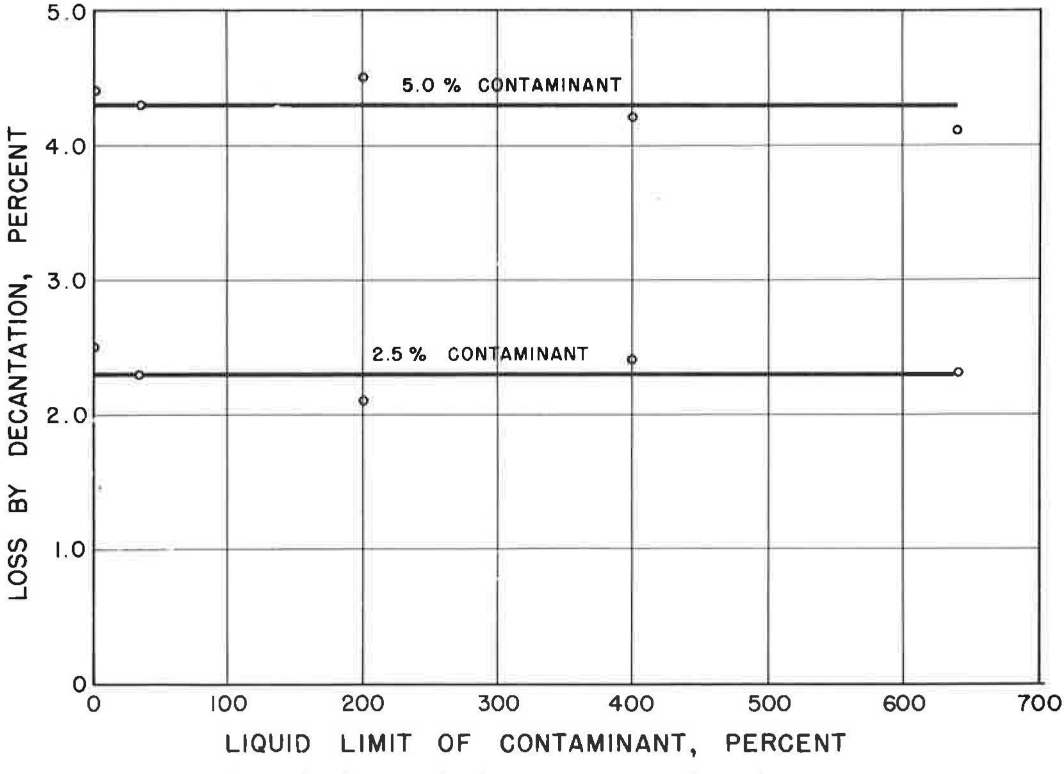

Figure 2. Relationship between loss by decantation and liquid limit of contaminant.

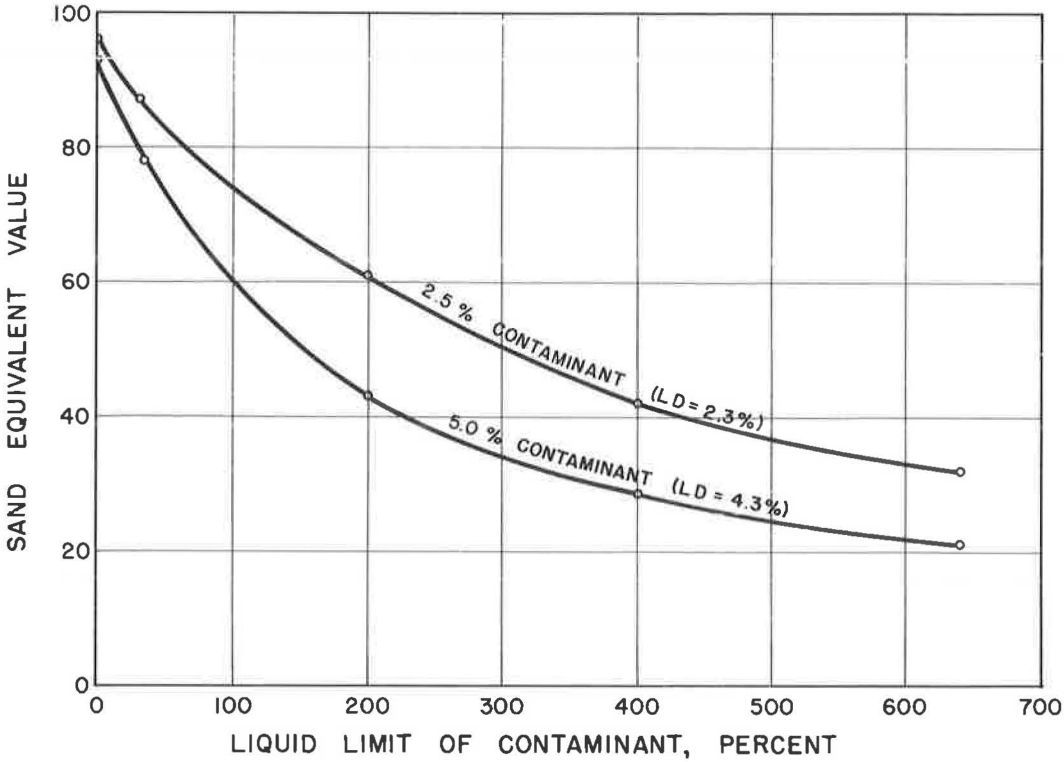

Figure 3. Relationship between sand equivalent value and liquid limit of contaminant.

weighing, the sample is agitated by rolling the pycnometer and then allowed to stand for a 15-sec settling period. The water containing the fine material is decanted and the washing process is repeated until the water remains clear after a 15-sec settling period. The pycnometer is again filled with water and weighed. The percent loss by decantation is calculated as follows:

$$\text{Percent loss} = \frac{Z_1 - Z_2}{Z_1 - Y} \times 100$$

where

Z_1 = weight of pycnometer containing sample and water before washing;
Z_2 = weight of pycnometer containing sample and water after washing and decanting; and
Y = weight of pycnometer filled with water at approximately same temperature at which Z_1 and Z_2 were determined.

Examination of the loss by decantation and sand equivalent tests shows that the loss by decantation results reflect only the amount of clay-size materials in the aggregate, whereas the sand equivalent results give an indication of amount and activity of the clay-size fraction. A linking parameter was needed to draw a correlation between the two tests, and the liquid limit of the clay-size fraction was chosen.

Fifteen samples of concrete sand from various locations in Texas were obtained. Each of these samples was thoroughly mixed and split with a sample splitter to obtain test specimens for three loss by decantation tests and three sand equivalent tests. The loss by decantation and sand equivalent values for samples 1 through 15 are plotted in Figure 1 and given in Table 1.

To investigate the effect of liquid limit on the results of the two tests, 10 samples were manufactured and tested (Table 2). A high quality concrete sand was washed in the laboratory with a detergent to remove all minus 200 mesh material. The contaminants used were (a) pure silica flour with a liquid limit of zero, (b) a natural clay with a liquid limit of 34 percent, (c) a silica-montmorillonite mixture with a liquid limit of 200 percent, (d) a silica-montmorillonite mixture with a liquid limit of 400 percent, and (e) pure montmorillonite with a liquid limit of 640 percent.

The washed sand was air dried and divided with a sample splitter to obtain sand for 30 sand equivalent test specimens and 30 loss by decantation test specimens. Three test specimens, each containing the specified amount of minus 200 mesh material, were then made for each of the 10 samples. After each test specimen was thoroughly mixed, water was added and the specimen was mixed again, then dried in an oven at 105 C. Sand equivalent and loss by decantation tests were then run on these test specimens; the results are presented in Figures 2 and 3 and in Table 1.

Results and Discussion

Figure 1 shows the data obtained from samples 1 through 15. Although these points form a definite curve, the irregularity of some points definitely indicates that some variable or combination of variables affects the two test values in different ways. A curve is drawn through the data points and the allowable limit for acceptable fine aggregate (by Texas Highway Department specifications) is indicated. Some materials would be acceptable on the basis of the loss by decantation value but rejected on the basis of the sand equivalent value.

Figures 2 and 3 show the effect of the liquid limit of the contaminant for two different percentages of contaminant on the results of the two tests. The sand equivalent values in Figure 3 verify those reported by Clough and Martinez (2). The variation in liquid limit of the contaminant has little or no effect on loss by decantation results, but has a pronounced effect on the sand equivalent value.

The relationship between loss by decantation and sand equivalent test values can be derived in the following manner. If the symbols in Figure 4 are used in the definition of the sand equivalent value, it can be written:

$$SE = \frac{100A}{A + KA} \tag{1a}$$

or

$$SE = \frac{100}{1 + K} \tag{1b}$$

For a given material, the factor K can be written as another factor, C times P, where P is the decimal fraction of the contaminant in the sample. Eq. 1b then becomes

$$SE = \frac{100}{1 + CP} \tag{2}$$

This equation can be written

$$C = \frac{100 - SE}{SE(P)} \tag{3}$$

If the values of C are plotted against values of the liquid limit (using the data in Table 3) and the data points fitted with a curve by the least squares method using $C = A_1 (LL) + A_2$ as a model, the resulting equation is

$$C = 0.1318 (LL) + 1.79 \tag{4}$$

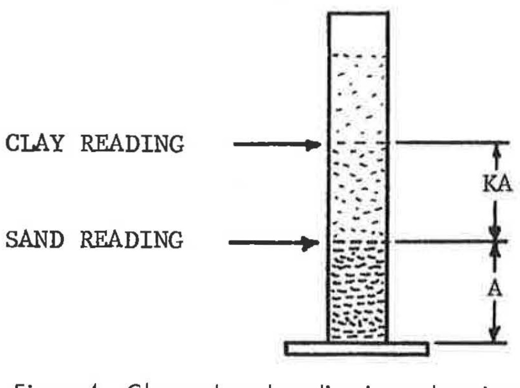

Figure 4. Clay and sand reading in sand equivalent test.

TABLE 3

VALUES OF C USED TO DETERMINE
C = F(LL)

Sample No.	Measured Sand Equiv. Value	$C = \frac{100 - SE}{SE(P)}$
101	94	2.55
102	87	5.98
103	61	25.57
104	41	57.56
105	32	85.00

Figure 2 shows that the loss by decantation value varies insignificantly with liquid limit, and can be considered constant for all practical purposes. The average value of the loss by decantation was 2.3 for 2.5 percent minus 200 mesh material. If these values are used in

$$LD = K_1 P \quad (5)$$

the value of K_1 is 92.

Eq. 5 can now be written

$$P = \frac{LD}{92.0} = 0.01087\ LD \quad (6)$$

The relationship between sand equivalent (SE) and loss by decantation (LD) can be found by substituting the expression for C from Eq. 4 and the expression for P from Eq. 5 into Eq. 2.

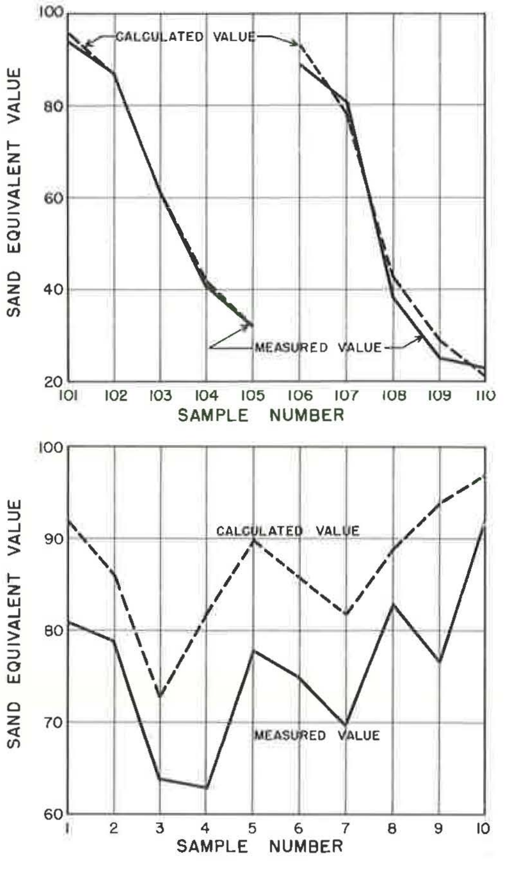

Figure 5. Correlation between calculated and measured sand equivalent values.

$$SE = \frac{100}{1 + \frac{LD}{K_1}(0.1318\ LL + 1.79)}$$

This relationship (K_1 = 92) has been used to calculate sand equivalent values for samples 106 through 110 and 1 through 10 (Table 1, Fig. 5).

There is a good correlation between the test values, and the calculated values are consistently higher than the test values for samples 1 through 10 (Fig. 5). The difference between the two sets of data for the latter samples can possibly be explained by considering the difference between the manufactured (106 through 110) and naturally occurring samples (1 through 10).

In naturally occurring aggregates there may be a definite adherence of the clay particles to the sand grains. The washing action in the loss by decantation test is not extremely vigorous, and a smaller percentage of the minus 200 mesh material is removed compared to the quantity removed by the vigorous washing action of the sand equivalent test. This causes the sand equivalent value to be lower for the naturally occurring samples than is predicted by the relations derived from the manufactured samples. The results on natural clay samples yield values of the adherence factor (K_1) ranging from 21 to 86.

The equation relating sand equivalent loss by decantation and liquid limit illustrates one of the primary differences between the two tests; the sand equivalent test indicates activity in addition to amount, but the loss by decantation test does not. The sand equivalent test is also superior in that it requires less expensive equipment, can be performed in the field, and the results can be obtained in about 40 min.

EFFECTS OF CLAY IN AGGREGATE ON PROPERTIES OF CONCRETE

Testing Program

Concrete Batches.—Fourteen batches were cast in this phase of the program, using a high quality siliceous aggregate (batches S-1 through S-9) and a high quality crushed limestone aggregate (batches L-1 through L-5). All batches contained the same high quality natural sand. The fine and coarse aggregates were washed with a detergent to remove all minus 200 mesh material. Loss by decantation values for the washed aggregate were zero. Table 4 gives the physical properties of the aggregates.

A series of eight concrete batches was cast to determine the effects of different amounts of a natural clay contaminant on the physical properties of concrete. The batches are designated as S-1 through S-4 and L-1 through L-4 in Table 5. The nominal amounts of clay contaminant used were 0.0, 0.8, 1.6, and 2.4 percent of the total aggregate weight. The maximum amount of clay contaminant now allowed by Texas Highway Department specifications is 2.5 percent loss by decantation for the fine aggregate and 1.0 percent for the coarse aggregate. For typical batch designs this is 1.6 percent of the total coarse and fine aggregate weight.

A second series of five concrete batches was cast to determine the effect of the contaminant liquid limit on the physical properties of concrete. Each of these batches (S-5 through S-9) contained nominally 1.6 percent clay contaminant. The contaminant used was a mixture of silica flour and montmorillonite. The desired liquid limit could be obtained by varying the proportions of these two constituents. Batch S-5 contained pure silica flour and batch S-9 contained pure montmorillonite. These batches are also included in Table 5.

TABLE 4

PHYSICAL PROPERTIES OF AGGREGATES

Property	Siliceous Coarse	Siliceous Fine	Crushed Limestone Coarse
Unit weight (lb/cu ft), dry loose	93.0	98.5	88.0
Specific gravity (SSD)	2.61	2.62	2.65
Absorption (% of dry wt)	1.24	0.81	1.44
Sieve analysis: cumulative percent retained on			
¾ in.	0.0	—	0.0
½ in.	35.0	—	35.0
⅜ in.	60.0	—	60.0
No. 4	100.0	0.24	100.0
No. 8	—	10.10	—
No. 16	—	26.21	—
No. 30	—	41.21	—
No. 50	—	83.29	—
No. 100	—	98.62	—
No. 200	—	100.00	—

TABLE 5

CONCRETE MIX DATA[a]

Batch Designation	Contaminant		Type I Cement		Aggregate		Total Water (lb)	Air Content (%)	Slump (in.)	Air Entrain. Admix (oz/cu yd)	Initial Unit Wt (pcf)
	Type	Amount (% tot. agg. by wt)	Sk	Lb	Coarse (lb)	Fine (lb)					
S-1[b]	—	0.00	5.02	472	1,840	1,301	247	6.1	$3\frac{1}{2}$	4.8	143.0
S-2	Natural clay	0.74	5.07	477	1,812	1,289	287	5.0	$3\frac{1}{4}$	8.7	144.3
S-3	Natural clay	1.48	5.11	480	1,957	1,164	287	4.5	3	9.7	146.0
S-4	Natural clay	2.36	5.36	495	1,960	1,077	300	4.1	3	10.0	145.0
S-5[c]	Silica flour	1.42	5.07	477	1,823	1,358	282	3.0	$2\frac{3}{4}$	3.8	147.5
S-6	Sil-Mont LL = 35	1.48	5.05	475	1,814	1,277	273	4.9	$2\frac{3}{4}$	5.8	144.0
S-7	Sil-Mont LL = 200	1.50	4.97	467	1,777	1,222	352	2.9	$3\frac{1}{4}$	8.5	142.9
S-8	Sil-Mont LL = 400	1.57	5.11	480	1,842	1,101	386	3.0	3	9.7	142.9
S-9	Mont LL = 740	1.60	4.95	465	1,701	1,114	406	3.3	3	8.3	138.8
L-1[b]	—	0.00	4.97	467	1,672	1,491	287	4.1	3	3.8	145.0
L-2	Natural clay	0.74	5.00	470	1,681	1,377	271	6.0	$3\frac{1}{2}$	8.6	141.0
L-3	Natural clay	1.49	5.11	480	1,716	1,382	289	3.0	3	6.3	145.0
L-4	Natural clay	2.25	4.97	467	1,672	1,328	334	4.2	$2\frac{3}{4}$	8.5	143.0
L-5	Limestone fines	1.48	5.05	475	1,698	1,405	296	3.1	3	4.8	145.5

[a]Quantities per cubic yard of concrete.
[b]Used as control batch for study of effects of percent contaminant.
[c]Used as control batch for study of effects of liquid limit of contaminant.

TABLE 6

SPECIMEN TESTING SCHEDULE

Specimen No.	Dimensions	Curing	Test Type
1	3- × 4- × 16-in. prism	3 days moist	Specimens were subjected to ASTM freeze-thaw test C310-57T with dynamic modulus and weight determinations made periodically.
2	3- × 4- × 16-in. prism	3 days moist	
3	3- × 4- × 16-in. prism	3 days moist	
4	4- × 4- × 11-in. prism	3 days moist	Specimens were stored under atmospheric conditions of 52 percent RH and 72 F; shrinkage measured periodically.
5	4- × 4- × 11-in. prism	3 days moist	
7	3- × 4- × 16-in. prism	7 days moist	Weight, dynamic modulus, flexural and compressive strengths determined at 7 days of age.
8	3- × 4- × 16-in. prism	7 days moist	
9	3- × 4- × 16-in. prism	7 days moist	
10	3- × 4- × 16-in. prism	28 days moist	Weight and dynamic modulus determinations were made at 3, 7, 14, and 28 days of age; flexural and compressive strengths determined at 28 days of age.
11	3- × 4- × 16-in. prism	28 days moist	
12	3- × 4- × 16-in. prism	28 days moist	
13	3- × 4- × 16-in. prism	3 days moist	Specimens cycled between atmospheric conditions at 17 percent RH, 120 F and 100 percent RH, 72 F. Weight and dynamic modulus determinations were made periodically.
14	3- × 4- × 16-in. prism	3 days moist	
15	4- × 4- × 11-in. prism	3 days moist	Specimen subjected to same atmospheric conditions as specimens 13 and 14; shrinkage measured periodically.

Liquid limit determinations were made on the minus 200 mesh fractions of representative samples of Texas pit-run materials. On the basis of these results, a natural clay with a liquid limit of 34 percent was selected for contaminating six concrete batches.

All concretes were batched in a 2-cu ft vertical drum Lancaster mixer. The dry aggregate and contaminant were thoroughly mixed and then one-half of the mixing water was added. This was followed by the addition of the cement and about one-fourth of the estimated water containing the air-entraining admix. Water was then added until a slump of $3 \pm \frac{1}{2}$ in. was obtained, after which air content and unit weight were determined.

Slump was determined in accordance with ASTM C143-39 and air content in accordance with ASTM C231-56T, except that vibration was used instead of the hand-rodding procedure. The testing schedule for these concretes is given in Table 6.

Shrinkage.—Shrinkage specimens were 4- by 4- by 11-in. prisms. Gage points were installed in the center of the end blocks which were free to move inward with the ends of the specimen. The gage points used were the same size as those used in ASTM C147-60T, Volume Change of Cement Mortar and Concrete, and provided a gage length of 10.0 ± 0.1 in.

The comparator used to measure shrinkage was similar in design to that described in ASTM C157-60T, except that it could accommodate the 4- by 4-in. cross-section specimens. When changes in length were determined, the specimen was placed in the

TABLE 7

PHYSICAL PROPERTIES OF CONCRETE[a]

Batch Design	Dynamic Modulus of Elasticity (10^{-6} lb/sq in.)		Modulus of Rupture (lb/sq in.)[b]		Compressive Strength (lb/sq in.)[c]	
	7 Day	28 Day	7 Day	28 Day	7 Day	28 Day
S-1	5.86	6.25	810	780	3,300	3,670
S-2	5.61	6.31	660	720	2,690	3,370
S-3	5.79	5.99	640	580	2,850	3,220
S-4	5.26	6.62	580	650	2,390	3,000
S-5	6.40	6.46	880	770	2,890	2,920
S-6	5.48	6.00	650	790	2,750	3,530
S-7	4.81	5.16	510	560	2,160	2,520
S-8	4.58	4.72	500	520	2,370	2,430
S-9	3.96	4.33	410	450	1,840	2,290
L-1	5.76	6.22	700	830	2,900	3,210
L-2	5.44	5.64	580	760	2,790	2,640
L-3	5.35	5.95	770	790	3,570	3,810
L-4	5.14	5.38	600	730	2,450	2,750
L-5	5.52	5.84	830	810	3,120	3,890

[a]All specimens were moist cured until time of testing.
[b]Center point loading 3- by 4- by 16-in. specimens.
[c]ASTM C116-49 modified cube.

comparator and allowed to rotate slowly. If any cyclic variation in the dial reading occurred as the specimen rotated, the lowest reading was recorded.

Strength.—Modulus of rupture was determined using 3- by 4- by 16-in. prismatic specimens under a midpoint loading condition. The specimens had a 14-in. span and were loaded with the 4-in. side in the vertical position. With the exception of the span length, this method of test conforms to ASTM C293-54T.

Compressive strength was determined using the two ends of the specimen remaining after the modulus of rupture test. The compressive strength test procedure conformed to ASTM C116-49.

X-Ray Diffraction.—Fifteen samples of clay from pit-run aggregates were analyzed using x-ray diffraction techniques. Cation exchange capacity and exchangeable cation tests were carried out to supplement the x-ray analysis.

Results and Discussion

Non-dimensionalization of the ordinates of the graphs presented in this paper has been accomplished by expressing quantities as a percentage of control quantities. Control batches are indicated in Table 5 and absolute values of the various properties are given in Tables 4 and 7.

The effect of contaminant quantity on concrete strength is shown in Figures 6 through 9. A significant decrease in the modulus of rupture at 7 days is indicated as contaminant quantity increases. The same trend is evident in compressive strength at 28 days; the strength reduction is less for the concrete containing crushed limestone.

Data on relative shrinkage for concrete at 28 days and at 1 yr indicate that the presence of clay in the siliceous aggregate significantly increases concrete shrinkage at early ages, but has only a slight effect on shrinkage at 1 yr (Fig. 10). The effect of contaminant quantity on shrinkage of concrete containing crushed limestone appears quite different. This difference might be attributed to the angularity and texture of the crushed limestone. The clay provides effective lubrication for the more angular and

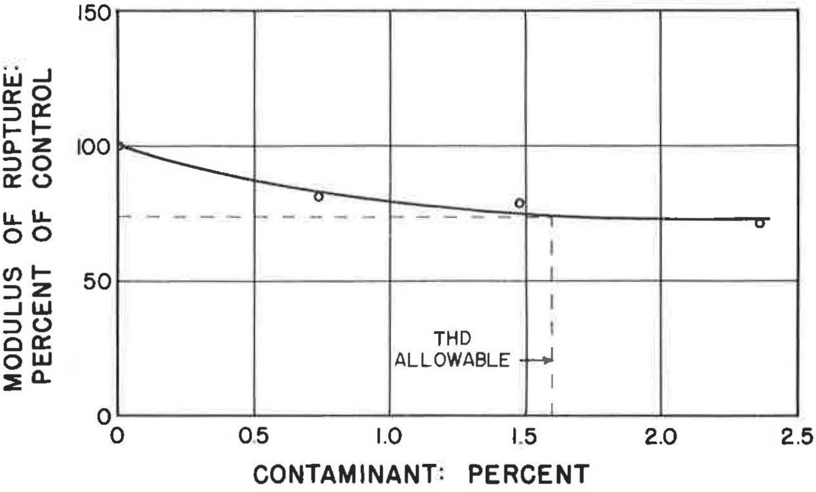

Figure 6. Relative 7-day modulus of rupture vs percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

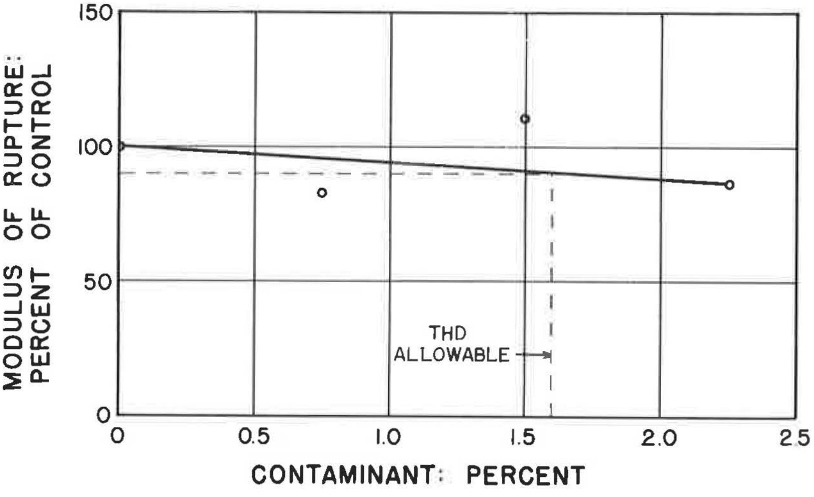

Figure 7. Relative 7-day modulus of rupture vs percent contaminant (natural clay LL = 34) for crushed limestone aggregate concrete.

rough textured limestone aggregate, which decreases the amount of water required for a given slump and tends to cancel the increased water requirement called for with the addition of clay. A point appears to be reached (at about 1.5% contaminant) where additional contaminant fails to provide additional lubrication, and the water requirement and consequently shrinkage begin to increase.

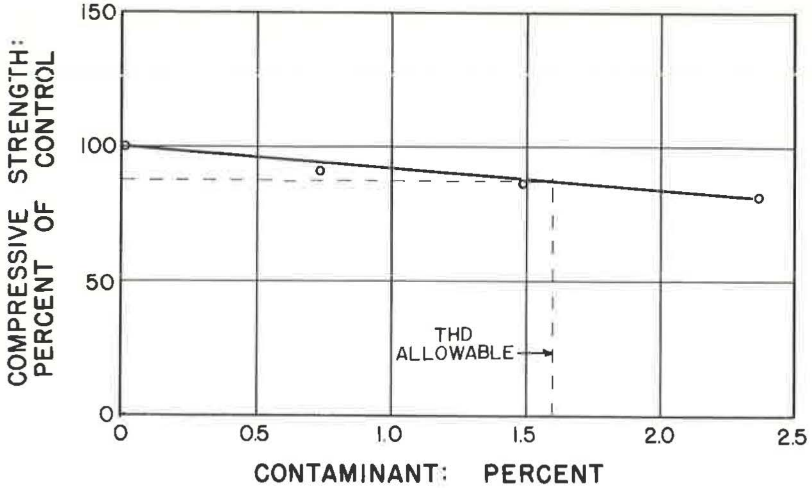

Figure 8. Relative 28-day compressive strength vs percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

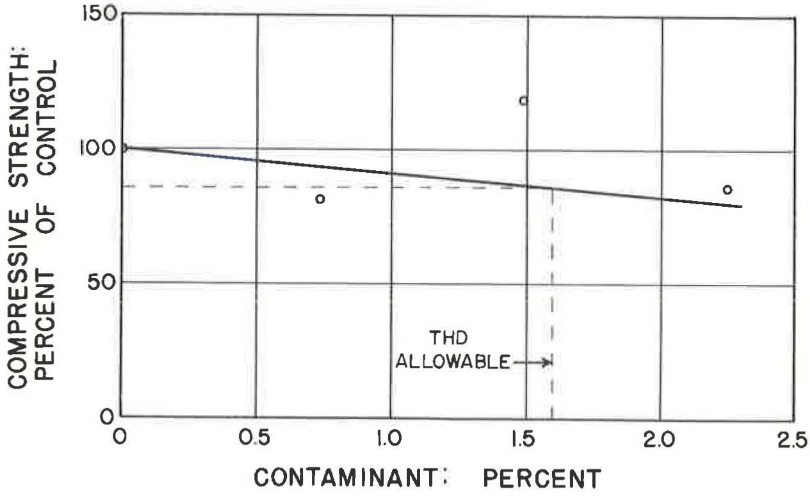

Figure 9. Relative 28-day compressive strength vs percent contaminant (natural clay LL = 34) for crushed limestone aggregate concrete.

The effects of contaminant liquid limit on various concrete properties are shown in Figures 11 through 13. A very pronounced decrease in both the modulus of rupture and the compressive strength is indicated with increasing liquid limit. In the case of the 7-day modulus of rupture, a large percentage of this decrease in strength is in the 0 to 40 percent liquid limit range. This strength reduction is of major concern because

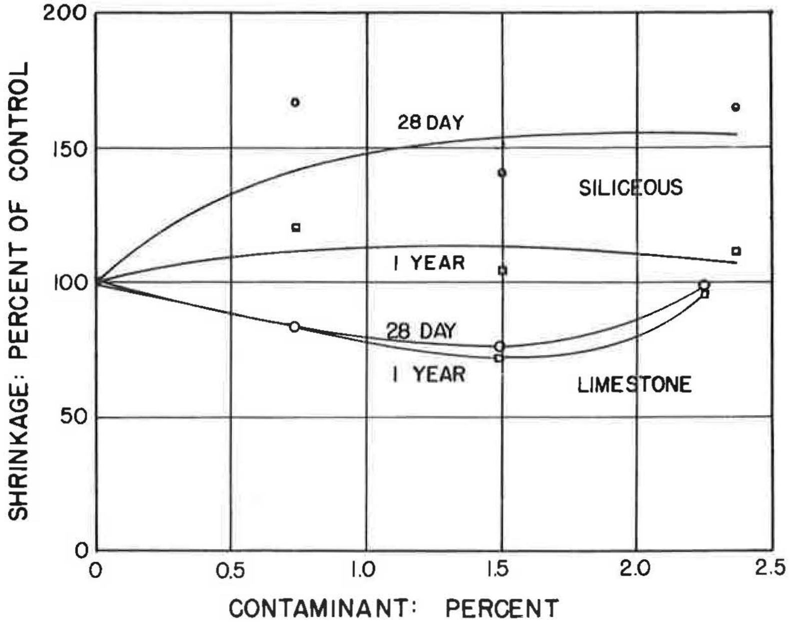

Figure 10. Relative shrinkage vs percent contaminant (natural clay LL = 34) for crushed limestone and siliceous aggregate concrete.

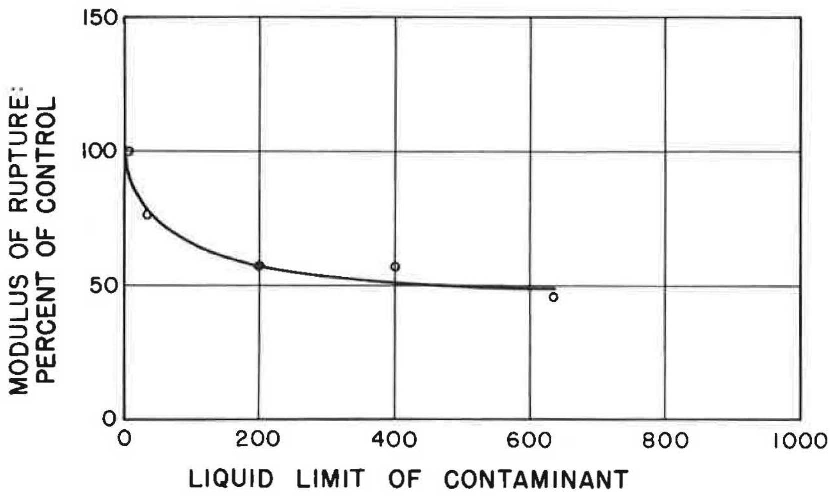

Figure 11. Relative 7-day modulus of rupture vs liquid limit (nominally 1.6% clay) for siliceous aggregate concrete.

the liquid limit of the clays naturally occurring in concrete aggregates in Texas is predominately within this range.

Relative shrinkage at ages of 28 days and 1 yr is shown in Figure 13. Here again, the influence of the contaminant liquid limit is quite pronounced.

The effects of contaminant quantity and liquid limit on the 7-day modulus of rupture and on the 28-day compressive strength are shown in Figures 14 and 15. Since limited

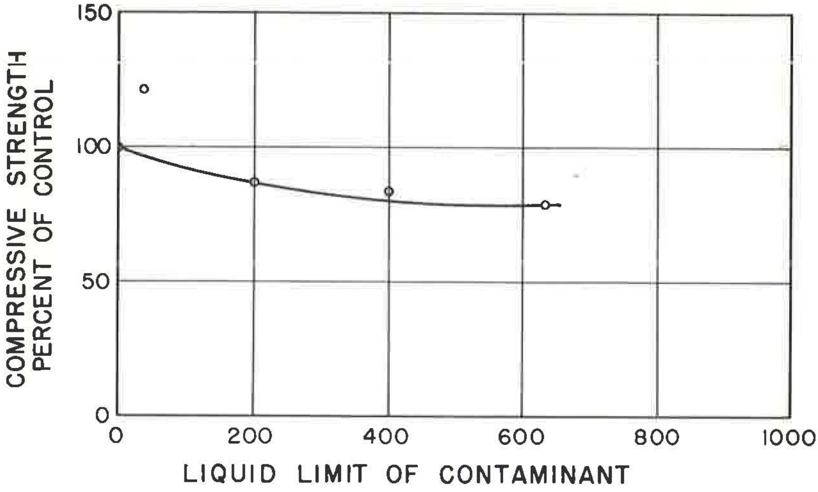

Figure 12. Relative 28-day compressive strength vs liquid limit (nominally 1.6% clay) for siliceous aggregate concrete.

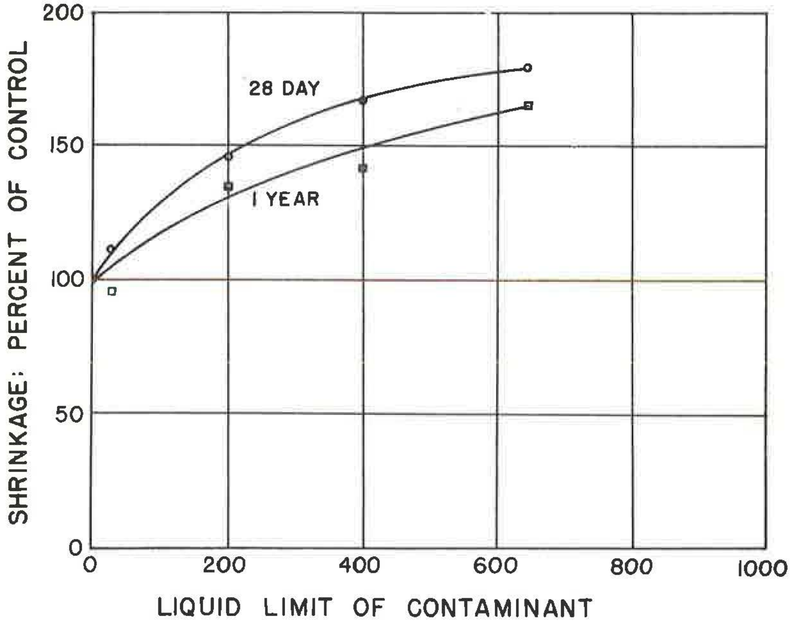

Figure 13. Relative shrinkage vs liquid limit of contaminant (nominally 1.6% clay) for siliceous aggregate.

data are available at this time, the dashed curves are speculative. These figures illustrate clearly that the effect of a contaminant depends on its activity as well as on the quantity present.

Figure 16 is a typical x-ray pattern obtained from clays found in natural concrete sand. The vertical scale is simply denoted intensity because this scale is an arbitrary, relative measure of the intensity of the refracted x-rays. The horizontal scale is twice the angle between the incident x-rays and the lattice planes of the clay. Most of the

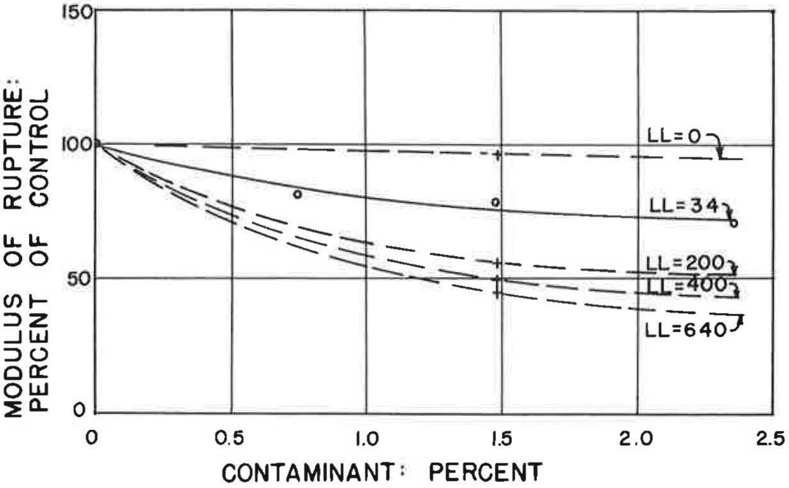

Figure 14. Relative 7-day modulus of rupture vs percent contaminant for different liquid limits, siliceous aggregate concrete.

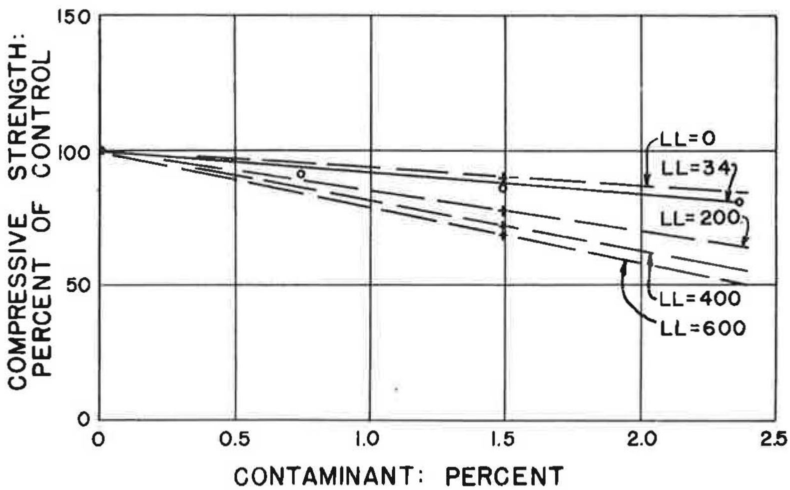

Figure 15. Relative 28-day compressive strength vs percent contaminant for different liquid limits, siliceous aggregate concrete.

clay minerals can be identified by the value of two theta at which the peak is found. Identification of some clay minerals is more difficult, however, and requires that test specimens be prepared using magnesium and water, magnesium and ethylene glycol, and potassium and water. In the diffraction patterns shown, the peaks of each clay mineral except montmorillonite occur at the same value of two theta for each of the three preparation solutions. This shift, or absence of the montmorillonite peak when the sample is prepared in different solutions, is an aid in identification. The width of

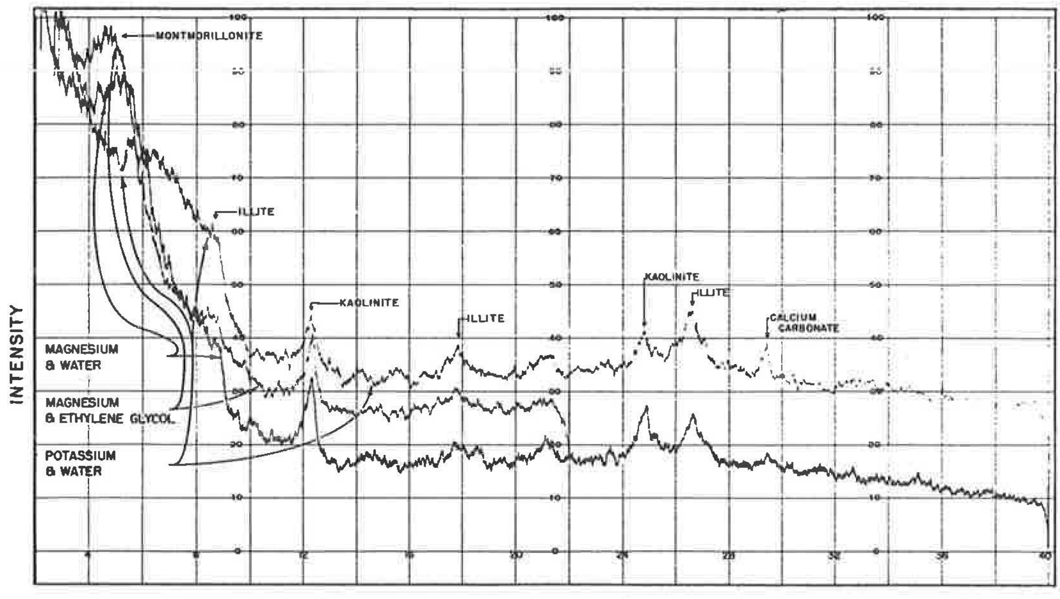

Figure 16. Typical x-ray diffraction pattern.

TABLE 8
ANALYSIS OF CLAYS

Sample No.	Type of Clay and Estimated Amount[a]	Cation Exchange Cap.[b]	Exchangeable Cations[b]			
			Na	Ca	Mg	K
1	I2, M2, K2, Q3					
2	M1, I3, K3, Q3	17.3	0.24	Calc.	3.2	0.37
3	M1, K2, I3, Q3	18.6	0.11	Calc.	1.8	0.53
4	M1, I2, K2, Q3	7.5	0.10	Calc.	0.94	0.18
5	M1, I2, K2, Q3	11.0	6.2	Calc.	4.2	0.33
6	M1, K2, I2, Q3	13.5	0.44	Calc.	1.8	0.29
7	M1, I2, K2, Q3	32.3	0.23	Calc.	2.2	0.63
8	—	—	—	—	—	—
9	M1, K2, I3, Q3	10.2	4.9	Calc.	8.0	0.97
10	M1, K2, I3, Q3	9.6	0.58	Calc.	1.2	0.29
11	I2, K2, M2, Q3	14.3	0.3	7.9	1.7	0.55
12	M1, I3, K3, Q3	—	—	—	—	—
13	M2, I2, K2, Q3, F3	—	—	—	—	—
14	—	7.7	0.22	Calc.	1.4	0.20
15	—	—	—	—	—	—
16	M1, K2, I3, Q3	17.1	1.2	15.5	5.7	0.75
17	M1, I2, K2, C3	—	—	—	—	—
18	M1, K3, I3, Q3	8.3	0.39	Calc.	0.58	0.25

[a]Abbreviations used are M = montmorillonite, I = illite, K = kaolinite, Q = quarts, F = feldspar, C = calcium carbonate; numerical code: L = greater than 40 percent, 2 = 10 to 40 percent, 3 = less than 10 percent.

[b]Milliequivalents per 100 gm.

the montmorillonite peak indicates a poorly crystalline structure and decayed or decaying micaceous material.

Data obtained from x-ray analysis and related tests are given in Table 8. The amount of each clay mineral was estimated from the x-ray pattern and is not based on quantitative test results. Samples are predominantly montmorillonite. If several clay minerals have the same quantity code designation within a sample, they are arranged in order of descending magnitude. These data are of value in indicating the deleterious effect of the clay, as clay activity is dependent on the mineral composition.

CONCLUSIONS

1. The strength of concrete is reduced as the quantity of contaminant in the aggregate is increased.
2. The strength of concrete is decreased as the liquid limit of the contaminant increases.
3. Shrinkage of the siliceous aggregate concrete is increased as the contaminant quantity increases.
4. Shrinkage of the siliceous aggregate concrete is increased as the liquid limit of the contaminant increases.
5. The dynamic modulus of elasticity of the concrete containing siliceous aggregate is decreased as the liquid limit of the contaminant increases.
6. Within the range of contaminant quantities tested, the dynamic modulus of elasticity of concrete does not change significantly as the quantity of contaminant increases.
7. Present Texas Highway Department specifications for concrete aggregate indirectly allow a 15 percent reduction in 28-day compressive strength and a 25 percent reduction in 7-day modulus of rupture values.
8. Some aggregates meet present Texas Highway Department specifications by the loss by decantation test while failing the requirements of the sand equivalent test.
9. A relationship exists between loss by decantation results, liquid limit of the minus 200 mesh fraction, and sand equivalent value.
10. Clay activity, as indicated by liquid limit, as well as the amount of the clay present in the aggregate, influence concrete strength. The sand equivalent test is an indicator of a combination of activity and amount of contaminant, whereas the loss by decantation test indicates only the amount. For this reason the sand equivalent test is a better indicator of the quality of fine aggregate for use in concrete. Loss by decantation results should be combined with liquid limit determinations to evaluate coarse aggregate.

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REFERENCES

1. Brindley, G. W. X-Ray Identification and Crystal Structure of Clay Minerals. Mineralogical Soc., London, 1951.
2. Clough, R. H., and Martinez, J. E. Research on Bituminous Pavements Using the Sand Equivalent Test. Highway Research Board Bull. 300, pp. 1-17, Nov. 1961.
3. Grim, Ralph E. Clay Mineralogy. New York, McGraw-Hill Book Co., 1953.
4. Hveem, F. N. Sand-Equivalent Test for Control of Materials During Construction. Highway Research Board Proc., Vol. 32, pp. 238-250, 1953.
5. O'Harra, W. G. Evaluation of the California Sand-Equivalent Test. Highway Research Board Proc., Vol. 34, pp. 297-300, 1955.
6. Tremper, Bailey, and Haskell, W. E. Findings. Calif. Highways and Public Works, Vol. 23, Nos. 11-12, Nov.-Dec. 1955.