

CORRELATION OF CONCRETE PROPERTIES WITH TESTS FOR CLAY CONTENT OF AGGREGATE

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Chapter I

INTRODUCTION

The presence of clays in the fine aggregate used to make concrete is known to be detrimental to the structural properties of the concrete. The Texas Highway Department presently makes use of the results of the Sand Equivalent and Loss by Decantation tests as a means of detecting such clay and controlling the quality of fine aggregate to be used in portland cement concrete. Article 421 of these specifications presently 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."

*This "affinity for water" will be referred to throughout this publication as the "activity" of the clay fraction.

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

Chapter II

OBJECTIVES

The broad objectives of this project as set forth in the proposal were as follows:

1. Determine the quantitative effects upon durability of known deleterious materials, individually and in known combinations, so that tolerable limits can be established for given service conditions.

2. Evaluate the dependability of existing short time quality control tests used for detecting deleterious materials and develop methods of test where no standard test is now available. The anticipated duration of this project was three years.

The specific objectives of the investigation reported in this publication were to:

1. Compare the results of the Sand Equivalent and Loss by Decantation tests.

2. Determine the effect of the liquid limit of the minus 200 mesh material found in concrete sand on the results of these two tests.

3. Determine the quantitative effects upon strength and shrinkage of known amounts of minus 200 mesh material.

4. Determine the quantitative effects upon strength and shrinkage of the liquid limit of the minus 200 mesh material.

5. Develop concrete strength and shrinkage data which will allow the establishment of realistic limits on the amount and activity of minus 200 mesh material in concrete aggregates.

6. Determine the types and properties of clays that occur naturally in concrete aggregates in Texas.

Chapter III

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 (AASHTO 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 F. N. Hveem while he was serving as Materials and Research Engineer, California Division of Highways.* It was to be used 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 sample be oven dried prior to testing and consequently results could be produced within 40 minutes.

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 four-inch mark with the calcium chloride solution. An oven dry sand sample is then poured into the cylinder. Air bubbles are removed and the sample is allowed to soak for 10 minutes. After the soaking period the cylinder is held horizontally and is shaken vigorously by alternately throwing the contents from end to end. The cylinder should complete 90 cycles in approximately 30 seconds with a nine-inch 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 minutes. The height of the sand and the height 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 weighing, the sample is agitated by rolling the pycnometer and then allowed to stand for a 15-second settling period. The water containing the fine material is decanted and the washing process is repeated until the water remains clear after a 15-second 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.

Y = Weight of the pycnometer filled with water at approximately the same temperature at which Z_1 and Z_2 were determined.

On examination of the Loss by Decantation and Sand Equivalent tests it is apparent 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 is needed to draw a correlation between the two tests, and the liquid limit of the clay size fraction was chosen to satisfy this need.

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 are presented in Table 3.

In order to investigate the effect of liquid limit on the results of the two tests, 10 samples were manufactured and tested. The sand used was a high quality concrete sand which was washed in the laboratory with a detergent to remove all minus 200 mesh material. The

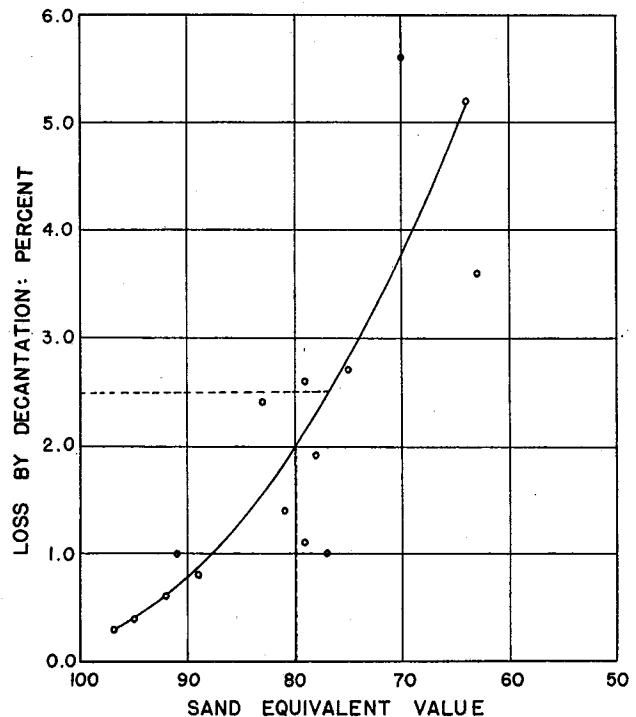


Figure 1. Relationship between Loss by Decantation and Sand Equivalent value for natural aggregate samples.

*Numerical superscripts refer to corresponding items in list of references.

Table 1
LIST OF AGGREGATE SAMPLES

Sample Number	T.H.D. District Number	Producer	Location of Pit
NATURALLY OCCURRING SAMPLES			
1	7	Cecil Montgomery, Aycock Pit	4.0 mi. W. of Ballinger on FM 2133
2	5	James Prentice, Clark Woods Pit	8.0 mi. SE of Slaton
3	22	D and D Gravel Co.	8.0 mi. S of Uvalde on Nueces R.
4	8	Atlas Sand and Gravel Co.	12.0 mi. NE of Abilene on FM 1082
5	4	Texas Sand and Gravel Co. Monaghan Plant	26.0 mi. NW of Amarillo on RM 1061
6	8	R. E. Jones Sand and Gravel Co.	12.0 mi. SE of Big Spring
7	22	H. B. Zachry	12.0 mi. NW of Del Rio on Devil's Ri.
8	9	Belton Sand and Gravel	Lampasas Pit
9	24	El Paso Sand Products	McCombs Pit No. 1 in El Paso
10	13	Gulf Materials Co.	5.0 mi. N of Victoria on US 87
11	1	OK Sand and Gravel Clarksville, Texas	10.8 mi. NE of Hugo, Okla. on SH 93
12	16	Fordyce Co., Hubert Pit	9.0 mi. S of Mathis on FM 666
13	11	Thorstenberg Materials Co.	Urbana, Texas
14	9	Heart of Texas Rock, Wortham Pit	Waco, Texas
15	24	El Paso Sand Products	McCombs Pit No. 1 in El Paso
16			This clay is from an alluvial deposit near College Station, Texas and was used as the contaminant in the concrete batches.
17	17	Gifford-Hill	Hearne, Texas
18	18	Boyd Ware, Fish Creek Pit	12.0 mi. NW of Gainesville, Texas
MANUFACTURED SAMPLES			
	Sample Number		
	101	Washed sand with 2½% silica flour	
	102	Washed sand with 2½% natural clay (LL = 34%)	
	103	Washed sand with 2½% silica-montmorillonite (LL = 200%)	
	104	Washed Sand with 2½% silica-montmorillonite (LL = 400%)	
	105	Washed sand with 2½% montmorillonite (LL = 640%)	
	106	Same as 101 through 105 but with 5% Contaminant	
	through 110		

contaminants used were: (1) pure silica flour with a liquid limit of zero, (2) a natural clay with a liquid limit of 34 percent, (3) a silica-montmorillonite mixture with a liquid limit of 200 percent, (4) a silica-montmorillonite mixture with a liquid limit of 400 percent, and (5) 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 speci-

fied amount of minus 200 mesh material, were then made for each of the 10 samples. A list of all samples is given in Table 1. After each test specimen was thoroughly mixed, water was added. The test specimen was mixed again and dried in an oven at 105°C. Sand Equivalent and Loss by Decantation tests were then run on these specimens. The results of these tests are presented in Figures 2 and 3 and in Table 3.

Test Results and Discussion

Figure 1 presents the data obtained from samples 1 through 15. Even though these points form a definite

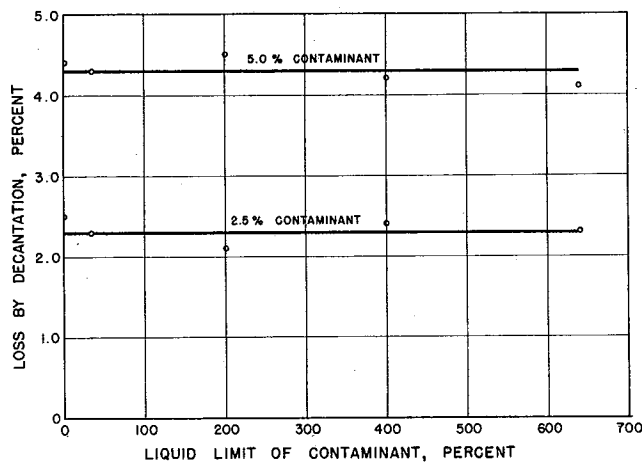


Figure 2. Relationship between Loss by Decantation and liquid limit of contaminant.

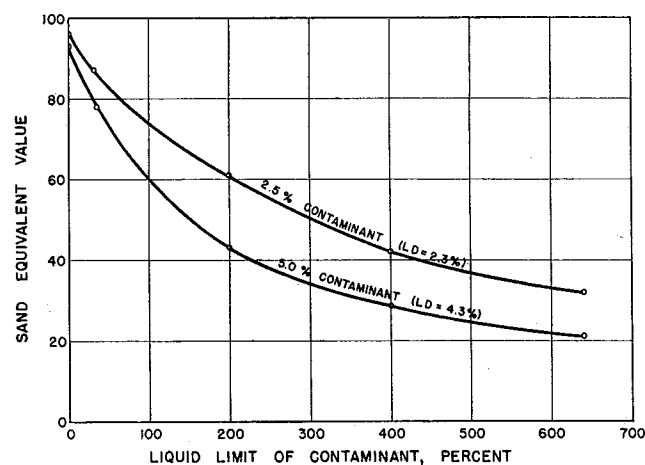


Figure 3. Relationship between Sand Equivalent value and liquid limit of contaminant.

Table 2
 VALUE OF C USED IN DETERMINING
 THE EQUATION: $C = F(LL)$

Sample Number	Measured Sand Equivalent 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

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 has been drawn through the data points and the allowable limit for acceptable fine aggregate (by Texas Highway Department specifications) is indicated in the figure. Note that 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 demonstrate the effect of the liquid limit of the contaminant for two different percentages of contaminants on the results of the two tests. The Sand Equivalent values of Figure 3 verify those reported by Clough and Martinez.¹ It can be seen that the variation in liquid limit of the contaminant has little or no effect on Loss by Decantation results, but has a very 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 of Figure 4 are used in the

Table 3
 MEASURED AND CALCULATED DATA FOR AGGREGATE SAMPLES

Sample Number	Loss by Decantation	Measured Sand Equivalent Value	Liquid Limit	Calculated Sand Equivalent 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	*	*
12	0.4	95	*	*
13	0.3	97	*	*
14	1.0	91	*	*
15	1.1	79	*	*
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

*There was not enough minus number 200 mesh material in this sample for a liquid limit determination.

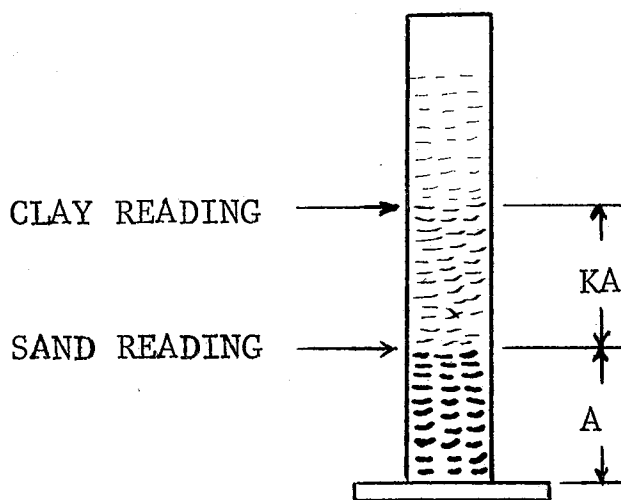


Figure 4. Illustration of clay and sand reading in Sand Equivalent test.

definition of the Sand Equivalent value, it can be written:

$$SE = 100A / (A + KA) \quad (1a)$$

$$\text{or } SE = 100 / (1 + K) \quad (1b)$$

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. Equation (1b) then becomes:

$$SE = 100 / (1 + CP) \quad (2)$$

This equation can be written

$$C = (100 - SE) / SE(P) \quad (3)$$

Values of C are plotted against values of the liquid limit (using the data from Table 2) in Figure 5. The data points in Figure 5 have been fitted with a curve by the least squares method using $C = A_1(LL) + A_2$ as a model. The resulting equation is

$$C = 0.1318(LL) + 1.79 \quad (4)$$

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

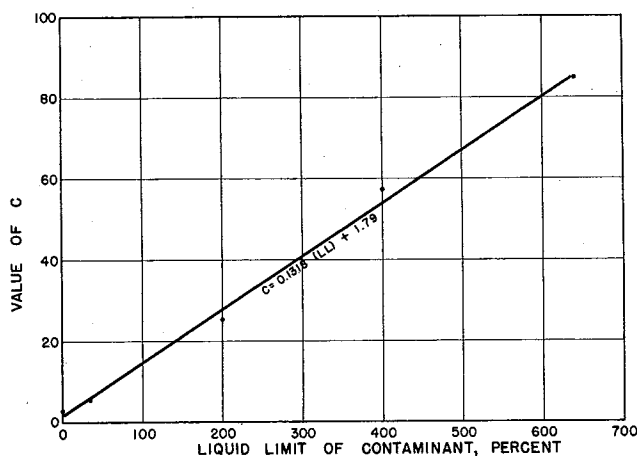


Figure 5. Relationship between value of C and the liquid limit of contaminant.

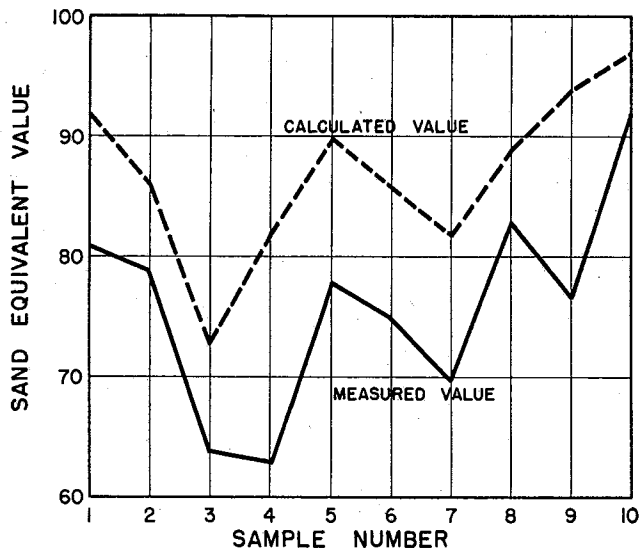
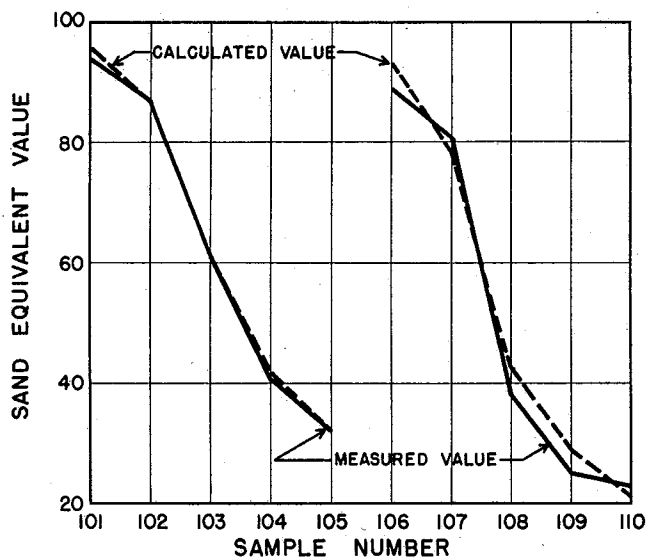


Figure 6. Correlation between calculated and measured Sand Equivalent value.

minus 200 mesh material. If these values are used in the equation,

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

the value of K_1 is found to be 92.

Equation (5) can now be written

$$P = LD/92.0 = 0.01087 LD. \quad (6)$$

The relationship between Sand Equivalent (SE) and Loss by Decantation (LD) can be found by substituting the expression for C from Equation (4) and the expression for P from Equation (5) into Equation (2). The resulting equation is

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

Sand Equivalent values have been calculated for samples 106 through 110 and 1 through 10 using this relationship ($K_1 = 92$) and are given in Table 3 and are plotted in Figure 6.

Figure 6 shows there is a good correlation between the test values and the calculated values of Sand Equivalent for samples 106 through 110, but that the calculated values are consistently higher than the test values for samples 1 through 10. 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. Thus, it is seen that Loss by Decantation is a highly inconsistent method of test for deleterious materials.

Chapter IV

STUDY OF EFFECTS OF CLAY IN AGGREGATE ON THE PROPERTIES OF CONCRETE

Testing Program

Concrete Batches

A total of 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 aggregate were washed with a detergent to remove all minus 200 mesh material. Loss by Decantation values for the washed aggregate were found to be zero. Physical properties of the aggregates are given in Table 6.

A series of eight concrete batches were 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 4. 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 were 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 de-

sired 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 4.

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 two-cubic-foot 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. Air content and unit weight were then determined.

Slump was determined in accordance with ASTM C143-39 and air content in accordance with ASTM C-231-56T except that vibration was used instead of the hand rodding procedure. The testing schedule for these concretes is presented in Table 7.

Shrinkage

Shrinkage specimens were 4 in. x 4 in. x 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

Table 4
CONCRETE MIX DATA
QUANTITIES PER CUBIC YARD OF CONCRETE

Designation	Contaminant		Type I Cement		Aggregate		Total Water lb.	Air Content %	Slump in.	Air Entraining Admix oz./cu.yd.	Initial Unit Wt. lb./cu.ft.
	Type	Amount (% total agg. by wt.)	Sacks	lb.	Coarse lb.	Fine lb.					
S-1*		0.00	5.02	472	1840	1301	247	6.1	3½	4.8	143.0
S-2	Natural Clay	0.74	5.07	477	1812	1289	287	5.0	3¼	8.7	144.3
S-3	Natural Clay	1.48	5.11	480	1957	1164	287	4.5	3	9.7	146.0
S-4	Natural Clay	2.36	5.26	495	1960	1077	300	4.1	3	10.0	145.0
S-5**	Silica Flour	1.42	5.07	477	1823	1358	282	3.0	2¾	3.8	147.5
S-6	Sil-Mont, LL=35	1.48	5.05	475	1814	1277	273	4.9	2¾	5.8	144.0
S-7	Sil-Mont, LL=200	1.50	4.97	467	1777	1222	352	2.9	3¼	8.5	142.9
S-8	Sil-Mont, LL=400	1.57	5.11	480	1842	1101	386	3.0	3	9.7	142.9
S-9	Mont, LL=640	1.60	4.95	465	1701	1114	406	3.3	3	8.3	138.8
L-1*		0.00	4.97	467	1672	1491	287	4.1	3	3.8	145.0
L-2	Natural Clay	0.74	5.00	470	1681	1377	271	6.0	3½	8.6	141.0
L-3	Natural Clay	1.49	5.11	480	1716	1382	289	3.0	3	6.3	145.0
L-4	Natural Clay	2.25	4.97	467	1672	1328	334	4.2	2¾	8.5	143.0
L-5	Limestone Flour	1.48	5.05	475	1698	1405	296	3.1	3	4.8	145.5

*Used as control batch for study of effects of percent contaminant.

**Used as control batch for study of effects of liquid limit of contaminant.

same size as those used in ASTM C157-60T, 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 in. x 4 in. cross section specimens. When changes in length were determined, the specimen was placed in the comparator and was allowed to rotate slowly. If any cyclic variation in the dial reading was noted as the specimen rotated, the lowest reading was recorded.

Strength

Modulus of rupture was determined using 3 in. x 4 in. x 16 in. prismatic specimens under a mid-point 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. These tests were performed by Dr. George Kunze of the Texas A&M University, Soil Physics Department.

Test Results and Discussion

Nondimensionalization 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 4 and absolute values of the various properties are presented in the tables of the appendix.

The effect of contaminant quantity on concrete strength is presented in Figures 7 through 14. A significant decrease in the modulus of rupture at 7 and 28 days is indicated as contaminant quantity increases. The same trend is evident in compressive strength, the strength reduction is less for the concrete containing crushed limestone.

Figures 15 and 16 show dynamic modulus of elasticity values plotted against percent contaminant. Con-

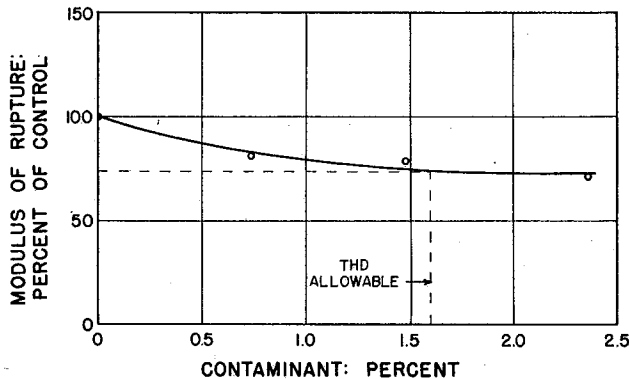


Figure 7. Relative 7-day modulus of rupture vs. percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

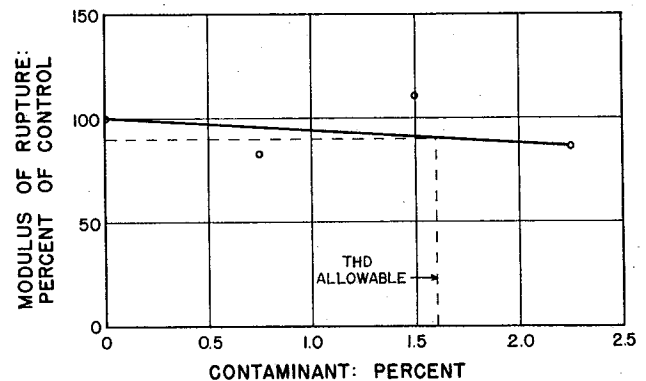


Figure 9. Relative 7-day modulus of rupture vs. percent contaminant (natural clay LL = 34) for crushed limestone aggregate concrete.

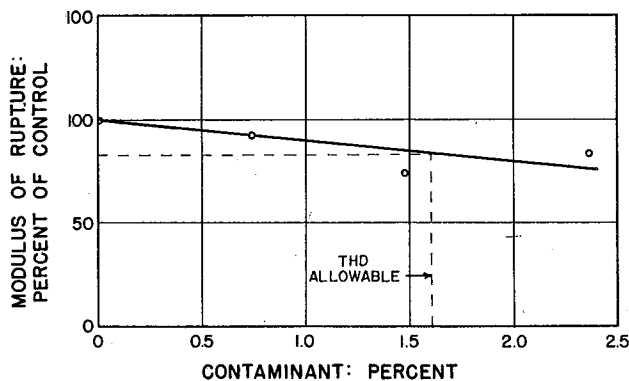


Figure 8. Relative 28-day modulus of rupture vs. percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

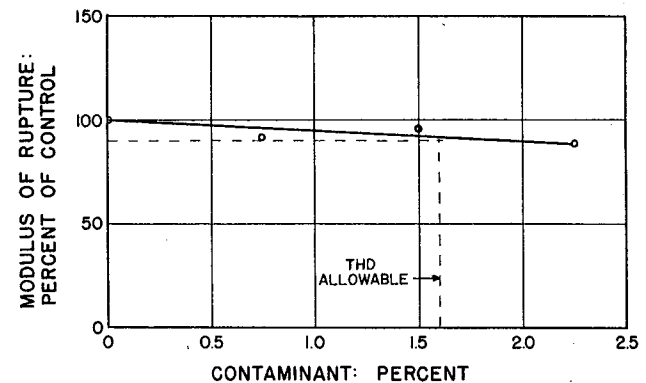


Figure 10. Relative 28-day modulus of rupture vs. percent contaminant (natural clay LL = 34) for crushed limestone aggregate concrete.

taminant quantity (within the range tested) has no apparent effect on the dynamic modulus of elasticity of siliceous aggregate concrete, while a slight reduction in this property is indicated in the case of limestone aggregate concrete.

The relative shrinkage for siliceous aggregate concrete at 28 days and one year is shown in Figure 17.

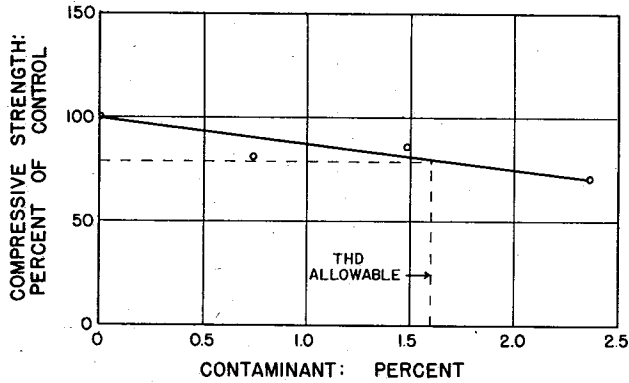


Figure 11. Relative 7-day compressive strength vs. percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

These data indicate that the presence of clay in the aggregate significantly increases shrinkage at early ages, but has only a slight effect on shrinkage at one year. The effect of contaminant quantity on shrinkage of concrete containing crushed limestone appears quite different, as shown in Figure 18. This difference might be attributed to the angularity and texture of the crushed limestone. The clay provides effective lubrication for

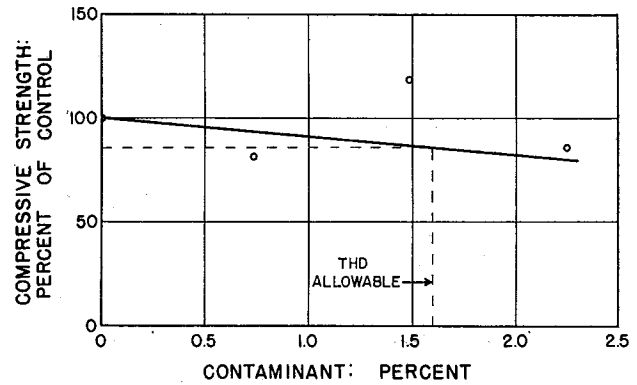


Figure 14. Relative 28-day compressive strength vs. percent contaminant (natural clay LL = 34) for crushed limestone aggregate concrete.

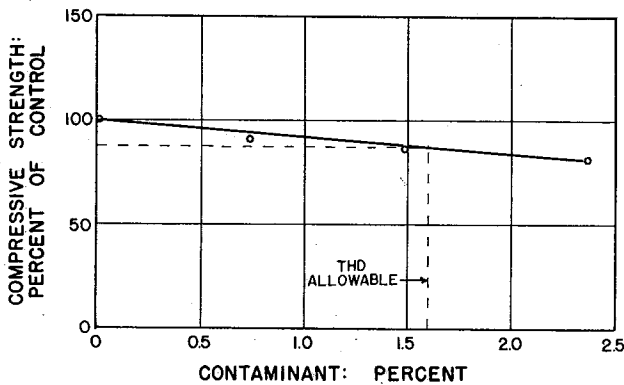


Figure 12. Relative 28-day compressive strength vs. percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

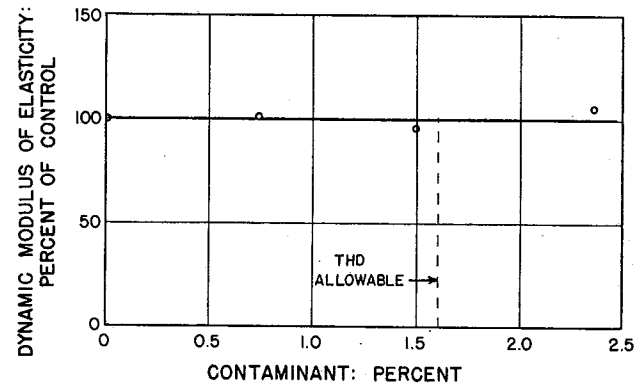


Figure 15. Relative 28-day dynamic modulus of elasticity vs. percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

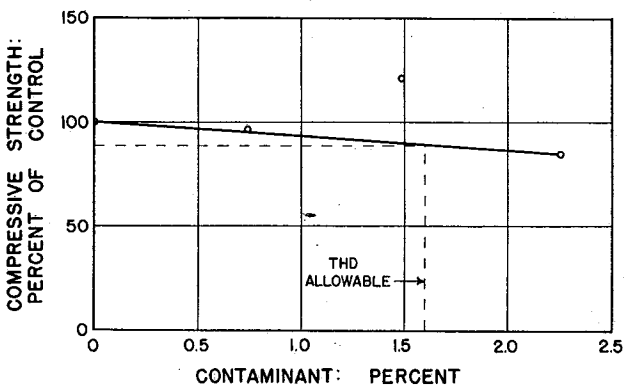


Figure 13. Relative 7-day compressive strength vs. percent contaminant (natural clay LL = 34) for crushed limestone aggregate concrete.

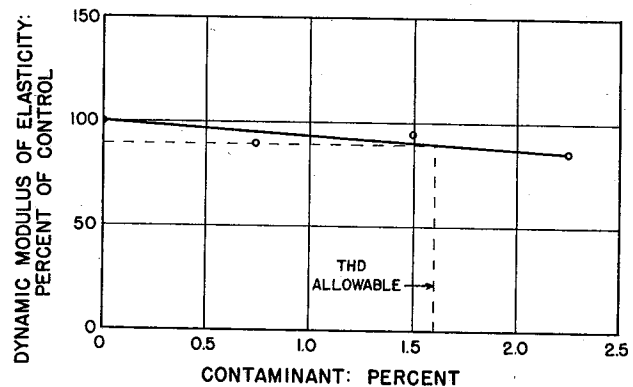


Figure 16. Relative 28-day dynamic modulus of elasticity vs. percent contaminant (natural clay LL = 34) for crushed limestone concrete.

the more angular and rough textured limestone aggregate. This decreases the amount of water required for a given slump and tends to cancel the increased water requirement inherent with the addition of clay. A point

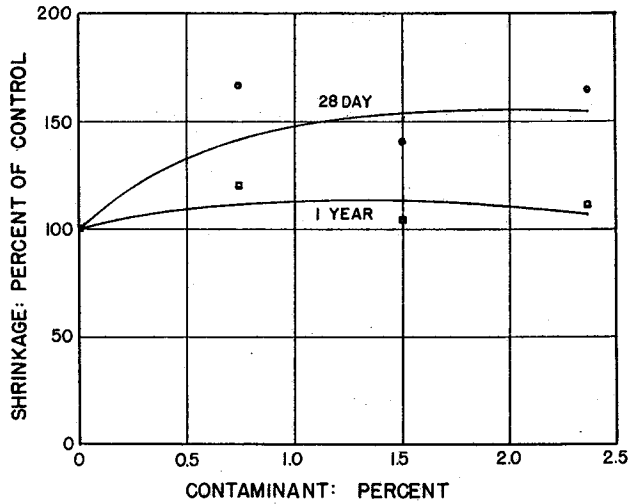


Figure 17. Relative shrinkage vs. percent contaminant (natural clay LL = 34) for siliceous aggregate concrete.

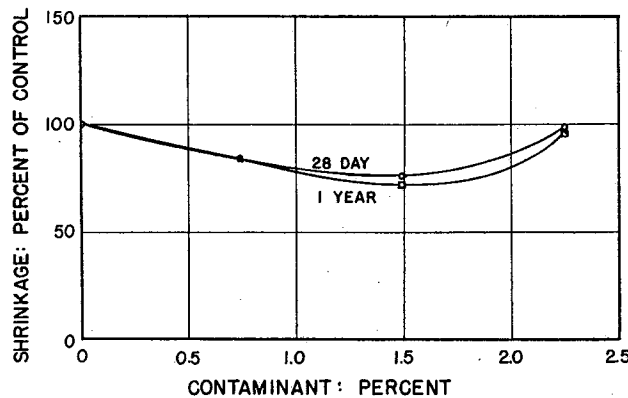


Figure 18. Relative shrinkage vs. percent contaminant (natural clay LL = 34) for crushed limestone aggregate concrete.

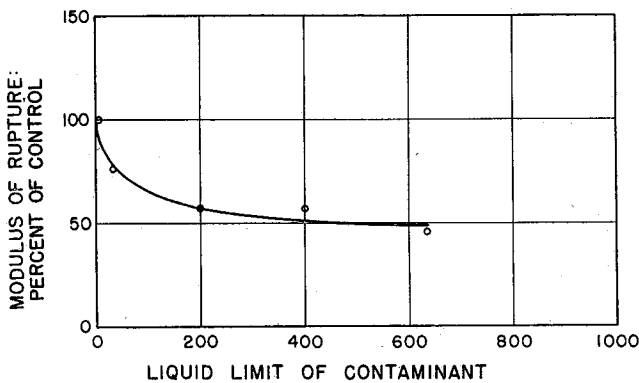


Figure 19. Relative 7-day modulus of rupture vs. liquid limit (nominally 1.6% clay) for siliceous aggregate concrete.

appears to be reached (at about 1.5 percent contaminant) where additional contaminant fails to provide additional lubrication and the water requirement and consequently shrinkage begins to increase.

The effect of contaminant liquid limit on various concrete properties is presented in Figures 19 through 24. A very pronounced decrease in both the modulus

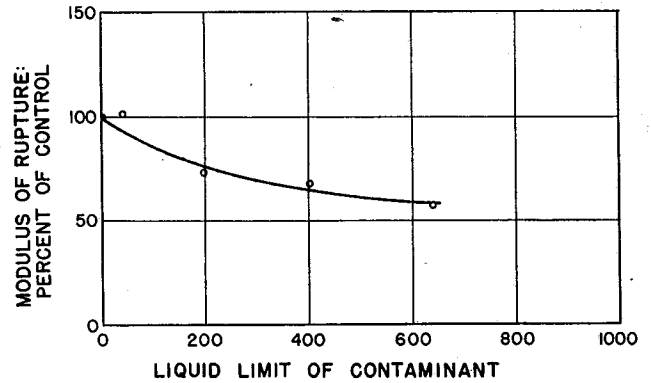


Figure 20. Relative 28-day modulus of rupture vs. liquid limit (nominally 1.6% clay) for siliceous aggregate concrete.

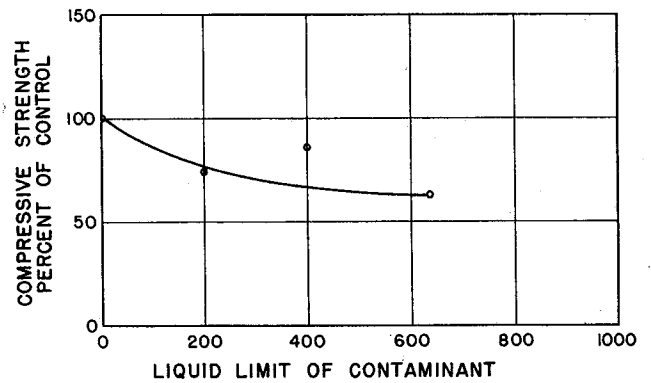


Figure 21. Relative 7-day compressive strength vs. liquid limit (nominally 1.6% clay) for siliceous aggregate concrete.

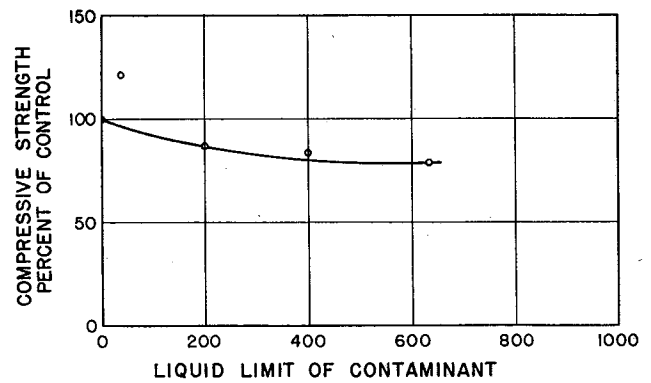


Figure 22. Relative 28-day compressive strength vs. liquid limit (nominally 1.6% clay) for siliceous aggregate concrete.

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 since the liquid limit of the clays that naturally occur in concrete aggregates in Texas are predominately within this range. Figure 23 indicates that the dynamic modulus of elasticity is also reduced as liquid limit increases.

Relative shrinkage at ages of 28 days and one year is shown in Figure 24. Here again, the influence of the contaminant liquid limit is quite pronounced.

The effect of contaminant quantity and liquid limit on the 7 day modulus of rupture and the 28 day compressive strength is presented in Figures 25 and 26. Since limited 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 the quantity present.

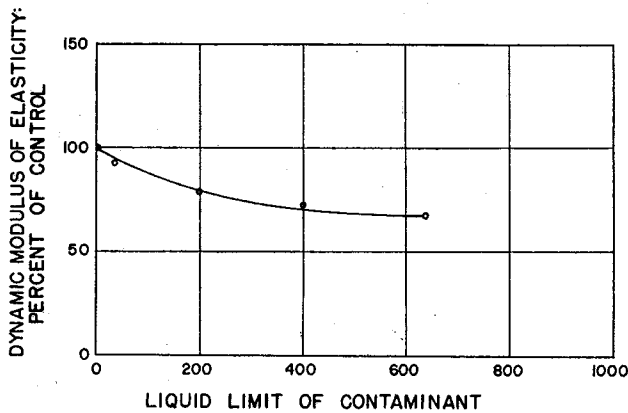


Figure 23. Relative 28-day dynamic modulus of elasticity vs. liquid limit of contaminant (nominally 1.6% clay) for siliceous aggregate concrete.

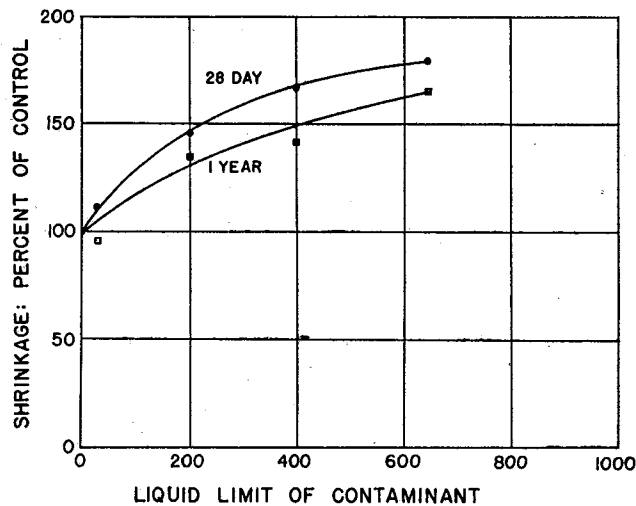


Figure 24. Relative shrinkage vs. liquid limit of contaminant (nominally 1.6% clay) for siliceous aggregate concrete.

Figure 27 is a typical x-ray pattern obtained from clays found in natural concrete sand. The vertical scale is simply denoted "intensity" since 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 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 the montmorillonite peak indicates a poorly crystalline structure and decayed or decaying micaceous material.

Data obtained from X-ray analysis and related test are presented in Table 5. The second column in this table gives the type of clay and the estimated amount in the sample. The amount of each clay mineral was esti-

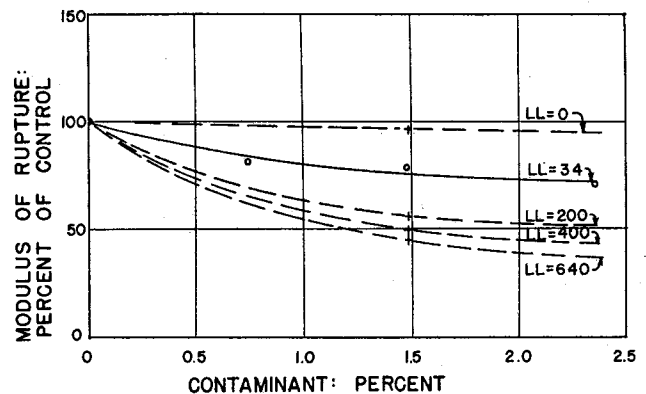


Figure 25. Relative 7-day modulus of rupture vs. percent contaminant for different liquid limits (siliceous aggregate concrete).

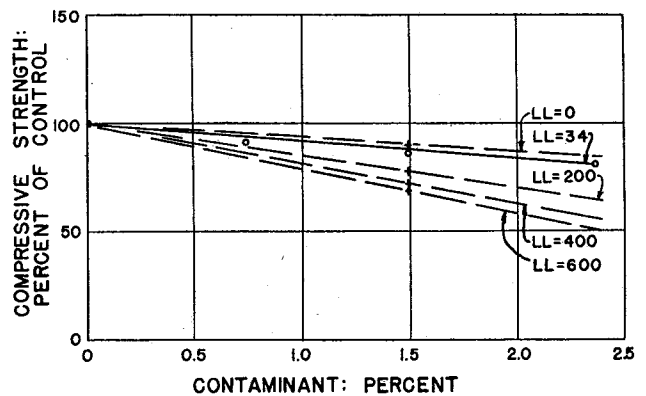


Figure 26. Relative 28-day compressive strength vs. percent contaminant for different liquid limits (siliceous aggregate concrete).

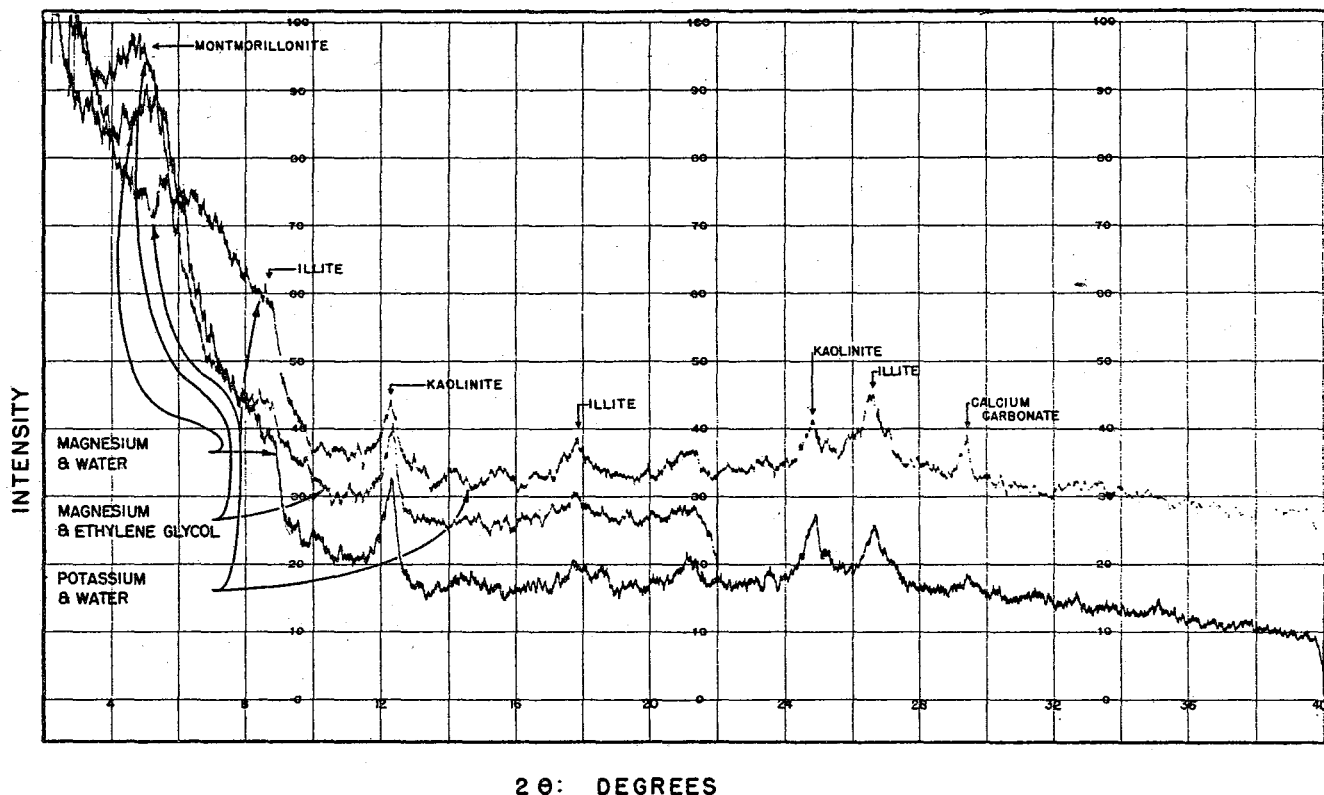


Figure 27. Typical X-ray diffraction pattern.

mated 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, since clay activity is dependent on the mineral composition.

Table 5
ANALYSIS OF CLAYS

Sample Number	Type of Clay and Estimated amount*	Cation Exchange capacity in milli-equivalents per 100 gm.	Exchangeable cations in milli-equivalents per 100 gms.			
			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

*Abbreviations used are M-Montmorillonite, I-Illite, K-Kaolinite, Q-Quartz, Fe-Feldspar, C-Calcium Carbonate. Numerical Code: 1-greater than 40 percent, 2-10 to 40 percent, 3-less than 10 percent. If several clay minerals have the same quantity code designation within a sample, they are arranged in order of descending magnitude.

Chapter V

CONCLUSIONS

1. The strength of concrete is reduced as the quantity of contaminant in the aggregate is increased (Figures 7 through 14).

2. The strength of concrete is decreased as the liquid limit of the contaminant increases (Figures 19 through 22).

3. Shrinkage of the siliceous aggregate concrete is increased as the contaminant quantity increases (Figure 17).

4. Shrinkage of the siliceous aggregate concrete is increased as the liquid limit of the contaminant increases (Figure 24).

5. The dynamic modulus of elasticity of the concrete containing siliceous aggregate is decreased as the liquid limit of the contaminant increases (Figure 23).

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 (Figures 15 and 16).

7. Present Texas Highway Department specifications for concrete aggregate will indirectly allow a 15

percent reduction in 28 day compressive strength (Figures 12 and 14), and a 25 percent reduction in 7 day modulus of rupture values (Figures 7 and 9).

8. Some aggregates will meet present Texas Highway Department specifications by the Loss by Decantation test while failing the requirements of the Sand Equivalent test (Figure 1).

9. A relationship exists between Loss by Decantation results, liquid limit of the minus 200 mesh fraction, and Sand Equivalent value (Page 10).

In this investigation it was observed that clay activity, as indicated by liquid limit, as well as the amount of the clay present in the aggregate influence resultant concrete strength. It was also found that the Sand Equivalent test is an indicator of a combination of activity and amount of contaminant, while the Loss by Decantation test indicates only the amount (Figures 2 and 3). For this reason:

10. 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.

Chapter VI

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1. Brindley, G. W., *X-ray Identification and Crystal Structure of Clay Minerals*, Mineralogical Society, London, 1951.

2. Clough, R. H. and Martinez, J. E., "Research on Bituminous Pavements Using the Sand Equivalent Test," Highway Research Board Bulletin 300, November, 1961.

3. Grim, Ralph E., *Clay Mineralogy*, McGraw-Hill Book Company, Inc., New York, 1953.

4. Hveem, F. N., "Sand-Equivalent Test for Control of Materials During Construction," Highway Research Board Proceedings, Volume 32, 1953.

5. O'Harra, W. G., "Evaluation of the California Sand-Equivalent Test," Highway Research Board Proceedings, Volume 34, 1955.

6. Tremper, Bailey and Haskell, W. E., "Findings," California Highways and Public works, Volume 23, Nos. 11-12, Nov.-Dec., 1955.

Chapter VII

APPENDIX

Table 6
PHYSICAL PROPERTIES OF AGGREGATES

	Siliceous Coarse Agg.	Siliceous Fine Agg.	Crushed Lime- stone Coarse Agg.
Unit weight in lb/cu. ft. (dry loose)	93.0	98.5	88.0
Specific Gravity (SSD)	2.61	2.62	2.64
Absorption (% of dry wt.)	1.24	0.81	1.44
Sieve Analysis			
Cumulative Percent Retained on			
$\frac{3}{4}$ in.	0.0	0.0	0.0
$\frac{1}{2}$ in.	35.0	35.0	35.0
$\frac{3}{8}$ in.	60.0	60.0	60.0
#4	100.0	0.24	100.0
#8		10.10	
#16		26.21	
#30		41.21	
#50		83.29	
#100		98.62	
#200		100.00	

Table 7
SPECIMEN TESTING SCHEDULE

Specimen Number	Specimen Dimensions	Curing	Test Type
1	3" x 4" x 16" prism	3 days moist	These specimens were subjected to ASTM freeze-thaw test C310-57T with dynamic modulus and weight determinations made periodically.
2	" " "	"	
3	" " "	"	
4	4" x 4" x 11" prism	3 days moist	These specimens were stored under atmospheric conditions of 52% R.H. and 72°F. Shrinkage measured periodically.
5	" " "	"	
6	" " "	"	
7	3" x 4" x 16" prism	7 days moist	Weight, dynamic modulus, flexural and compressive strengths determined at 7 days of age.
8	" " "	"	
9	" " "	"	
10	3" x 4" x 16" 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	" " "	"	
12	" " "	"	
13	3" x 4" x 16" prism	3 days moist	Specimens cycled between atmospheric conditions at 17% R.H., 120°F and 100% R.H., 72°F. Weight and dynamic modulus determinations were made periodically.
14	" " "	"	
15	4" x 4" x 11" prism	3 days moist	Specimen subjected to same atmospheric conditions as specimens 13 and 14. Shrinkage measured periodically.

Table 8
PHYSICAL PROPERTIES OF CONCRETE*

Batch Design	Dynamic Modulus of Elasticity 10 ⁻⁶ lb/sq. in.		Modulus of Rupture lb/sq. in. Center Point Loading 3" x 4" x 16" specimens		Compressive Strength lb/sq. in. ASTM C116-49 Modified Cube	
	7-day	28-day	7-day	28-day	7-day	28-day
	S-1	5.86	6.25	810	780	3300
S-2	5.61	6.31	660	720	2690	3370
S-3	5.79	5.99	640	580	2850	3220
S-4	5.26	6.64	580	650	2390	3000
S-5	6.40	6.46	880	770	2890	2920
S-6	5.48	6.00	650	790	2750	3530
S-7	4.81	5.16	510	560	2160	2520
S-8	4.58	4.72	500	520	2370	2430
S-9	3.96	4.33	410	450	1840	2290
L-1	5.76	6.22	700	830	2900	3210
L-2	5.44	5.64	580	760	2790	2640
L-3	5.35	5.95	770	790	3570	3810
L-4	5.14	5.38	600	730	2450	2750
L-5	5.52	5.84	830	810	3120	3890

*All specimens were moist cured until time of testing.

Table 9
NOTATION

SE—The Sand Equivalent value.
 LD—The Loss by Decantation given as a percentage.
 P—The decimal fraction of the minus 200 mesh material in a sample of sand.
 A—The sand reading in inches in the Sand Equivalent test.
 K—The ratio of the clay reading minus the sand reading and the sand reading in the Sand Equivalent test.

$$C = \frac{K}{P}$$
 LL—The liquid limit of the minus 200 mesh fraction.
 K_a—Adherence Factor, the ratio in percent between the fraction decanted in the Loss by Decantation test and the fraction of minus 200 mesh material actually present in an aggregate.

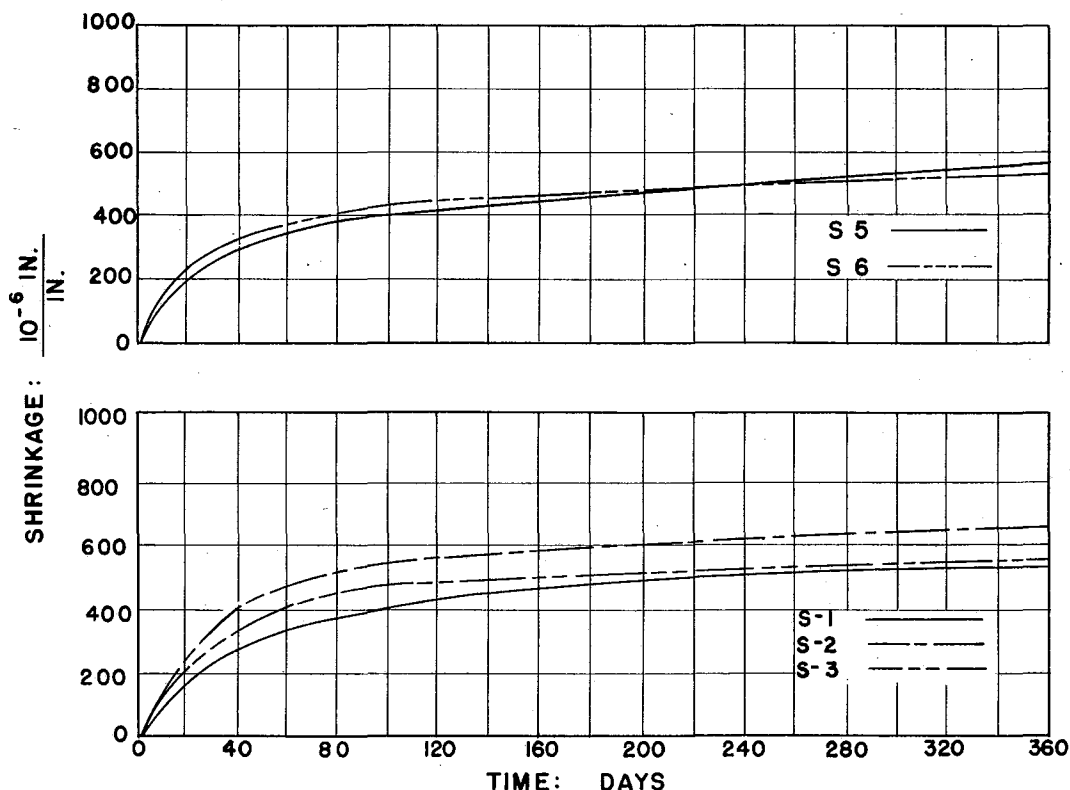


Figure 28. Absolute Shrinkage Curves for Batches S-1, S-2, S-3, S-5, and S-6.

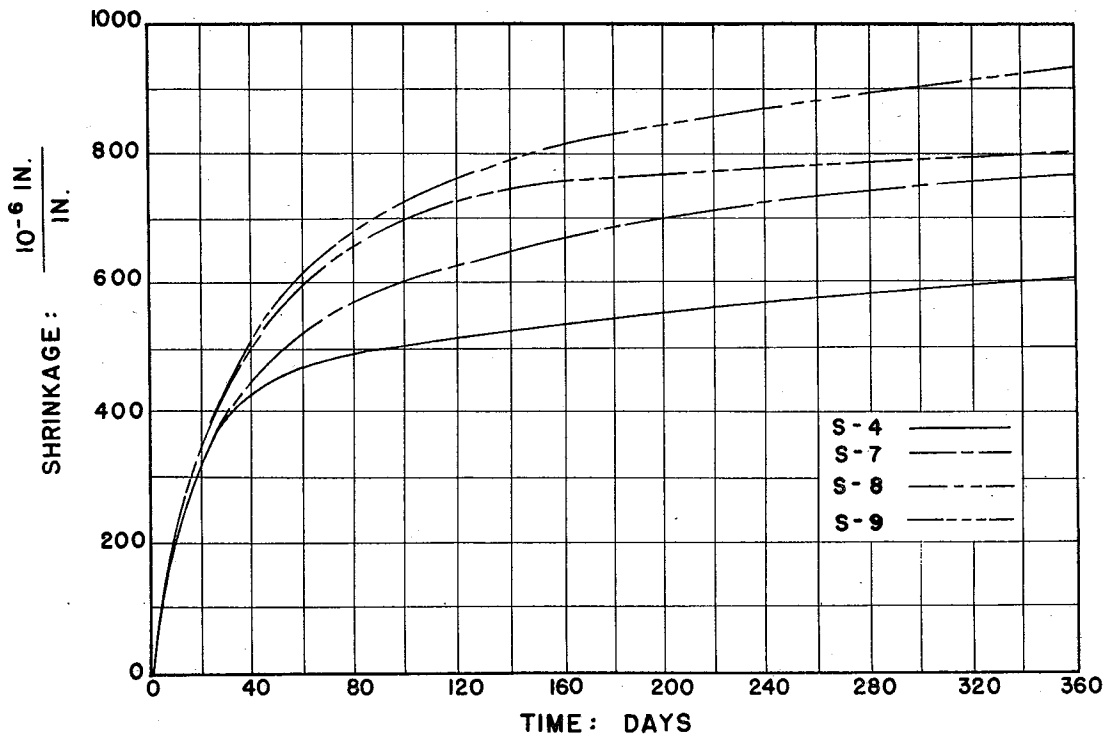


Figure 29. Absolute shrinkage curves for Batches S-4, S-7, S-8 and S-9.

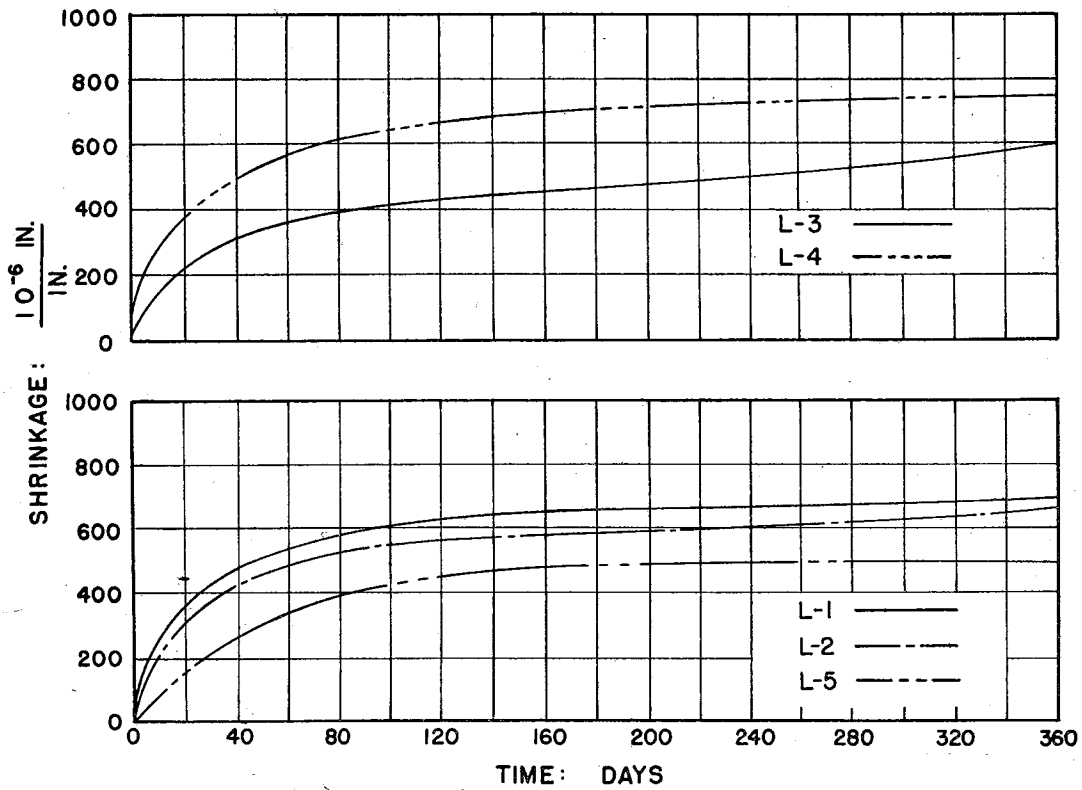


Figure 30. Absolute shrinkage curves for Batches L-1 through L-5.