Research Report
UKTRP-83-7

ENGINEERING PROPERTIES OF TWO SPENT SHALES AND MINUS 1/4-INCH RAW SHALE FOR THE MEANS PROJECT

by

Vincent P. Drnevich
Chairman, Department of Civil Engineering

and

David L. Allen
Chief Research Engineer
Kentucky Transportation Research Program

and

Tommy C. Hopkins
Chief Research Engineer
Kentucky Transportation Research Program

College of Engineering
University of Kentucky
Lexington, Kentucky

February 1983

INTRODUCTION

A geotechnical investigation was performed to determine the physical properties (classification) and engineering properties of the Sunbury oil shale from a proposed oil shale mining site in Montgomery County (Means Project). Three materials were recieved in sealed metal drums and were labeled Raw Oil Shale (only material less than 0.25 inch), Sunbury, spent shale, and Sunbury shale (2.5-inch to 1/4-inch). The material labeled Sunbury, spent shale, ~~(hereafter referred to as Spent Shale No. 1), had very little fines and the particles were angular in shape.~~ The Sunbury ,spent shale, 2.5-inch to 0.25 inch, (hereafter referred to as Spent Shale No. 2), was subangular or rounded in shape. The various types of geotechnical laboratory tests performed on these materials are listed in Table 1.

PHYSICAL PROPERTIES

The "as delivered " moisture content of the raw shale was 2.85 percent. Liquid and plastic limit tests were performed on the raw shale according to ASTM D 423-66 and ASTM D 424-59. The material had a liquid limit of 26.8 and a plastic index of 5.3. The specific gravity of the raw material was 2.39 as determined according to ASTM D 854-58. Particle-size analyses for all three materials were determined according to ASTM D 422-63. Particle-size distributions are shown in Figures 1 and 2.

ENGINEERING PROPERTIES

A standard compaction test was performed on the raw shale according to ASTM D 698-70, Method A (compactive effort= 12,730 ft.-lb./ft3). The results are shown in Figure 3.

To determine the effective stress parameters that are used to evaluate the stability of compacted embankments, three istropically consolidated-drained triaxial tests were performed on each of the three materials. The triaxial specimens for the raw shale were compacted at optimum moisture content. For the two spent shale materials, the triaxial specimens were compacted at a moisture content of 11.3 percent and a dry density of 86.4 pounds per cubic foot. This was from previous data reported by Drnevich et al (1) on the spent shale. The specimens were four inches in diameter and eight inches in height. These dimensions limited the largest particle size to 3/4-inch. For spent shale No. 1 (angular shape) all particles larger than 3/4-inch size were crushed for the triaxial test. However, for spent shale No. 2 (rounded particles) it was decided not to crush the particles larger than 3/4-inch size for fear of changing the response of the material due to mixing the angular, crushed particles, with the rounded particles. Therefore, all of the material of spent shale No. 2 that was larger than 3/4-inch size was simply scalped. Filter paper strips were mounted along side of each specimen to permit faster drainage of the pore fluid, thus preventing a build-up of pore pressures during shear.

When performing a consolidated-drained triaxial test, it is essential that accurate readings of the volume change of the specimen be obtained during the test. If the specimen is not saturated or if air bubbles are present in the drainage lines, improper volume change readings will occur. To facilitate saturation, the specimen and drainage lines were evacuated of air by vaccuuming and then allowing water, under back pressure, to fill the voids. After saturation, the specimen was allowed to consolidate to the desired effective stress for a minimum of 24 hours.

During the test, a pore pressure transducer was connected to the top drainage line. This was monitored to determine if positive pore pressures were building up in the specimen. If positive pore pressures began to build up, then the strain rate was reduced to allow the pressures to dissipate. The bottom drainage line was connected to a burette from which the volume change was monitored throughout the test. A summary of the triaxial testing conditions is given in Table 2.

The results of the triaxial tests are illustrated in figures 4 through 6. The failure envelopes for all the materials curved downward, possibly due to particle crushing at higher confining pressures. This is similar to data reported by Marsal(2). For the test data associated with these two materials equivelent sets of cohesion, $\tilde{c}_e$, and friction angle, $\tilde{\phi}_e$, were determined by fitting the curved Kf

-lines in Figures 4 through 6 with a hyperbolic function of the following form:

$$q_f = \bar{p}/(b\bar{p}_f + c)$$

where q_f = maximum deviator stress at failure

$\bar{p}_f$ = maximum effective normal stress at failure and

b, c = constants.

The tangent to the curve at any point is obtained from the first derivative,

$$dq_f / d\bar{p}_f = (c)/(b^2 \bar{p}_f^{\,2} + 2bc\bar{p}_f + c^2) = \tan\alpha$$

The arcsin of the above equation gives $\bar{\phi}_e$. Table 3 lists these values of $\bar{\phi}_e$ for various effective pressures of embankments for these materials. The equivalent effective cohesion value, $\bar{c}_e$, for any particular $\bar{p}$ and its associated $\bar{\phi}_e$, is defined from the following equation:

$$c_e = ((\bar{p}_f / (b\bar{p}_f + c)) - \tan\alpha\, \bar{p}_f)/\cos\bar{\phi}_e .$$

The last column of Table 3 lists values of $\bar{c}_e$. Values of $\bar{\phi}_e$ and $\bar{c}_e$ in Table 3 are equivalent because they provide equivalent values of $\bar{\phi}$ and $\bar{c}$ for a given $\bar{p}_f$ to simulate the curved failure envelope. They are not true values of friction and cohesion.

One-dimensional compression tests were performed on the materials. The test consisted of two different phases. The first phase of testing was designed to determine how the material in a dry state would perform under one-dimensional loading. The purpose of the second phase was to evaluate creep characteristics of the oil shales when inundated with water.

The procedure for the first phase consisted of compacting the shales to dry density at natural moisture content in a 6-inch diameter mold to a height of 2.625 inches. These dimensions were used to mimimize the effects of frictional forces acting on the sides of the molds during loading. The specimens were loaded and deformations were recorded in a manner similar to the consolidation tests. Loads of 1, 2, 3, 4, 8, and 16 tons per square foot were used. For each load when the sample deformed less than .0025 inch in two minutes, the next load was applied.

The strain for each load was calculated by dividing the deformation occuring under each load by the original height of the specimen. the stress-strain curves for the three materials are given in Figure 7.

Creep characteristics of the shales were studied by reloading the previously loaded specimen to 4 tons per square foot. The specimen was allowed to compress for approximately fifteen minutes or until all deformation had stopped. The mold and specimen were inundated in water while the stress level remained constant at 4 tons per square foot. The time required to submerge the specimen was less than five seconds. Upon inundation, a timer was immediately started and deformations and elapsed times were recorded. Strains were calulated by dividing deformations associated with time after inundation by the original specimen height before loading. The strains after inundation were plotted as a function of time as shown in Figure 8. This figure indicates that the raw shale was most susceptable to inundation.

Subsequent to the report on the overburden materials, slake-durability tests were performed on them as well as the two spent shales reported herein. The raw shale was not tested because the particles were too small. The procedure used is the same as that reported by Franklin and Chandra(3). The slake-durability-index is defined as the ratio of the oven-dried weight of the material left after two ten-minute test cycles (with the material oven-dried between cycles) to the initial oven-dried weight, multiplied by 100. The results are shown in Table 4. The two spent shales would classify as durable rock (slake-durability-index, SDI, greater than 95), however, the indices of the three overburden materials were less than 95.

REFERENCES

1. Drnevich,V.P.;Hopkins,T.C.;Allen,D.L.;and Hale,S.S.; Engineering Properties of Kentucky Oil Shales;Procedings, 1981 Eastren Oil Shale Symposium; Lexington, Kentucky.

2. Hirschfeld,R.C.;and Poulos,S.J.; Embankment-Dam Engineering (Mechanical Properties of Rockfill by Raul J. Marsal), Casagranda Volume, John Wiley and Sons,Inc., New York.

3. Franklin,J.A.;and Chandra,R.; The Slake-Durability Test, International Journal of Rock Mechanics, Vol. 9, Perganon Press, Great Britian, pp 325-341, 1972.

TABLE 1. SUMMARY OF TESTING PROGRAM*

MATERIAL NAME	NATURAL MOISTURE	SPECIFIC GRAVITY	LIQUID LIMIT	PLASTIC LIMIT	GRAIN SIZE	MOISTURE DENSITY	SLAKE DURABILITY	TRIAXIAL TESTS 20 psi	40 psi	80 psi
NANCY							X			
HENLEY							X			
CLAY CITY							X			
SUNBURY (raw)	X	X	X	X	X	X		X	X	X
SUNBURY (spent)					X		X	X	X	X
SUNBURY (spent) (2.5x1/4)					X		X	X	X	X* *70psi

* X INDICATES TEST WAS PERFORMED

TABLE 2. SUMMARY OF TRIAXIAL TEST CONDITIONS.

MATERIAL NAME	EFFECTIVE CONFINING PRESSURE (psi)	'B' PORE PRESSURE PARAMETER	AVERAGE STRAIN RATE (in./min.)
SUNBURY (raw)	20	1.00	0.00113
	40	1.00	0.00085
	80	0.84	0.00102
SUNBURY SPENT(No.1) (crushed)	20	0.98	0.00316
	40	1.00	0.00288
	80	0.82	0.00253
SUNBURY SPENT(No.2) (2.5x1/4)	20	0.95	0.00291
	40	1.00	0.00253
	70	0.82	0.00233

Table 3. VALUES OF $\bar{\bar{\phi}}$, $\bar{\bar{\phi}}_e$, $\bar{\bar{c}}$, & $\bar{\bar{c}}_e$ FOR VARIOUS PRESSURES.

RAW SHALE

$\bar{\bar{p}}_f$ (psi)	q_f (psi)	SIN $\bar{\bar{\phi}}$	$\bar{\bar{\phi}}$ (degrees)	$\bar{\bar{c}}$ (psi)
10	7.315	.719	46.0	0.180
20	14.347	.692	43.8	0.702
30	21.112	.666	41.8	1.519
40	27.624	.666	41.8	2.586
50	33.898	.641	39.9	3.815
60	39.947	.596	36.6	5.215
70	45.782	.575	35.1	6.762
80	51.414	.555	33.7	8.431
90	56.854	.537	32.5	10.107
100	62.112	.519	31.3	11.951
110	67.196	.502	30.1	13.843
120	72.115	.486	29.1	15.788

SUNBURY SPENT (No.1)-CRUSHED

$\bar{\bar{p}}_f$ (psi)	q_f (psi)	SIN $\bar{\bar{\phi}}$	$\bar{\bar{\phi}}_e$ [1] (degrees)	$\bar{\bar{c}}_e$ (psi)
10	7.645	.736	45.4	0.421
20	14.749	.685	43.2	1.439
30	21.368	.639	39.7	2.857
40	27.548	.598	36.7	4.525
50	33.333	.561	34.1	6.380
60	43.860	.527	29.7	10.522
70	48.662	.496	27.8	12.777
80	48.662	.467	27.8	12.777
90	53.192	.441	26.2	15.048
100	57.471	.417	24.7	17.359
110	61.521	.395	23.3	19.676
120	65.360	.375	22.0	21.959

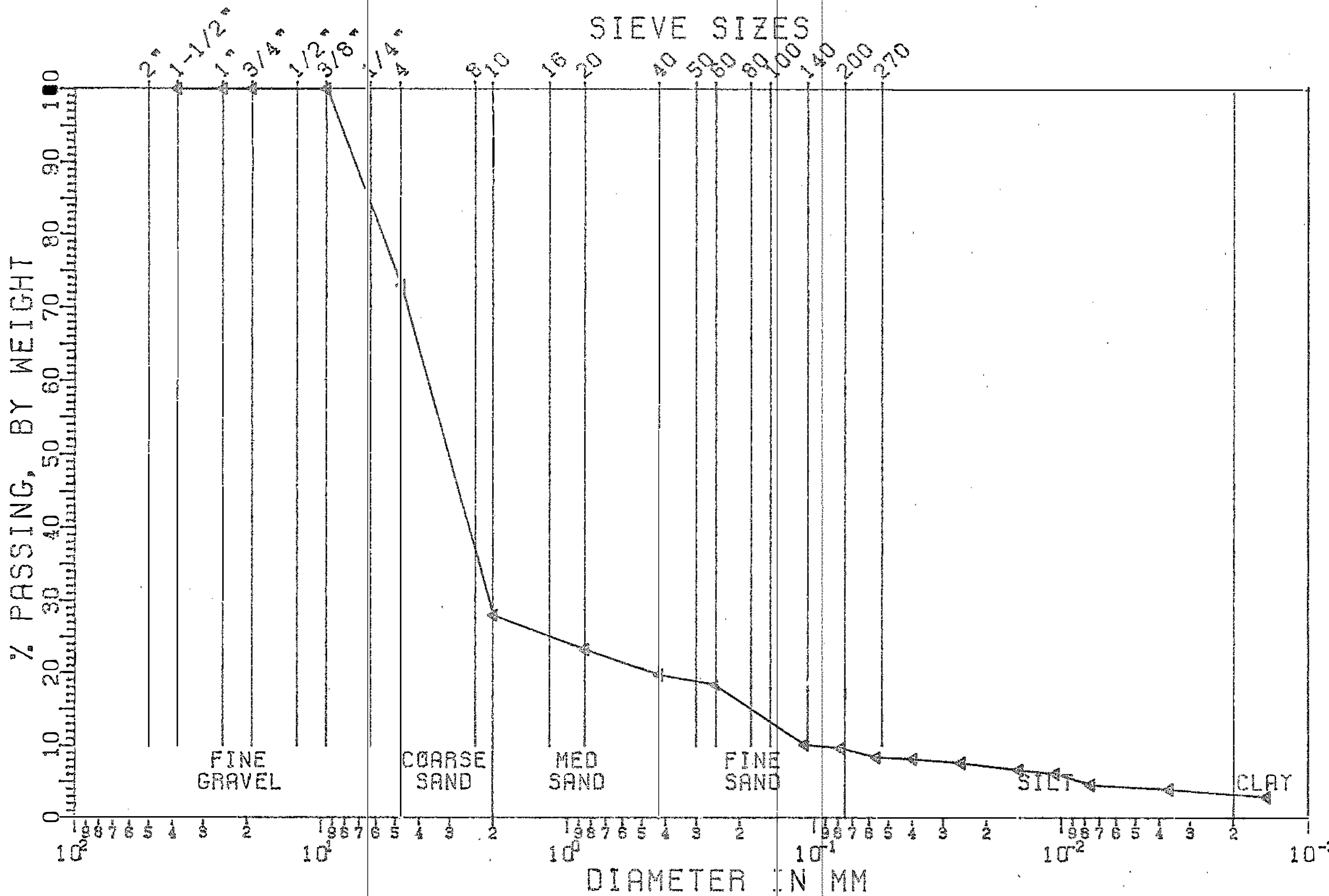
SUNBURY SPENT (No.2)-NOT CRUSHED

$\bar{\bar{p}}_f$ (psi)	q_f (psi)	SIN $\bar{\bar{\phi}}$	$\bar{\bar{\phi}}_e$ [1] (degrees)	$\bar{\bar{c}}_e$ (psi)
10	7.645	.736	45.4	0.421
20	14.749	.685	43.2	1.439
30	21.368	.639	39.7	2.857
40	27.548	.598	36.7	4.525
50	33.333	.561	34.1	6.380
60	43.860	.527	29.7	10.522
70	48.662	.496	27.8	12.777
80	48.662	.467	27.8	12.777
90	53.192	.441	26.2	15.048
100	57.471	.417	24.7	17.359
110	61.521	.395	23.3	19.676
120	65.360	.375	22.0	21.959

1. Equivalent values to approximate curved failure envelopes.

TABLE 4. SLAKE-DURABILITY INDEX

MATERIAL	SLAKE-DURABILITY-INDEX
NANCY	45.2
HENLEY	79.1
CLAY CITY	85.8
SUNBURY-SPENT-CRUSHED-(No.1)	99.8
SUNBURY-SPENT-NOT CRUSHED-(No.2)	98.8



SUNBURY (RAW)

FIGURE 1.

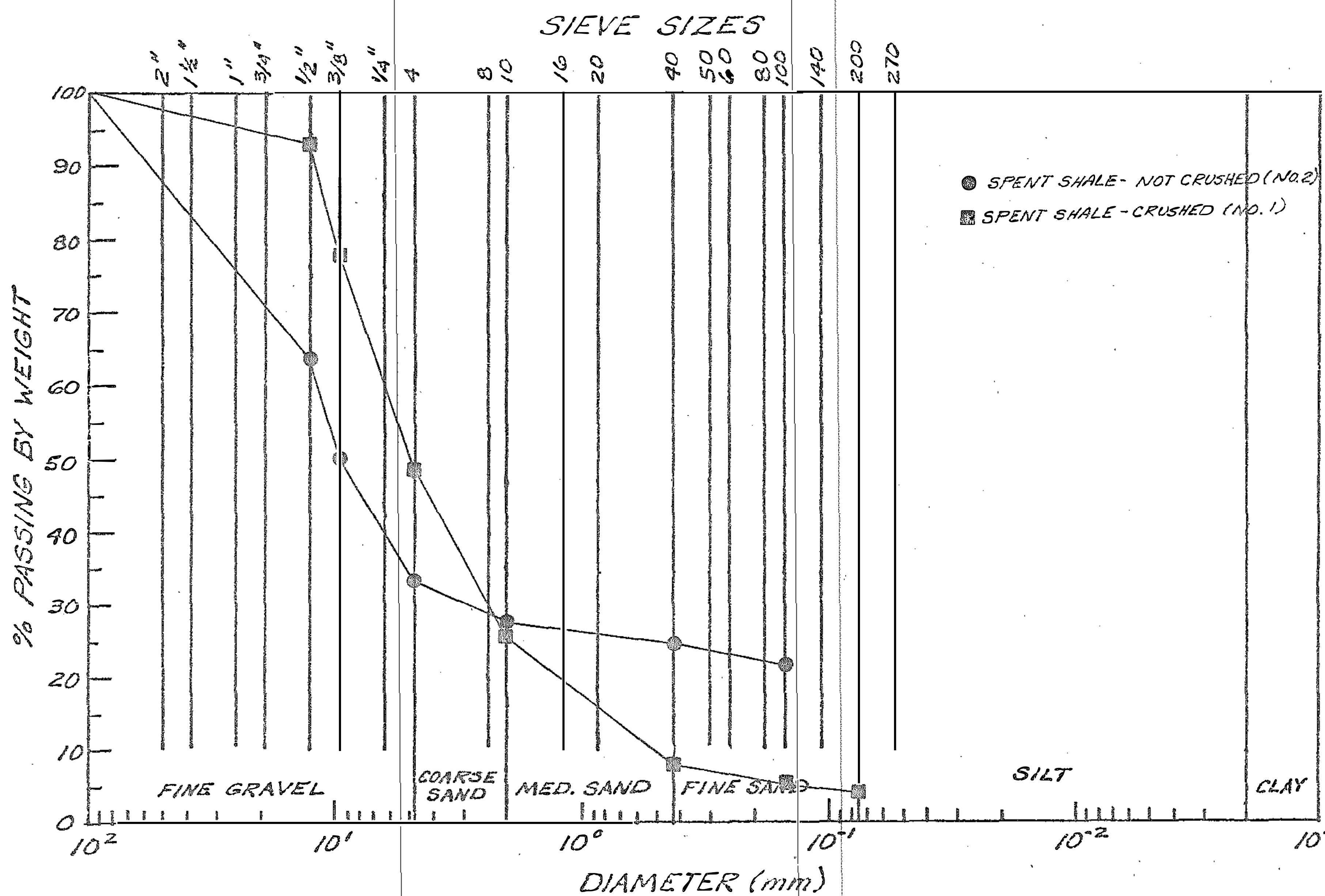


FIGURE 2. GRAIN-SIZE DISTRIBUTIONS.

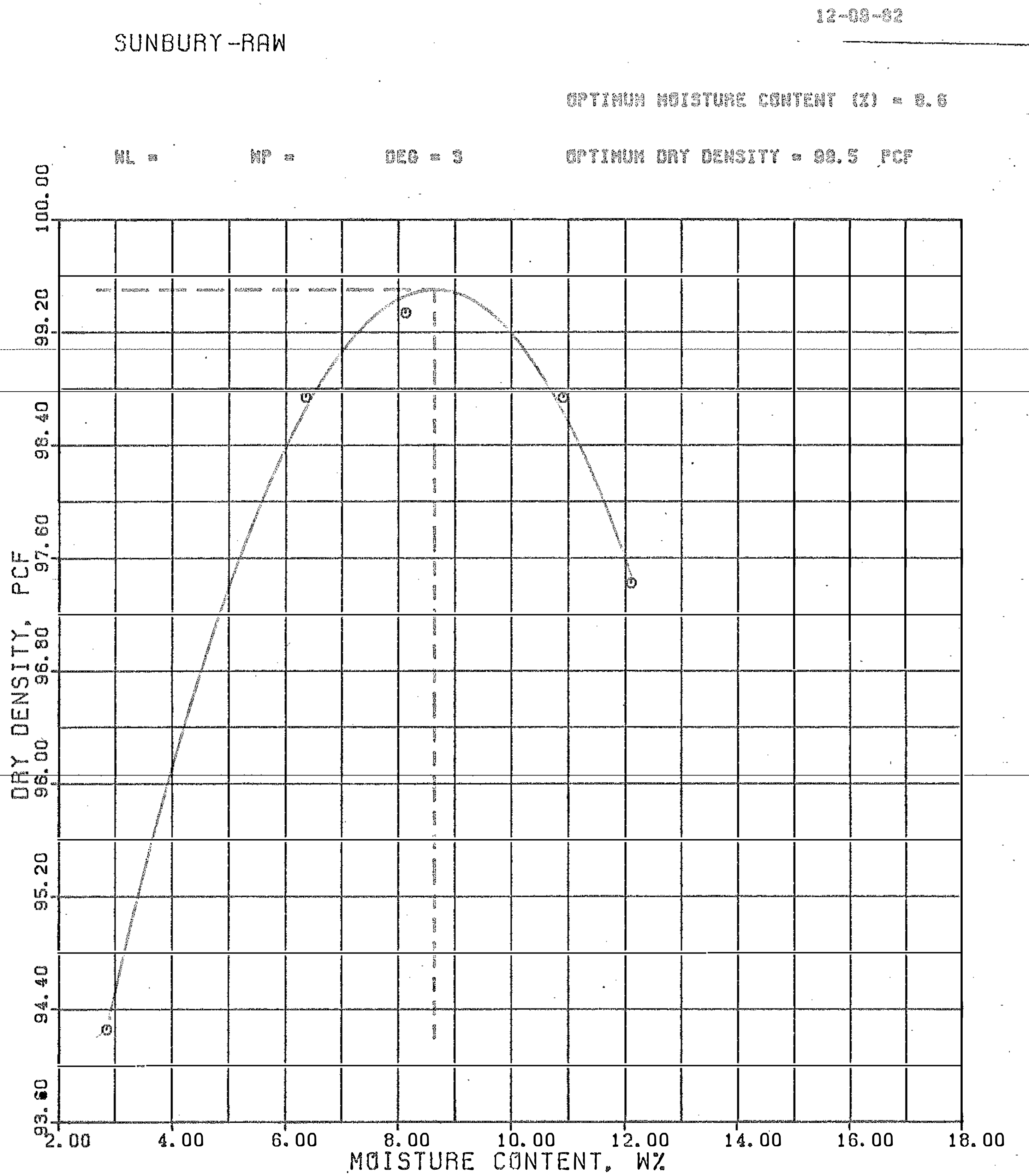
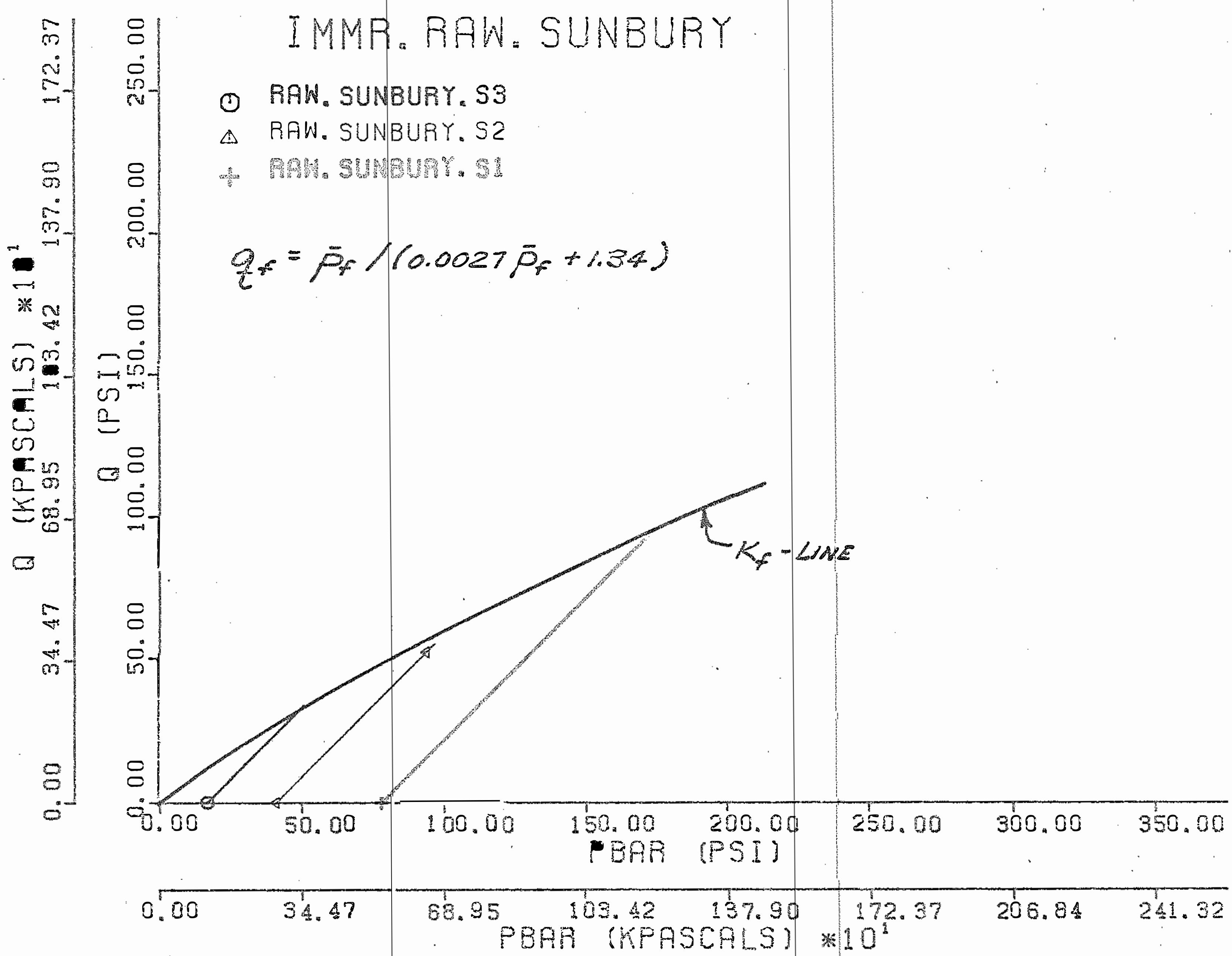

12-09-82
SUNBURY-RAW
OPTIMUM MOISTURE CONTENT (%) = 8.6
WL =
WP =
DEG = 3
OPTIMUM DRY DENSITY = 99.5 PCF
DRY DENSITY, PCF
100.00
99.20
98.40
97.60
96.80
96.00
95.20
94.40
93.60
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
MOISTURE CONTENT, W%

FIGURE 3.



IMMR. RAW. SUNBURY
RAW. SUNBURY. S3
RAW. SUNBURY. S2
RAW. SUNBURY. S1
$q_f = \bar{P}_f / (0.0027 \bar{P}_f + 1.34)$
K_f - LINE
Q (PSI)
Q (KPASCALS) *10[1]
PBAR (PSI)
PBAR (KPASCALS) *10[1]
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
34.47
68.95
103.42
137.90
172.37
206.84
241.32

FIGURE 4.

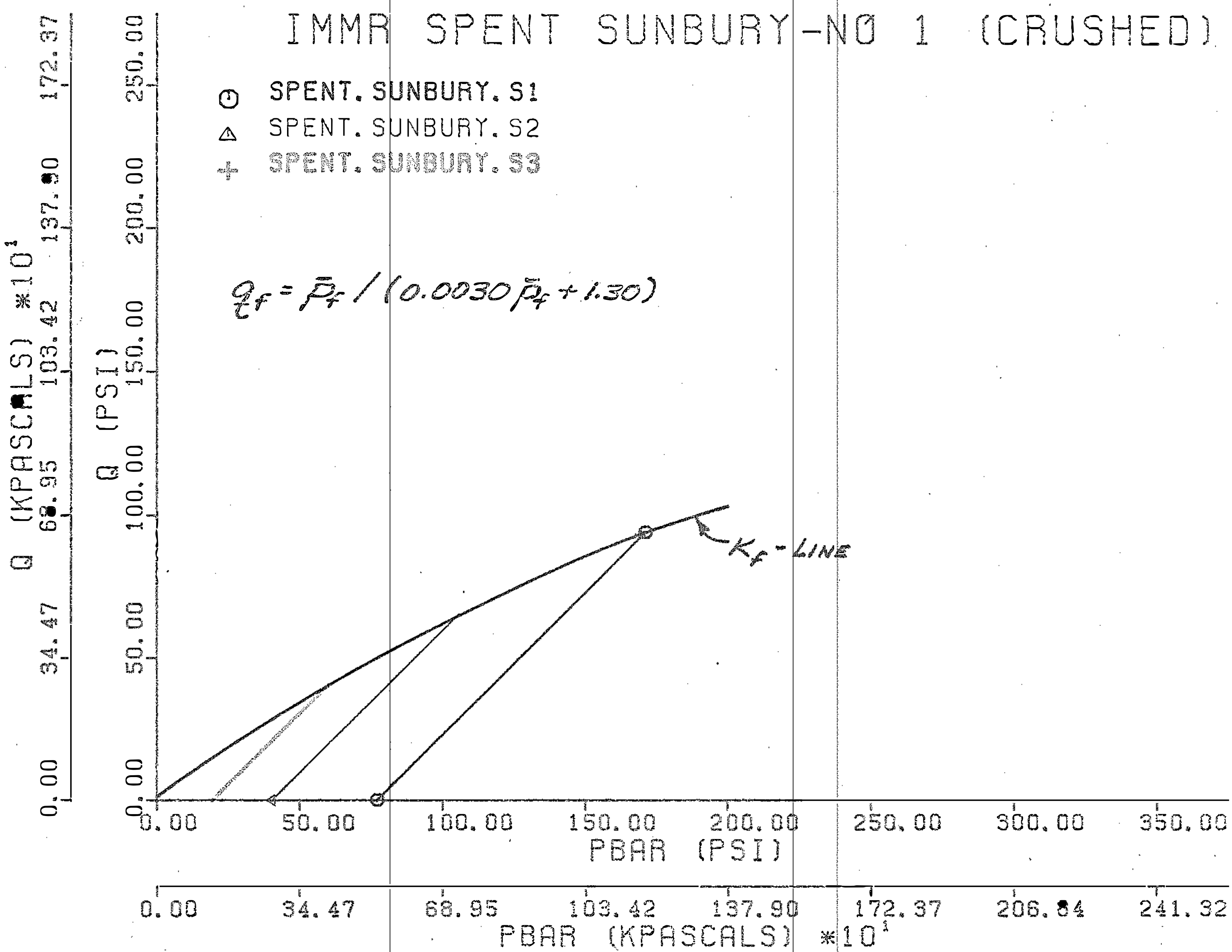
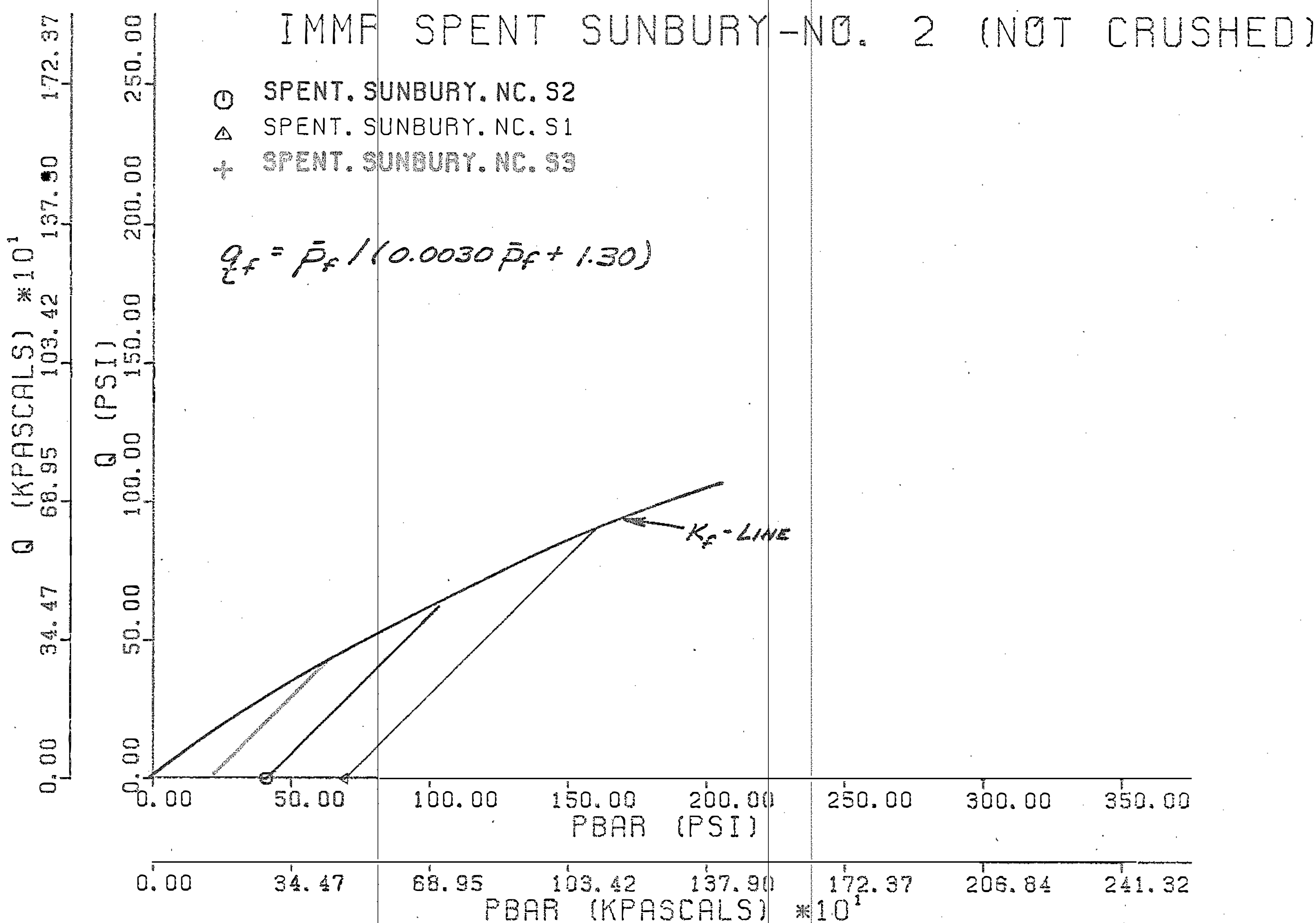

IMMR SPENT SUNBURY-NØ 1 (CRUSHED)
SPENT. SUNBURY. S1
SPENT. SUNBURY. S2
SPENT. SUNBURY. S3
$q_f = \bar{p}_f / (0.0030 \bar{p}_f + 1.30)$
K_f - LINE
Q (KPASCALS) *10[1]
0.00
34.47
68.95
103.42
137.90
172.37
Q (PSI)
0.00
50.00
100.00
150.00
200.00
250.00
PBAR (PSI)
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
PBAR (KPASCALS) *10[1]
0.00
34.47
68.95
103.42
137.90
172.37
206.84
241.32

FIGURE. 5



IMMR SPENT SUNBURY-NO. 2 (NOT CRUSHED)
SPENT. SUNBURY. NC. S2
SPENT. SUNBURY. NC. S1
SPENT. SUNBURY. NC. S3
Q_f = P̄_f / (0.0030 P̄_f + 1.30)
K_f - LINE
Q (KPASCALS) *10^1
Q (PSI)
PBAR (PSI)
PBAR (KPASCALS) *10^1
0.00
34.47
68.95
103.42
137.90
172.37
206.84
241.32
50.00
100.00
150.00
200.00
250.00
300.00
350.00

FIGURE 6.

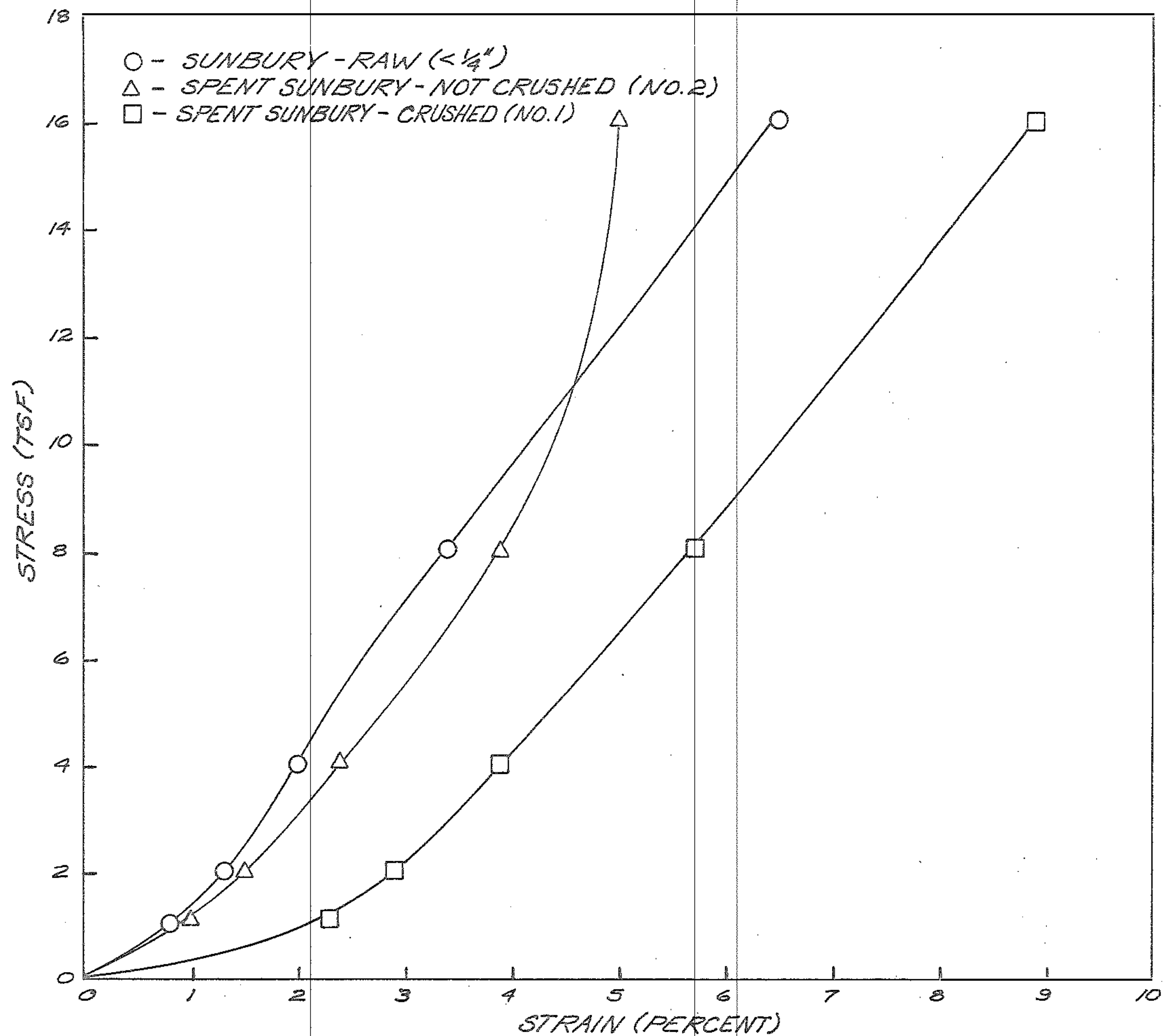

○ - SUNBURY - RAW (< 1/4")
△ - SPENT SUNBURY - NOT CRUSHED (NO.2)
□ - SPENT SUNBURY - CRUSHED (NO.1)
STRESS (TSF)
STRAIN (PERCENT)
0
2
4
6
8
10
12
14
16
18
1
3
5
7
9

FIGURE 7.

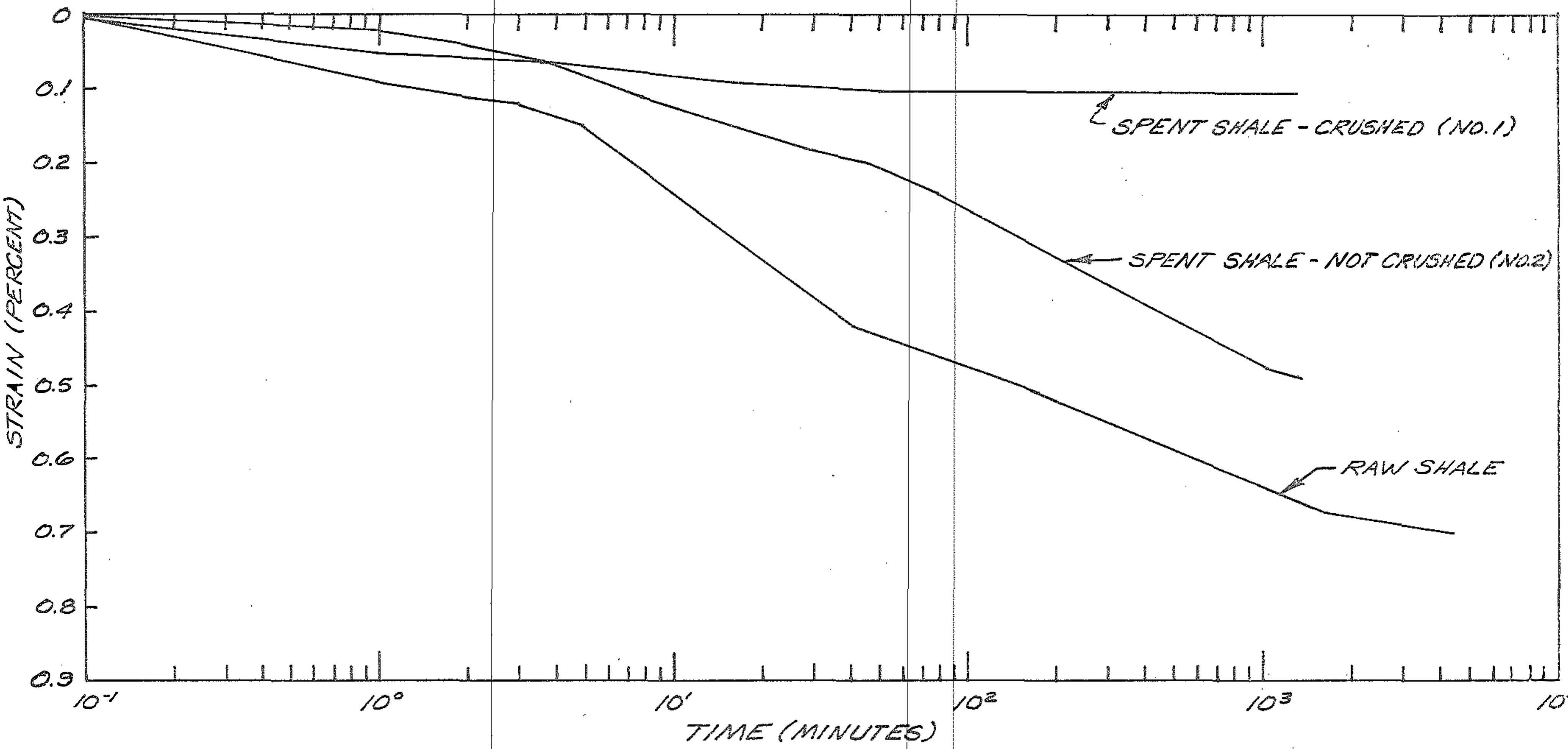

0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
STRAIN (PERCENT)
SPENT SHALE - CRUSHED (NO.1)
SPENT SHALE - NOT CRUSHED (NO.2)
RAW SHALE
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
TIME (MINUTES)

FIGURE 8.