MISCELLANEOUS PAPER C-69-16

TESTS OF ROCK CORES CASTLE STUDY AREA, CALIFORNIA

by

K. L. Saucier

R. W. Crisp

October 1969

Sponsored by

Space and Missile Systems Organization
U. S. Air Force Systems Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

TELEPHONE OR VERBAL CONVERSATION RECORD

For use of this form, see AR 340-15; the proponent agency is The Adjutant General's Office.

DATE: 29 February 1972

SUBJECT OF CONVERSATION: Distribution Statement on Reports

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PERSON CALLING	ADDRESS	PHONE NUMBER AND EXTENSION
PERSON CALLED	**OFFICE**	**PHONE NUMBER AND EXTENSION**

OUTGOING CALL

PERSON CALLING	OFFICE	PHONE NUMBER AND EXTENSION
Mr. James M. Polatty	Concrete Division	
PERSON CALLED	**ADDRESS**	**PHONE NUMBER AND EXTENSION**
Captain B. W. Bullard	Space & Missile Systems Organization	

SUMMARY OF CONVERSATION

I called SAMSO and talked to CPT Bullard. CPT Bullard was familiar with the WES reports covering rock tests for SAMSO. I explained the requirements of AR 70-31. He agreed that Statement A should be utilized on all of the SAMSO rock test reports.

JAMES M. POLATTY, Chief
Engineering Mechanics Branch
Concrete Division

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Laura Hanisee said following MP's covering rock tests for SAMSO were to be changed to Statement A :

C-69-3
C-69-12
C-69-16
C-70-4
C-70-6
C-70-7
C-70-9
C-70-10
C-70-11
C-70-14
C-70-16
C-70-17

DA FORM 751, 1 APR 66 — REPLACES EDITION OF 1 FEB 50 WHICH WILL BE USED.

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ARMY-MRC VICKSBURG, MISS.

ABSTRACT

Laboratory tests were conducted on rock core samples received from seven core holes in the Castle area of Mariposa and Madera Counties, California. The results were used to determine the quality and uniformity of the rock to depths of 200 feet below ground surface. Specific gravity, Schmidt hardness, wave velocity, and compressive strength tests indicated the rock to be highly variable in physical properties. The core was identified as predominantly soda tonalite. Approximately one-third of the rock tested was sufficiently weathered and fractured to be classed as incompetent material. An assessment of the area on a hole-to-hole basis indicates that the area in the vicinity of only two of the seven holes appears to offer possibilities as a uniform, competent hard rock medium.

PREFACE

This study was conducted in the Concrete Division of the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U. S. Air Force Space and Missile Systems Organization (SAMSO) of the Air Force Systems Command. The study was coordinated with CPT Rupert G. Tart, Jr., SAMSO Project Officer, and Mr. M. V. Anthony of TRW, Inc., Norton Air Force Base, California. The work was accomplished during the period March to June 1969 under the general supervision of Mr. Bryant Mather, Chief, Concrete Division, and under the direct supervision of Messrs. J. M. Polatty, Chief, Engineering Mechanics Branch, W. O. Tynes, Chief, Concrete and Rock Properties Section, and K. L. Saucier, Project Officer. Mr. A. D. Buck was responsible for the petrography work. Mr. Saucier performed the majority of the program analysis and prepared this report, with the assistance of Mr. R. W. Crisp.

Director of the WES during the investigation and the preparation and publication of this report was COL Levi A. Brown, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

ABSTRACT-- 3

PREFACE--- 4

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT------ 7

CHAPTER 1 INTRODUCTION--- 8

1.1 Background-- 8
1.2 Objective--- 8
1.3 Scope--- 8
1.4 Samples--- 9
1.5 Report Requirements--- 9

CHAPTER 2 TEST METHODS--- 12

2.1 Schmidt Number-- 12
2.2 Specific Gravity and Porosity--------------------------------- 12
2.3 Indirect Tension--- 13
2.4 Direct Tension-- 13
2.5 Compressive Strength Tests------------------------------------ 14
2.6 Dynamic Properties-- 15
2.7 Petrographic Examination-------------------------------------- 15
2.8 Three-Dimensional Elastic Properties-------------------------- 15

CHAPTER 3 QUALITY AND UNIFORMITY TEST RESULTS------------------ 17

3.1 Tests Utilized-- 17
3.2 Moderately to Highly Weathered Rock and Fractured Rock--- 18
3.3 Slightly Weathered to Unweathered Rock------------------- 19
3.4 Fine-Grained Rock--- 22
3.5 Rock Failing Along Seams or Bands-------------------------- 23

CHAPTER 4 SPECIAL TESTS--- 25

4.1 Petrographic Examination-------------------------------------- 25
4.2 Porosity and Tensile Splitting Test Results---------------- 30
4.3 Elastic Moduli-- 31
4.4 Anisotropy Tests--- 32
4.5 Comparative Tensile Tests------------------------------------ 34

CHAPTER 5 DISCUSSION AND CONCLUSIONS---------------------------- 44

5.1 Discussion--- 44
5.2 Conclusions-- 44

APPENDIX A DATA REPORT - C-CR-10 CORES, 12 MARCH 1969---------- 49

APPENDIX B DATA REPORT - C-CR-19 CORES, 14 MARCH 1969---------- 61

APPENDIX C DATA REPORT - C-CR-5 CORES, 19 MARCH 1969----------- 71

APPENDIX D DATA REPORT - C-CR-11 CORES, 20 MARCH 1969---------- 81

APPENDIX E DATA REPORT - C-CR-1 CORES, 26 MARCH 1969----------- 93

APPENDIX F DATA REPORT - C-CR-14 CORES, 28 MARCH 1969---------- 105

APPENDIX G DATA REPORT - C-CR-27 CORES, 3 APRIL 1969----------- 115

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
feet per second	0.3048	meters per second
pounds	0.45359237	kilograms
pounds per square inch	0.070307	kilograms per square centimeter

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The purpose of this study was to supplement the information being obtained for the area evaluation study by the U. S. Air Force Space and Missile Systems Organization (SAMSO). It was necessary to determine the properties required on the specific materials for an analysis of the quality and uniformity of the rock. Results of tests on cores from the Castle area of Mariposa and Madera Counties in California are reported herein.

1.2 OBJECTIVE

The objective of this investigation was to conduct laboratory tests on samples from areas containing hard, near-surface rock to determine the integrity and the mechanical behavior of the materials as completely as possible, analyze the data thus obtained, and report the results to appropriate users.

1.3 SCOPE

Laboratory tests were conducted as indicated on the following page on samples received from the field. Table 1.1 gives pertinent information on the various tests.

Tests conducted to determine the general quality, uniformity, and integrity of the rock in the area sampled were: (1) relative hardness (Schmidt number), (2) specific gravity, (3) porosity, (4) unconfined compression, (5) dynamic elastic properties, and (6) petrographic examination.

Special tests conducted to determine the degree of anisotropy of the sampled rock and to facilitate comparison of results of direct and indirect tensile tests were: (1) dynamic elastic properties along three mutually perpendicular axes, and (2) tensile strength, respectively.

1.4 SAMPLES

Samples were received from seven holes in the Castle area designated as C-CR-1, -5, -10, -11, -14, -19, and -27. All samples were NX size cores (2-1/8-inch[1] diameter). Test specimens of the required dimensions as given in Table 1.1 were prepared for the individual tests. Quality and uniformity tests were conducted on selected specimens from all holes. Special tests were conducted on specimens of core from Holes C-CR-1, -5, -10, -11, -19, and -27.

1.5 REPORT REQUIREMENTS

The immediate need for the test results required that data

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[1] A table of factors for converting British units of measurement to metric units is presented on page 7.

reports be compiled and forwarded to the users as work was completed on each hole. The data reports of the individual test results are included herein as Appendixes A through G.

TABLE 1.1 SUMMARY OF TESTS

Test	Specimen Size	Test Equipment	Recording Equipment	Measured Properties	Computed Properties
Relative hardness	1 diameter by 2 diameter	Schmidt hammer	--	Relative hardness	--
Specific gravity		Scales	--	Specific gravity	Density
Porosity		Pressure pycnometer	Scales	Porosity, percent	--
Indirect tension		440,000-pound test machine	--	Tensile strength	--
Direct tension		30,000-pound test machine	--	Tensile strength	--
Unconfined compression		440,000-pound test machine	X-Y recorder	Compressive strength	--
Cyclic compression		440,000-pound test machine	X-Y recorder	Compressive strength	Young's, shear, and bulk moduli and Poisson's ratio
Dynamic moduli	1 diameter by 3 diameter	Sonic driver, pickup, amplifiers	Oscilloscope display	Fundamental frequencies	Young's, shear, and bulk moduli and Poisson's ratio
Sonic velocity	1 diameter by 3 diameter	Ultrasonic transducers	Oscilloscope display	Compressional velocity	Shear velocity
Petrographic examination	Variable	Microscopes, X-ray diffraction	--	Appearance, texture, and mineralogy	--
Three-dimensional elastic properties	1 diameter by 2 diameter	Pulse generator, amplifiers	Oscilloscope	Compressional and shear velocities	Young's, shear, and bulk moduli and Poisson's ratio

CHAPTER 2

TEST METHODS

2.1 SCHMIDT NUMBER

The Schmidt number is a measure of the relative degree of hardness as determined by the degree of rebound of a small mass propelled against a test surface. Twenty-four readings per specimen were taken as suggested by Deere and Miller.[1] The average of these readings is the Schmidt number or relative hardness. The hardness is often taken as an approximation of rock quality, and may be correlated with other physical characteristics such as strength, density, and modulus.

2.2 SPECIFIC GRAVITY AND POROSITY

The specific gravity of the "as-received" samples was determined by the loss of weight method conducted according to method CRD-C 107 of the "Handbook for Concrete and Cement."[2] A pycnometer is utilized

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[1] Deere, D. U. and Miller, R. P.; "Engineering Classification and Index Properties for Intact Rock"; Technical Report No. AFWL-TR-65-116, December 1966; Air Force Weapons Laboratory, Kirtland Air Force Base, N. Mex.; Unclassified.

[2] U. S. Army Engineer Waterways Experiment Station, CE; "Handbook for Concrete and Cement"; August 1949 (with quarterly supplements); Vicksburg, Miss.; Unclassified.

to determine the loss of weight of the sample upon submergence. The specific gravity is equal to the weight in air divided by the loss of weight in water.

Porosity, herein defined as the volume of voids expressed as a percentage of total volume, was determined after the samples utilized for the specific gravity test had been dried to constant weight. The amount of water forced into the test sample under 1,200-psi fluid pressure in a pressure pycnometer was carefully measured. Utilizing the known density of the water, the void space in the test sample was calculated. For very dense material, the sample was broken into small pieces to allow the fluid to saturate it.

2.3 INDIRECT TENSION

The tensile strength was determined by the indirect method, commonly referred to as the tensile splitting or Brazilian method, in which a tensile failure stress is induced in a cylindrical test specimen by a compressive force applied on two diametrically opposite line elements of the cylindrical surface. The test was conducted according to method CRD-C 77 of the "Handbook for Concrete and Cement."[2]

2.4 DIRECT TENSION

For purposes of comparison, specimens were prepared and tested for tensile strength according to the American Society for Testing and Materials proposed "Standard Method of Test for Direct Tensile

Strength of Rock Core Specimens." Tensile splitting tests were conducted on specimens cut adjacent to the direct tensile test specimens.

For the direct tension tests, the specimens were right circular cylinders, the sides of which were straight to within 0.01 inch over the full length of the specimen and the ends of which were parallel and not departing from perpendicularity to the axis of the specimen by more than 0.25 degree. Cylindrical metal caps cemented to the ends of the specimen provided the means for applying the direct tensile load. The load was applied continuously by a 30,000-pound-capacity universal testing machine at a constant rate such that failure occurred within 5 to 15 minutes.

2.5 COMPRESSIVE STRENGTH TESTS

The unconfined and cyclic compression test specimens were prepared according to the American Society for Testing and Materials and Corps of Engineers standard method of test for triaxial strength of undrained rock core specimens, CRD-C 147.[2] Essentially, the specimens were cut with a diamond blade saw, and the cut surfaces were ground to a tolerance of 0.001 inch across any diameter with a surface grinder prior to testing. Electrical resistance strain gages were utilized for strain measurements, two each in the axial (vertical) and horizontal (diametral) directions. Static Young's, bulk, and shear moduli were computed from strain measurements. Stress was applied with a 440,000-pound-capacity universal testing machine.

2.6 DYNAMIC PROPERTIES

Bulk, shear, and Young's moduli, Poisson's ratio, and shear velocity were determined on selected rock samples for the data reports by use of the method of vibrating unconfined samples in the fundamental modes of vibration. The resonant frequencies were utilized to compute the aforementioned elastic properties as given in CRD-C 18.[2]

The velocity at which a compressional wave travels through an isotropic solid is often used as a relative measure of the competency of the material. Compression wave velocities were determined on selected rock core samples by the method given in CRD-C 51.[2]

2.7 PETROGRAPHIC EXAMINATION

A limited petrographic examination was conducted on samples selected to be representative of the material received from the several holes. The examination was limited to identifying the rock, determining general condition, identifying mineralogical constituents, and noting any unusual characteristics which may have influenced the test results.

2.8 THREE-DIMENSIONAL ELASTIC PROPERTIES

Compressional and shear wave velocities, bulk, shear, and Young's moduli, and Poisson's ratio were determined by the American Society for Testing and Materials proposed "Standard Method of Test for

Laboratory Determination of Ultrasonic Pulse Velocities and Elastic Constants of Rock." The method consisted essentially of generating a wave in the specimen with a pulse generator unit and measuring, with an oscilloscope, the time required for the compression and shear waves to travel the length of the specimen, the resulting wave velocity being the distance traveled divided by the travel time. These compressional and shear velocities, along with the bulk density of the specimen, were used to compute the elastic properties.

In the case of the special tests used to determine the degree of anisotropy of the samples, compressional and shear velocities were measured along two mutually perpendicular, diametral (lateral) axes and along the longitudinal axis. This was facilitated by grinding four 1/2-inch-wide strips down the sides of the cylindrical surface at 90-degree angles and generating the compression and shear waves perpendicular to these ground surfaces.

CHAPTER 3

QUALITY AND UNIFORMITY TEST RESULTS

3.1 TESTS UTILIZED

Based on past experience with tests on samples received from other areas (Warren, Wyoming; Mountain Home, Idaho; Fairchild, Washington), the following tests were selected for use in determining the quality and uniformity of the Castle area rock: compressional wave velocity, unconfined compressive strength, Schmidt number, and specific gravity.

Core samples received from the seven holes in the Castle area were petrographically identified as fine- to medium-grained soda tonalite, some material being weathered to various degrees, some cores containing intrusions ranging in composition between granite and granodiorite (see Section 4.1).

Test results were divided into five groups:

1. Fractured rock.
2. Moderately to highly weathered rock.
3. Slightly weathered to unweathered rock.
4. Fine-grained rock.
5. Rock failing along seams or bands.

All specimens except those in group 4 were medium-grained.

3.2 MODERATELY TO HIGHLY WEATHERED ROCK AND FRACTURED ROCK

Some specimens from each of three holes, C-CR-11, -14, and -27, were found to be moderately to highly weathered. Physical tests performed on these specimens yielded the following results:

Hole	Specimen No.	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
				psi	fps
C-CR-11	1a	2.561	13.9	1,330	4,770
	1b	2.574	14.0	--	4,515
	2a	2.645	--	3,050	4,230
	2b	2.627	--	2,230	4,060
	5	2.702	29.9	6,170	7,250
C-CR-14	2	2.649	13.7	220	3,495
	3	2.608	14.6	940	4,555
	4	2.703	26.7	4,090	7,635
	6a	2.671	--	2,710	6,805
	9	2.715	25.7	7,060	9,975
	11	2.710	--	5,160	8,760
	13	2.715	29.3	6,140	10,270
	14	2.620	15.9	1,710	7,360
	16	2.697	30.5	3,860	8,930
C-CR-27	1a	2.729	30.7	4,240	10,785
Average		2.662	22.3	3,495	6,895

Unconfined compression tests performed on this group of specimens indicated that the moderately to highly weathered rock from the Castle area is highly incompetent, yielding an average compressive strength of only 3,495 psi. This incompetence is further evidenced by very low compressional wave velocities and Schmidt numbers. As expected, large variations were evident in the weathered material.

Samples were secured from several holes of rock which contained obvious fractures, but which remained sufficiently intact for testing purposes. It was believed that results from these tests would yield some information on the integrity of the fractures evident in the rock mass. Results are given below.

Hole	Specimen No.	Specific Gravity	Compressive Strength	Compressional Wave Velocity
			psi	fps
C-CR-19	11	2.666	2,700	10,605
C-CR-1	3	2.485	600	8,780
	4	2.602	2,060	6,795
C-CR-27	14	2.722	9,970	16,900
	16b	2.688	7,580	16,025
Average		2.633	4,580	11,820

The specific gravity and compressive strength results indicate that the fractured rock is roughly comparable to the weathered material in overall quality. The wave velocities of the fractured rock, somewhat higher than those of the weathered rock, indicate that the fractures were apparently rather tightly closed.

3.3 SLIGHTLY WEATHERED TO UNWEATHERED ROCK

The majority of the specimens from the seven holes in the Castle area were medium-grained, slightly weathered to unweathered, and contained no fractures, seams, or bands. Physical test results for this group of specimens are given below:

Hole	Specimen No.	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
				psi	fps
C-CR-10	1	2.616	42.8	18,970	11,950
	4a	2.622	40.6	13,830	13,875
	4b	2.623	39.8	19,510	12,905
	7a	2.857	47.2	23,480	16,490
	8	2.864	52.9	30,280	18,335
	9a	2.628	43.0	19,460	13,090
	10	2.841	56.5	31,860	19,330
	12a	2.824	53.3	24,770	19,040
	13a	2.891	55.9	11,710	20,105
	14a	2.805	55.7	24,280	19,100
	15a	2.825	49.2	19,800	16,725
	16a	2.780	49.3	19,080	15,685
	17	2.813	51.3	20,710	17,070
C-CR-5	2a	2.769	43.5	14,130	14,650
	4a	2.774	46.0	29,140	14,460
	4b	2.792	46.9	27,430	14,650
	7	2.768	54.9	22,810	17,840
	9a	2.701	--	25,570	16,360
	9b	2.788	51.4	20,210	16,830
	11a	2.783	49.4	18,070	15,760
	13a	2.783	47.3	22,430	14,880
C-CR-11	8	2.725	49.4	12,470	14,420
	10	2.712	48.0	22,000	13,700
	13a	2.727	50.5	25,090	16,200
	15	2.720	49.2	12,280	13,970
	16	2.721	50.2	16,510	14,250
	18a	2.736	51.5	22,730	15,460
	18b	2.729	51.6	22,740	15,080
	19a	2.718	46.3	19,840	15,000

(Continued)

Hole	Specimen No.	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
				psi	fps
C-CR-14	18a	2.735	51.9	22,170	17,735
C-CR-27	3	2.780	44.6	9,480	16,130
	9	2.825	55.3	18,970	18,365
C-CR-19	1	2.716	29.6	9,540	7,480
	3a	2.728	35.1	14,940	10,895
	4	2.717	34.7	11,890	11,100
	7a	2.727	32.2	9,860	10,055
	7b	2.742	34.9	12,910	10,250
	9a	2.639	47.6	23,800	14,960
	9b	2.650	46.0	13,740	14,525
	14	2.732	42.3	13,260	14,380
	16	2.720	45.1	18,860	14,960
	17a	2.605	--	22,890	15,300
	17b	2.690	--	13,760	16,730
Average		2.743	46.8	19,240	15,120

Organization of the rather large population of data into one group obviously masks the effects of differences in structure, mineralogy, rock type, etc., and yields a wide range of physical test results. However, such grouping appeared to be the practical method of evaluating the material with respect to relative competence or incompetence compared with the weathered and fractured rock. Accordingly, the results indicate that the large majority of the material sampled and tested is relatively competent rock. The rock typifying the average material would not normally be classified as very hard, highly competent, etc., because few samples tested yielded specific gravity results >2.8, strengths >30,000 psi, and velocities >20,000 fps. However, the results are consistently in the range of results obtained on good to competent rock despite the structural and mineralogical differences noted previously.

3.4 FINE-GRAINED ROCK

Several specimens from Hole C-CR-1 were found to consist of fine-grained material as opposed to the medium-grained material common to the other specimens from the Castle area. Physical tests on this group yielded the following results:

Hole	Specimen No.	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
				psi	fps
C-CR-1	2a	2.842	--	38,570	21,305
	2b	2.856	59.8	45,000	21,800
	10	2.902	59.5	36,570	22,590
	11a	2.884	--	32,000	19,010
	11b	2.882	51.0	39,860	18,060
	14	2.875	56.3	25,860	21,000
Average		2.874	56.6	36,310	20,630

Unconfined compression tests indicated that the fine-grained rock was considerably stronger than the other rock in the Castle area, exhibiting an average compressive strength of 36,310 psi and a minimum of 25,860 psi. Though varying slightly, specific gravities and compressional wave velocities were also slightly higher for this more competent material.

3.5 ROCK FAILING ALONG SEAMS OR BANDS

Several specimens from Holes C-CR-1 and -27 failed along seams or bands discovered after testing was completed. These bands or seams were differentiated from the fractured specimens in that they were very tightly closed--in many cases so tightly closed as to be undetected prior to test. Results are given below:

Hole	Specimen No.	Specific Gravity	Schmidt No.	Compressive Strength	Compressional Wave Velocity
				psi	fps
C-CR-1	5a	2.914	--	16,940	18,940
	5b	2.932	56.8	21,710	20,555
	7	2.882	55.6	17,940	19,135
	8	2.870	--	15,860	21,550
	12b	2.866	59.3	11,430	19,070
	16	2.872	57.8	12,140	20,880
C-CR-27	5a	2.817	53.2	14,670	17,385
	7	2.765	56.4	17,090	17,525
	10	2.764	55.5	18,530	17,385
	12a	2.769	58.0	19,700	17,525
	18	2.726	53.8	15,450	16,000
Average		2.834	56.3	16,495	18,725

Average unconfined compressive strength for this group was only slightly lower than the average for the unweathered group, and considerably greater than that for the group containing fractures. Indications are, therefore, that the banding weakened the parent rock, but did not render it incompetent as did the fracturing.

Generally, the group consisted of rather competent material; the weakest specimen exhibited a compressive strength of 11,430 psi. This competence was further evidenced by Schmidt numbers and compressional wave velocities considerably larger than those exhibited by the fractured and weathered specimens.

CHAPTER 4

SPECIAL TESTS

4.1 PETROGRAPHIC EXAMINATION

Ten boxes of NX size rock core from seven core holes located in adjacent counties (Mariposa and Madera) in California were received for testing. Each box contained about 15 feet of core. The pieces of core from each hole represented scattered depths to 200 feet.

The contents of each box were inspected in order to select representative material for petrographic examination. This inspection indicated that the bulk of the cores could be assigned to three visually distinct varieties of rock. There were smaller amounts of other varieties representing weathered or special types. The six pieces of core selected for petrographic examination are identified below:

CD Serial No.	Core Hole No.	Piece No.	Approximate Depth	Description
			feet	
SAMSO-5 DC-4	C-CR-1	14	183.0	Fine-grained dark-colored igneous rock containing a high-angle healed fracture. This is one of the three visually distinct main varieties.

(Continued)

69294

CD Serial No.	Core Hole No.	Piece No.	Approximate Depth	Description
			feet	
SAMSO-5 DC-1	C-CR-5	3	37.5	Medium-grained light-colored igneous rock. The rock is almost coarse-grained. This is one of the three visually distinct main varieties.
SAMSO-5 DC-5	C-CR-11	12	132.0	Medium-grained light-colored igneous rock; much finer-grained than above variety. This is one of the three visually distinct main varieties.
SAMSO-5 DC-6	C-CR-14	16	176.0	A slightly weathered version of the previously listed medium-grained light-colored rock.
SAMSO-5 DC-3	C-CR-19	17	190.0	Medium-grained white igneous rock. This is a sample of the material described as aplite dikes in the core logs.
SAMSO-5 DC-7	C-CR-27	8	96.0	Light-colored medium-grained igneous rock with a gneissic (layered) appearance that is attributed to flow structure. There was only a small amount of this rock, and all of it was from this hole.

Each of the six specimens was sawed axially; one of the sawed surfaces of each piece was polished.

A composite sample from the length of each piece was ground until all of it passed a No. 325 sieve (44μ). X-ray diffraction patterns were made of each sample as a tightly packed powder. These patterns were examined and compared to make mineralogical identifications and comparisons.

Some of the sized powder from each piece was slurried with water on a glass slide and X-rayed in the air-dry condition and after saturation with glycerol to identify clays.

A thin section of each of the three major varieties of rock and of the white aplite dike rock was made and examined with a polarizing microscope.

Some of the powder of pieces 12, 14, and 17 (C-CR-11, -1, and -19) was examined as powder immersion mounts with a polarizing microscope to determine the approximate composition of the plagioclase feldspar in them. Broken surfaces and polished surfaces of the samples were examined with a stereomicroscope. All X-ray patterns were made with an XRD-5 diffractometer using nickel-filtered copper radiation.

The following observations were made during the visual inspection of the seven cores to select petrographic samples:

1. There was some weathered, fragmented rock present in all the samples except that from Core Hole C-CR-5. The weathered material is recognizable by its tan color and because it occurs in shorter, more

fragmented pieces than the fresh rock.

2. The core from most of the holes contained two of the three major varieties that have been described.

3. All of the core received from Core Holes C-CR-14 and -19 appeared to be weathered rock as judged by its color.

4. The core from Hole C-CR-27 was the most varied of all the cores. Pieces 7 through 12 and pieces 17 and 18 resembled metamorphic gneiss and schist instead of igneous rock. However, the presence of igneous rock above and between these pieces suggests instead that these features were developed during solidification and are not due to any metamorphic process.

Piece 12 from Core Hole C-CR-11 is typical of the medium-grained light-colored igneous rock from this area. It contains plagioclase feldspar and biotite mica, and smaller amounts of quartz, potassium feldspar (orthoclase), and a dark amphibole (hornblende). There is also a little magnetite.

Pieces 16, 14, 3, and 8 from Core Holes C-CR-14, -1, -5, and -27, respectively, represent the other varieties of similar igneous rock that can be separated on the basis of appearance. They differ from piece 12 in composition as follows: (1) they contain less biotite, (2) they contain more hornblende, (3) they do not contain detectable potassium feldspar, and (4) they contain a small amount of a 14 A mineral (probably chlorite).

Piece 14 from Core Hole C-CR-1, which is the fine-grained dark-colored igneous rock, contains substantially more hornblende than any of the other pieces. This accounts for its darker color.

These five pieces (Nos. 16, 14, 3, 8, and 12) of core range from fine-grained to almost coarse-grained rock; all but piece 16 from Hole C-CR-14 are fresh rock; piece 16 is a slightly weathered version of piece 12 from Hole C-CR-11. The rock in each of the five pieces of core is generally equigranular. The plagioclase feldspar was checked in pieces 12 and 14; it is andesine with a composition of about $Ab_{60}\ An_{40}$.

The seven cores containing rock like that represented by the five pieces just described were logged as diorite and granodiorite in the field. Application of the classification system of Shand[1] to the petrographic data established by laboratory examination indicates that the rock is soda tonalite. Although both diorite and granodiorite are similar to tonalite, the latter name is preferable because of the presence of quartz and the absence or small amount of potassium feldspar in these rocks.

Piece 17 from Hole C-CR-19 is typical of the medium-grained white

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1 Shand, S. J.; "Eruptive Rocks"; Third Edition, 1947; John Wiley and Sons, New York, N. Y.; Unclassified.

rock logged in the field as aplite dikes. It contains quartz, plagioclase feldspar, and potassium feldspars as its main minerals with small amounts of biotite, muscovite, chlorite, and kaolinite. The rock is granodiorite, since it does not contain quite enough potassium feldspars to be called granite. These light-colored intrusions into the host tonalite rock probably range from granite to granodiorite in composition.

In summary, petrographic examination of six pieces of NX core that are typical of igneous rock from seven holes in the Castle area indicates the following:

1. The majority of the rock in the cores is fine- to medium-grained soda tonalite. Most of this is fresh rock, although there is some weathered rock in the core from most of the holes.

2. Several of the cores contain intrusions of medium-grained light-colored rock described as aplite dikes. These intrusions are generally a few inches thick. This rock probably ranges in composition between granite and granodiorite.

4.2 POROSITY AND TENSILE SPLITTING TEST RESULTS

Porosity and tensile strength tests were conducted at random to provide basic information on these properties. Due to the meaningless results which would be obtained on the fractured or banded specimens, especially the tensile strength of nonoriented specimens, only results for the weathered, unweathered, and fine-grained rock are reported herein (see Table 4.1).

Generally, the porosities of slightly weathered to unweathered specimens ranged from 0.0 to 1.4 percent and porosities for the weathered specimens from 0.2 to 6.5 percent. The moderately to highly weathered rock exhibited a very low average tensile strength, 200 psi. For the other rock tested, however, the tensile strengths averaged approximately 1,000 psi, indicating that weathering had a very significant effect on the tensile strength.

4.3 ELASTIC MODULI

Samples representative of the different materials in each hole were selected for deformation moduli tests for the data reports. The dynamic tests reported in the data reports were conducted by the resonant frequency method. After dynamic tests were completed, a portion of each sample was prepared for static testing. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given in Table 4.2.

The fine-grained material and that containing seams or bands exhibited the highest elastic moduli and wave velocities. The high degree of similarity of moduli and wave velocities for the two groups indicated that the tightly closed seams or bands had no significant effect on the elastic properties of the material.

The slightly weathered to unweathered material exhibited somewhat lower moduli and wave velocities, the average values for the group generally falling about 25 percent below the averages for the fine-grained and seamed or banded materials. The slightly weathered to unweathered specimens yielded quite variable results, partially due to the large population of the group. However, within the group, a slight increase in degree of weathering was usually indicated by a decrease in wave velocity and moduli, with some of the unweathered specimens exhibiting moduli and wave velocities comparable to those for the fine-grained material.

Significantly, the average results for all groups of rock except the highly weathered material indicate exceptionally good agreement between the static and dynamic methods of test. The highly weathered rock results are erratic and low for a rocklike material, thus indicating that the weathered tonalite is indeed a relatively poor rock.

4.4 ANISOTROPY TESTS

Compressional and shear wave velocity tests were conducted on 10 specimens from the Castle area, one velocity determined in the axial direction and two other velocities determined on mutually perpendicular, diametral (lateral) axes. The test was previously described in Section 2.8. Results of the velocity determinations are given in Table 4.3.

A convenient method to determine the degree of anisotropy is to examine the maximum percent deviation from the average of the compressional wave velocity. The three weathered specimens appear to be highly anisotropic, especially in the vertical (axial) direction. The point of division between isotropy and anisotropy is hard to define. The proposed ASTM test method states that the equations for computation of elastic moduli should not be used if "any of the three compressional wave velocities varies by more than 2 percent from their average value. The error in E and G due to both anisotropy and experimental error then does not exceed 6 percent." This appears to be rather restrictive for rock--only two of the ten specimens tested in this study had deviations of 2 percent or less. Assuming an arbitrary value of 10 percent deviation from the average as the limit of isotropy, five specimens are determined to be isotropic and five anisotropic. Significantly, four of the five specimens determined to be anisotropic either were weathered or contained a detectable defect.

Computations of elastic moduli and constants were made on the five specimens with compressional wave velocity deviations of less than 10 percent. The possible error is, of course, greater for the specimens with larger deviations, i.e., up to approximately 20 percent error for the specimens with 7 percent deviation in velocity. Results are given in Table 4.4. The moduli agree quite well with moduli determined on similar specimens by the fundamental frequency method.

To evaluate the effect of anisotropy on a rock mass, one should determine the state of stress expected or applied. The effect of elastic anisotropy on the stress distribution is greatest for a uniaxial state of stress, a state which exists in very little massive rock. Obert[2] indicates that if the stress field is hydrostatic and the ratio of moduli due to anisotropy is approximately two, the maximum difference in stress for the isotropic and anisotropic cases would be only 10 to 15 percent. He further states that "It can be inferred that for most rock, the effects of elastic anisotropy are no larger than the normal variations in rock strength and, hence, they can be neglected. The most likely exceptions to this generalization would be strongly foliated metamorphic rocks, such as micaceous schists,... where the moduli of elasticity often differ by a factor greater than two."

4.5 COMPARATIVE TENSILE TESTS

Ten NX size rock specimens were selected to represent the several

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[2] Obert, Leonard and Duvall, W. I.; "Rock Mechanics and the Design of Structures in Rock"; 1967; John Wiley and Sons, New York, N. Y.; Unclassified.

variations of color, texture, grain size, and weathering present in the core received from the seven drill holes in the Castle area. The specimens were prepared and tested for tensile strength according to the ASTM proposed "Standard Method of Test for Direct Tensile Strength of Rock Core Specimens." For comparative purposes, tensile splitting tests were conducted on specimens cut adjacent to the direct tensile test specimens.

Results are given in Table 4.5. The three specimens which yielded direct tensile strengths of over 1,000 psi failed on the first attempt in bond. Personal communication with Mr. E. J. Deklotz of the U. S. Army Engineer Division Laboratory, Missouri River, who personally helped prepare the proposed ASTM test method, revealed that approximately 30 to 40 percent of the direct tension test specimens tested by the above-mentioned method fail in the bonding agent, especially if the rock is competent material. Retest yielded good breaks on Specimen 12 from Hole C-CR-5 and Specimen 9 from Hole C-CR-10; however, Specimen 9 from Hole C-CR-1 was apparently stronger in tension than the bonding strength of the several epoxy formulations tried since all attempts with the specimen resulted in bond failure.

The direct tensile strength of the rock tested is somewhat lower than the tensile splitting strength, ranging between 60 and 100 percent and averaging approximately 70 percent of the splitting strength. The difference appears to be greater for the more weathered rock.

This is probably due to the apparently weakened condition of the material in the vertical direction. The compressional and shear wave velocities determined on these same specimens, Section 4.4, indicated that the vertical direction was the least competent for the three weathered specimens. The direct tensile test, of course, imparts the stress in the vertical direction, while the tensile splitting test stresses the rock in the horizontal direction of a vertically drilled core.

TABLE 4.1 POROSITY AND TENSILE STRENGTH RESULTS

Group	Hole	Specimen No.	Porosity	Tensile Strength
			percent	psi
Moderately to highly weathered rock	C-CR-11	1b	6.5	175
	C-CR-14	1	2.8	120
		3b	2.4	120
		6b	2.4	140
	C-CR-27	1b	0.2	450
	Average		2.9	200
Slightly weathered to unweathered rock	C-CR-10	6b	--	1,645
		7a	0.6	--
		13b	--	1,585
		14a	1.0	--
		16b	--	1,465
	C-CR-5	2b	--	600
		4b	1.1	--
		4c	--	1,590
		11	1.4	--
		11b	--	900
		13b	--	1,030
	C-CR-11	13b	1.4	1,045
		19b	1.0	1,240
	C-CR-14	18b	0.3	1,270
	C-CR-19	3b	--	620
		3c	--	525
		7a	0.7	--
		9b	0.0	--
		10a	--	890
		10b	--	645
		14a	--	735
	Average		0.8	1,050
Fine-grained rock	C-CR-1	11c	--	1,330
		11d	--	1,330
	Average		--	1,330

TABLE 4.2 ELASTIC MODULI TEST RESULTS

Dynamic

Hole	Specimen No.	Modulus: Young's	Modulus: Shear	Modulus: Bulk	Poisson's Ratio	Wave Velocity: Compressional	Wave Velocity: Shear
		10^6 psi	10^6 psi	10^6 psi		fps	fps
Moderately to Highly Weathered Rock:							
C-CR-11	1	0.5	0.2	0.3	0.17	4,265	2,500
C-CR-14	6	0.6	*	*	*	6,250	3,160
	16	1.0	*	*	*	8,110	5,040
C-CR-27	1	3.6	1.7	1.2	*	12,500	7,040
Average		1.4	1.0	0.8	0.17	7,780	4,435
Slightly Weathered to Unweathered Rock:							
C-CR-10	4	4.7	2.3	1.7	*	13,195	8,060
	7	9.2	4.3	3.6	*	17,530	10,640
	12	12.8	5.3	7.4	0.21	20,515	11,810
C-CR-5	2	5.7	2.2	4.4	0.28	14,060	7,820
	4	6.5	2.9	3.0	0.14	13,910	8,845
	9	7.8	3.4	3.5	0.13	16,295	9,665
C-CR-11	10	6.0	2.7	2.6	0.12	13,885	8,530
	18	8.6	3.5	5.5	0.24	16,235	9,765
C-CR-14	18	9.5	4.1	4.8	0.17	18,260	10,545
C-CR-19	4	3.1	1.5	1.2	*	11,135	6,430
	9	7.0	3.0	3.3	0.15	15,225	9,330
	16	6.3	2.8	2.8	0.12	14,960	8,800
Average		7.3	3.2	3.7	0.17	15,435	9,185
Fine-Grained Rock:							
C-CR-1	2	13.2	5.5	7.6	0.21	20,730	11,980
	11	8.3	3.7	3.8	0.13	17,120	9,835
	14	11.8	4.9	6.6	0.20	19,530	11,425
Average		11.1	4.7	6.0	0.18	19,125	11,080
Rock Containing Seams or Bands:							
C-CR-1	5	12.1	4.9	7.4	0.23	19,420	11,255
C-CR-27	5	11.0	4.6	5.9	0.19	19,195	11,240
	12	11.1	4.7	5.6	0.17	19,455	11,410
Average		11.4	4.7	6.3	0.20	19,355	11,300

Static

Hole	Specimen No.	Modulus: Young's	Modulus: Shear	Modulus: Bulk	Poisson's Ratio
		10^6 psi	10^6 psi	10^6 psi	
Moderately to Highly Weathered Rock:					
C-CR-11	1a	0.3	*	*	*
	2a	0.2	0.1	0.2	0.36
C-CR-14	6a	0.8	0.3	0.9	0.35
	16	0.8	0.3	0.5	0.21
Average		0.5	0.2	0.5	0.31
Slightly Weathered to Unweathered Rock:					
C-CR-10	4b	5.0	2.2	2.4	0.15
	8	10.4	4.3	5.8	0.20
	13a	10.5	4.5	5.2	0.16
	17	9.4	3.8	6.0	0.24
C-CR-5	2a	5.2	2.0	4.1	0.29
	4a	6.2	2.6	3.4	0.20
	13a	8.2	3.3	5.7	0.26
C-CR-11	10	8.4	3.6	4.2	0.17
	18a	9.0	3.8	5.0	0.20
C-CR-14	18a	8.0	3.3	4.4	0.20
C-CR-19	4	4.0	1.6	2.9	0.25
	9a	5.8	2.4	3.4	0.22
	16	8.4	3.5	4.8	0.21
Average		7.6	3.1	4.4	0.21
Fine-Grained Rock:					
C-CR-1	2b	12.6	5.2	7.5	0.22
	11b	10.5	4.5	5.5	0.18
	14	10.7	4.5	5.9	0.20
Average		11.3	4.7	6.3	0.20
Rock Containing Seams or Bands:					
C-CR-1	5b	10.0	4.2	5.6	0.20
C-CR-27	5a	9.5	3.8	6.1	0.24
	12a	10.8	4.5	6.0	0.20
Average		10.1	4.2	5.9	0.21

* Due to erratic response to tests, results could not be obtained on some specimens.

TABLE 4.3 VELOCITY DETERMINATIONS

		Velocity	
		Compressional**	Shear**
Hole C-CR-1, Specimen 6:*		fps	fps
Fine- to medium-grained		14,625	7,375
Depth: 128 feet		13,235	9,075
Specific gravity: 2.86		12,150	8,755
Compressive deviation: 10 pct†			
	Average	13,335	8,400
Hole C-CR-1, Specimen 9:			
Medium- to coarse-grained		20,830	12,020
Depth: 150 feet		19,090	12,180
Specific gravity: 2.89		18,585	12,195
Compressive deviation: 7 pct			
	Average	19,500	12,130
Hole C-CR-5, Specimen 12:			
Coarse-grained		14,565	8,765
Depth: 179 feet		13,945	10,000
Specific gravity: 2.78		11,820	8,390
Compressive deviation: 12 pct			
	Average	13,445	9,050
Hole C-CR-10, Specimen 4:			
Fine-grained		12,570	8,390
Depth: 63 feet		12,235	8,590
Specific gravity: 2.61		12,195	8,000
Compressive deviation: 2 pct			
	Average	12,335	8,325

(Continued)

* Contained healed seam.
** First velocity listed is in axial (longitudinal) direction; other two are on mutually perpendicular, diametral (lateral) axes.
† Maximum percent deviation from the average of the compressional wave velocity.

(1 of 3 sheets)

TABLE 4.3 (CONTINUED)

		Velocity	
		Compressional	Shear
		fps	fps
Hole C-CR-10, Specimen 9:			
Fine-grained		13,585	8,620
Depth: 102 feet		12,820	9,140
Specific gravity: 2.62		12,830	8,905
Compressive deviation: 4 pct			
	Average	13,080	8,890
Hole C-CR-11, Specimen 1:			
Coarse-grained (very weathered)		5,620	3,580
Depth: 19 feet		6,635	3,340
Specific gravity: 2.60		10,310	4,385
Compressive deviation: 37 pct			
	Average	7,520	3,770
Hole C-CR-11, Specimen 5:			
Coarse-grained (weathered)		8,725	6,610
Depth: 64 feet		11,310	7,505
Specific gravity: 2.72		11,945	7,615
Compressive deviation: 18 pct			
	Average	10,660	7,245
Hole C-CR-11, Specimen 11:			
Coarse-grained		12,835	7,950
Depth: 123 feet		12,330	8,885
Specific gravity: 2.72		13,610	9,150
Compressive deviation: 5 pct			
	Average	12,925	8,660

(Continued)

(2 of 3 sheets)

TABLE 4.3 (CONCLUDED)

		Velocity	
		Compressional	Shear
Hole C-CR-19, Specimen 8:		fps	fps
Coarse-grained (weathered)		10,615	6,120
Depth: 82 feet		11,045	6,845
Specific gravity: 2.68		12,825	7,900
Compressive deviation: 12 pct			
	Average	11,495	6,955
Hole C-CR-27, Specimen 3:			
Coarse-grained		16,170	8,355
Depth: 41 feet		16,675	10,765
Specific gravity: 2.74		16,040	10,370
Compressive deviation: 2 pct			
	Average	16,295	9,830

(3 of 3 sheets)

TABLE 4.4 ELASTIC PROPERTIES

Hole	Specimen		Moduli			Poisson's Ratio
			Young's	Shear	Bulk	
			10^6 psi	10^6 psi	10^6 psi	
C-CR-1	9		14.05	5.62	9.38	0.25
			13.35	5.77	6.48	0.16
			12.97	5.78	5.72	0.12
		Average	13.46	5.72	7.19	0.18
C-CR-10	4		5.43	2.47	2.25	--
			5.26	2.59	1.80	--
			5.05	2.25	2.23	0.12
		Average	5.25	2.44	2.09	0.12
C-CR-10	9		6.10	2.62	3.02	0.16
			5.80	2.95	1.87	--
			5.80	2.80	2.08	--
		Average	5.90	2.79	2.32	0.16
C-CR-11	11		5.50	2.31	2.95	0.19
			5.55	2.89	1.71	--
			6.67	3.06	2.69	--
		Average	5.91	2.75	2.45	0.19
C-CR-27	3		6.77	2.57	6.20	0.31
			9.76	4.27	4.55	0.14
			9.04	3.96	4.19	0.14
		Average	8.52	3.60	4.98	0.20

TABLE 4.5 TENSILE STRENGTH DETERMINATIONS

Direct tensile strength shown is the result of second attempt for Specimen 9 from Hole C-CR-1, Specimen 12 from Hole C-CR-5, and Specimen 9 from Hole C-CR-10, which failed in the bonding epoxy.

Hole	Specimen	Depth	Description*	Tensile Strength		
				Direct	Splitting	Ratio of Direct to Splitting
		feet		psi	psi	pct
C-CR-1	6	128	Fine- to medium-grained	850**	1,050**	81
C-CR-1	9	150	Medium- to coarse-grained	1,530†	2,155	71
C-CR-5	12	179	Coarse-grained	1,015	1,010	100
C-CR-10	4	63	Fine-grained	570	930	61
C-CR-10	9	102	Fine-grained	1,060	1,170	91
C-CR-11	1	19	Coarse-grained (very weathered)	††	175	--
C-CR-11	5	64	Coarse-grained (weathered)	245	550	45
C-CR-11	11	123	Coarse-grained	690	1,080	64
C-CR-19	8	82	Coarse-grained (weathered)	285	455	63
C-CR-27	3	41	Coarse-grained	770	1,035	74
	Average (except for Specimen 1 from Hole C-CR-11)			780	1,050	72

* All specimens were salt and pepper, cream to light gray colored except Specimens 6 and 9 from Hole C-CR-1, which were light brown and dark gray colored.

** Broke on a seam.

† Failed in bonding epoxy.

†† Broke during preparation.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1 DISCUSSION

The wide variation in physical characteristics of the samples received from the Castle area dictates the evaluation of the area holes on a hole-to-hole basis. Accordingly, a rock quality chart based on compressive strength divided into three categories (poor, marginal, and good) was prepared, Figure 5.1. Hole 14 contained poor rock throughout the entire depth tested, and Holes C-CR-5 and -10 contained good rock throughout. The other holes contained some poor and marginal material, primarily in the upper elevations.

The locations of the drill holes are shown in Figure 5.2. Holes C-CR-5 and -10 appear to be in an area bounded on the east by the Chowchilla River and on the west by the town of Mariposa. This area possibly would be an area of competent, uniform, good quality rock. Of course, further investigation would be required to fully define the area. The area farther to the east in which Holes C-CR-11, -14, -19, and -27 are located appears to be weathered and altered to various degrees and various depths. Hole C-CR-1 is too isolated to be of much help in evaluating the area.

5.2 CONCLUSIONS

Based on the results of tests of rock core samples reported herein, the following conclusions appear to be justified:

1. The core received from the Castle area was identified as predominantly soda tonalite with some granite and granodiorite intrusions.

2. Four distinct groups of material (based on physical characteristics) are present: (a) moderately to highly weathered rock and fractured rock, (b) slightly weathered to unweathered rock, (c) fine-grained hard rock, and (d) rock failing on tightly closed bands or seams.

3. The weathered and fractured rock, comprising approximately 1/3 of the test samples, was incompetent material. The remainder of the rock, including that failing on bands or seams, is relatively competent material.

4. Three-dimensional compressional wave velocity tests conducted on representative samples indicate that the weathered specimens are very anisotropic (10 percent variation) with respect to the vertical direction and much of the other material is slightly anisotropic (2 percent variation).

5. An assessment of the area on a hole-to-hole basis indicates that the area in the vicinity of Holes C-CR-5 and -10 appears to offer possibilities as a uniform, competent hard rock medium. The area geographically defined by the other drill holes apparently contains significant amounts of weathered and fractured rocks.

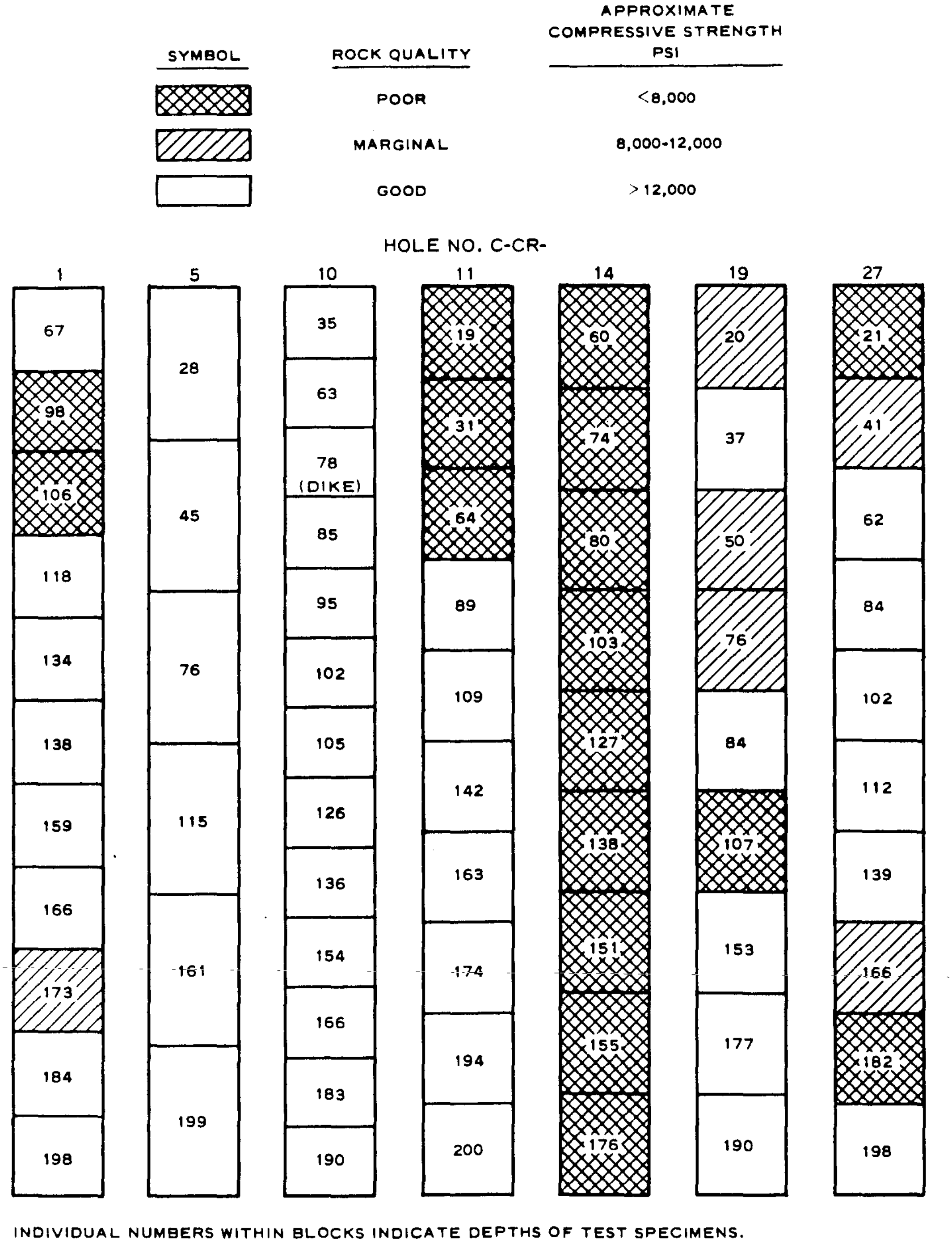


Figure 5.1 Depth versus quality for individual holes.

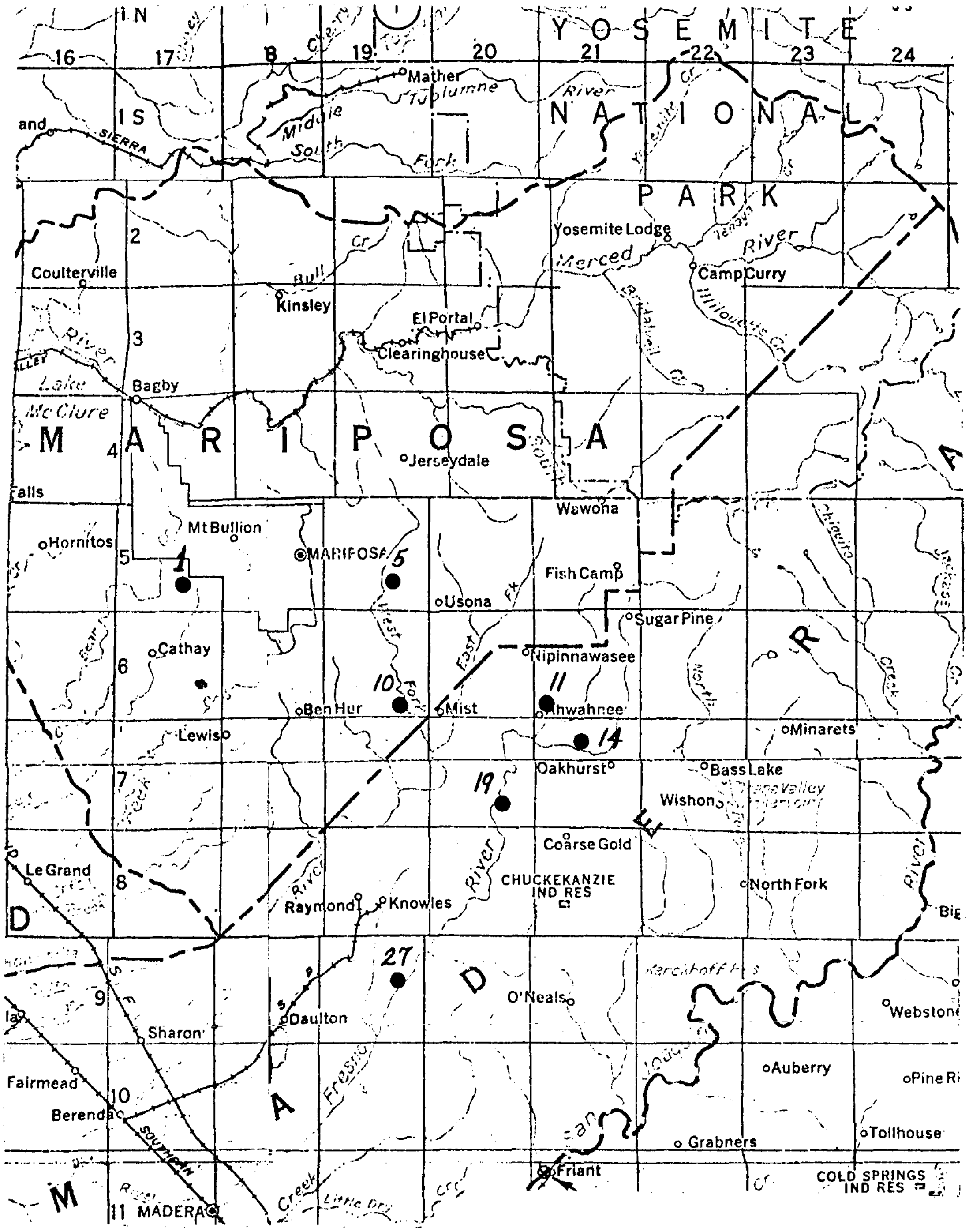


Figure 5.2 Location of drill holes.

APPENDIX A

DATA REPORT - C-CR-10 CORES

12 March 1969

Hole Location: Mariposa County, California

Township 6S, Range 19E, Section 34

Core Piece No.	Approximate Depth, ft
1	35
2	37
3	55
4	63
5	69
6	78
7	85
8	95
9	102
10	105
11	120
12	126
13	136
14	154
15	166
16	183
17	190

SERIES I TESTS

Results

Core samples

1. About 23 ft of NX rock core samples from 34.4 to 191.0 ft deep in hole C-CR-10 were received on 19 February 1969 for testing. Field logs indicate the samples were mostly granodiorite with aplite dikes and quartz diorite, and diabase.

2. The samples were grouped as given below according to obvious differences in color and texture.

Group No.	Sample No.	Description
1	1-4 and 9	Fine grained, light tan color; except 9, white color
2	5-8, 10-11, & 15	Fine grained, gray colored; No. 6 had dike
3	12-14	Medium grained, gray
4	16-17	Coarse grained, gray, salt and pepper appearance

A photograph of end pieces representing each group is shown in plate 1.

Uniformity tests

3. To determine variations within the hole specific gravity, Schmidt hammer, compressive strength, and compressional wave velocity tests were conducted on representative specimens of the four groups. Results are given below:

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
			Group 1		
1	2.616	42.8	3.68	11,950	18,970
4a	2.622	40.6	4.49	13,875	13,830
4b	2.623	39.8	3.94	12,905	19,510
9a	2.628	43.0	4.54	13,090	19,460
Average	2.622	41.6	4.16	12,955	17,940
			Group 2		
6a	2.815	--	--	16,585	7,200*
7a	2.857	47.2	3.43	16,490	23,480
8	2.864	52.9	4.52	18,335	30,280
10	2.841	56.5	4.05	19,330	31,860
15a	2.825	49.2	4.55	16,725	19,800
Average	2.847	51.5	4.14	17,720	26,360
			Group 3		
12a	2.824	53.3	6.03	19,040	24,770
13a	2.891	55.9	4.96	20,105	11,710*
14a	2.805	55.7	5.54	19,100	24,280
Average	2.840	54.7	5.51	19,415	24,530
			Group 4		
16a	2.780	49.3	3.54	15,685	19,080
17	2.813	51.3	3.66	17,070	20,710
Average	2.796	50.3	3.60	16,377	19,900

*Deleted from average.

4. The Schmidt hammer test was not conducted on specimen No. 6a, which contained an aplite dike at an approximate 30-deg angle to the axis of the core. The specimen failed along the dike at a substantially lower stress than comparable specimens without dikes. Specimen 13a broke along a fracture plane, which apparently existed, but was undetected, prior to testing. All tests indicate that the fine-grained, possibly

weathered material of group 1 and the coarse-grained rock of group 4, are apparently slightly less competent than the other two materials.

5. Porosity and tensile strength tests conducted on random samples from each group yielded results commensurate with the specific gravity and compressive strength results.

Porosity		Tensile Strength	
Specimen	Percent	Specimen	psi
4a	1.8	2	740
7a	0.6	6b	1645
14a	1.0	13b	1585
Average	1.1	16b	1465
		Average	1360

Moduli of deformation

6. Representative samples for dynamic and static moduli test were selected from the four groups of core. After the dynamic tests were completed, a portion of each sample was prepared for static testing. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given below:

Specimen No.	Modulus, psi x 10^6			Poisson's Ratio	Wave Velocity, fps	
	Young's	Shear	Bulk		Shear	Compressional
			Dynamic			
4	4.71	2.26	1.71	0.04*	8,060	13,195
7	9.22	4.30	3.57	0.07*	10,640	17,530
12	12.81	5.29	7.36	0.21	11,810	20,515
			Static			
4b	5.0	2.16	2.37	0.15	--	--
8	10.4	4.33	5.78	0.20	--	--
13a	10.5	4.53	5.15	0.16	--	--
17	9.4	3.79	6.03	0.24	--	--

*Doubtful result.

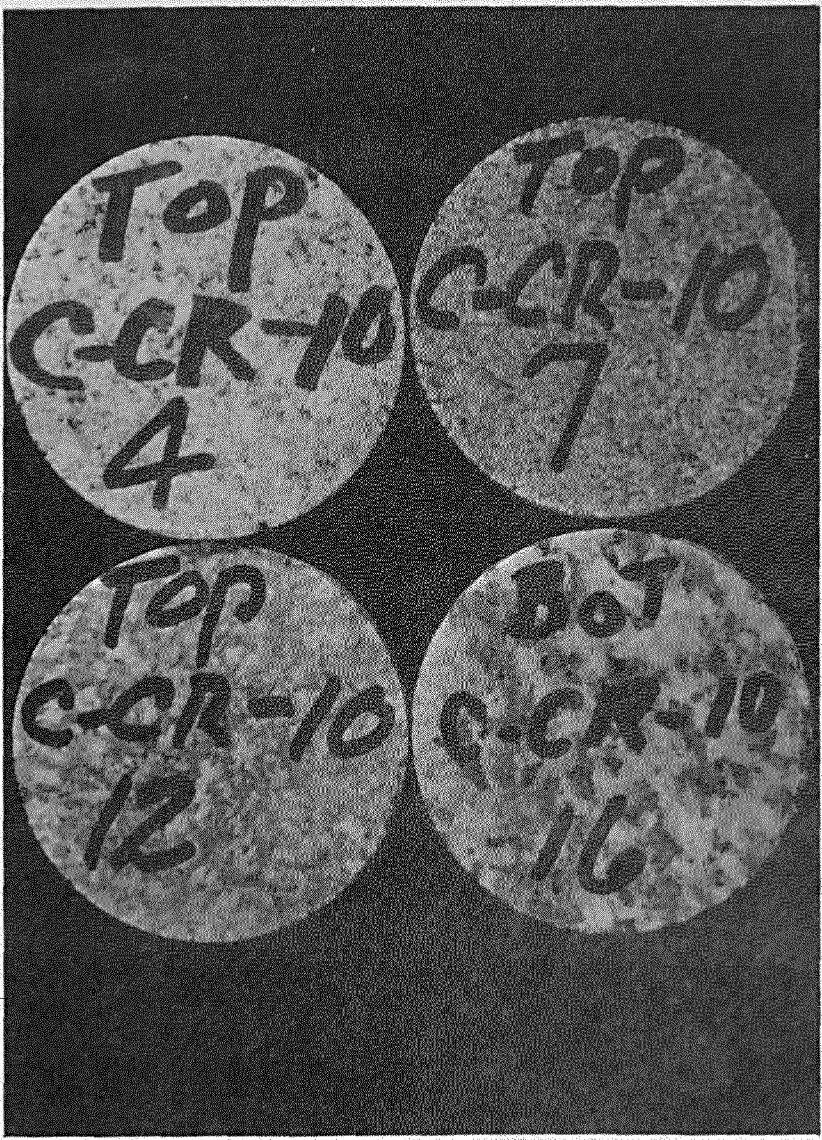
7. The dynamic tests represent groups 1, 2, and 3, and the static tests represent all 4 groups. The static and dynamic Young's moduli compare fairly well; however, the static shear and bulk moduli are probably more representative due to the more reasonable Poisson's ratios obtained statically.

8. Stress-strain curves for specimens 4b, 8, 13a, and 17 are given in plates 3, 4, 5, and 6, respectively. Specimen 4b was cycled at 8000 and 16,000 psi, specimen 8 at 8000 and 16,000 psi, specimen 13a at 10,000 psi, and specimen 17 at 10,000 psi. Only specimen 4b exhibited a significant amount of hysteresis. The erratic behavior of the gages on specimen 13a was probably associated with slippage on the preexisting fracture plane detected during compression testing (paragraph 4).

Conclusions

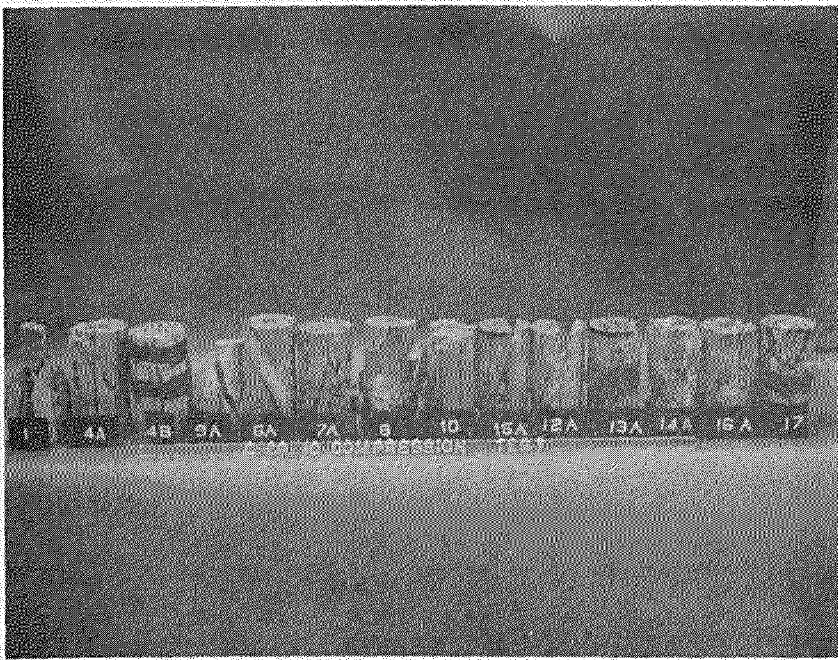
9. The core log indicated that the samples received from hole C-CR-10 for testing, (34.4 to 191.0 ft) to be predominantly granodiorite with aplite dikes. The samples were grouped according to color and texture and tested for quality and uniformity. Typical properties are given below:

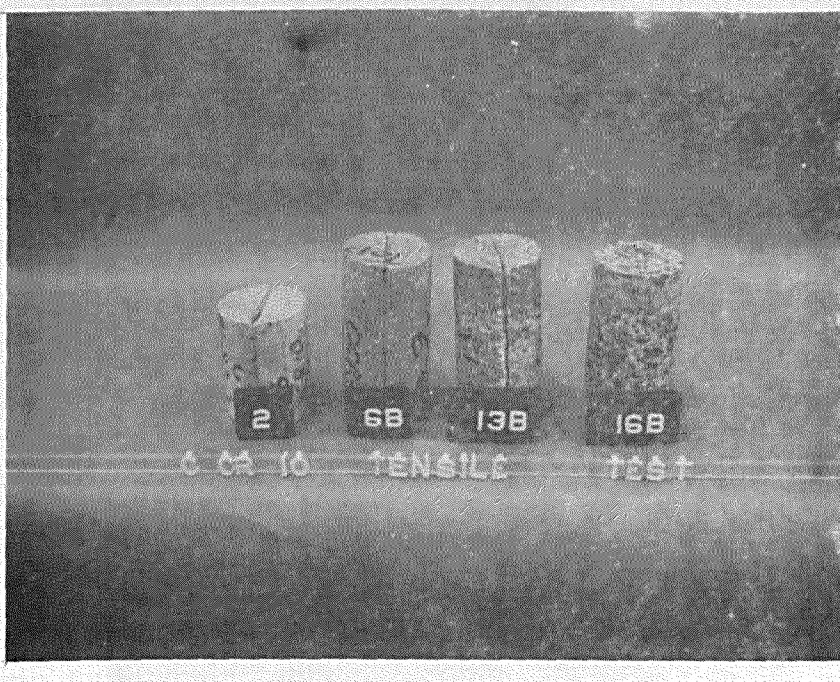
Property	Group 1	Group 2	Group 3	Group 4
Description	Fine grained light tan	Fine grained gray	Medium grained gray	Coarse grained gray
Specific gravity	2.62	2.85	2.84	2.80
Percent porosity	1.8	0.6	1.0	--
Compressive strength, psi	17,940	26,360	24,530	19,900
Young's modulus, psi x 10^6	5.0	10.4	10.5	9.4
Compressional wave velocity fps	12,955	17,720	19,415	16,375
Tensile Strength, psi	740	1,645	1,585	1,465



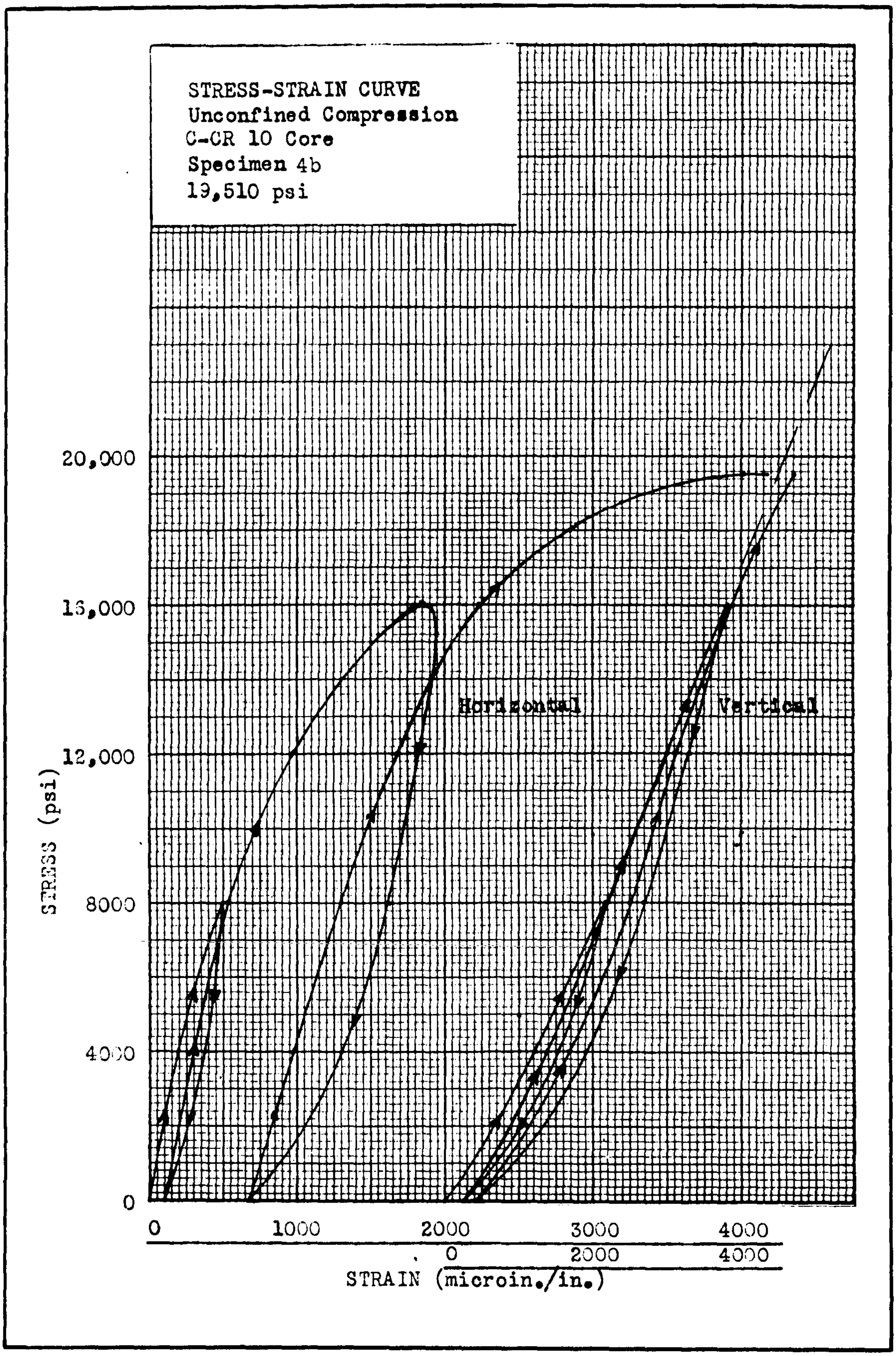
End Pieces Cut From Test Specimens

PLATE 1





Posttest Photographs of Test Specimens



STRESS-STRAIN CURVE
Unconfined Compression
C-CR 10 Core
Specimen 4b
19,510 psi
20,000
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
2000
4000
STRAIN (microin./in.)

PLATE 3

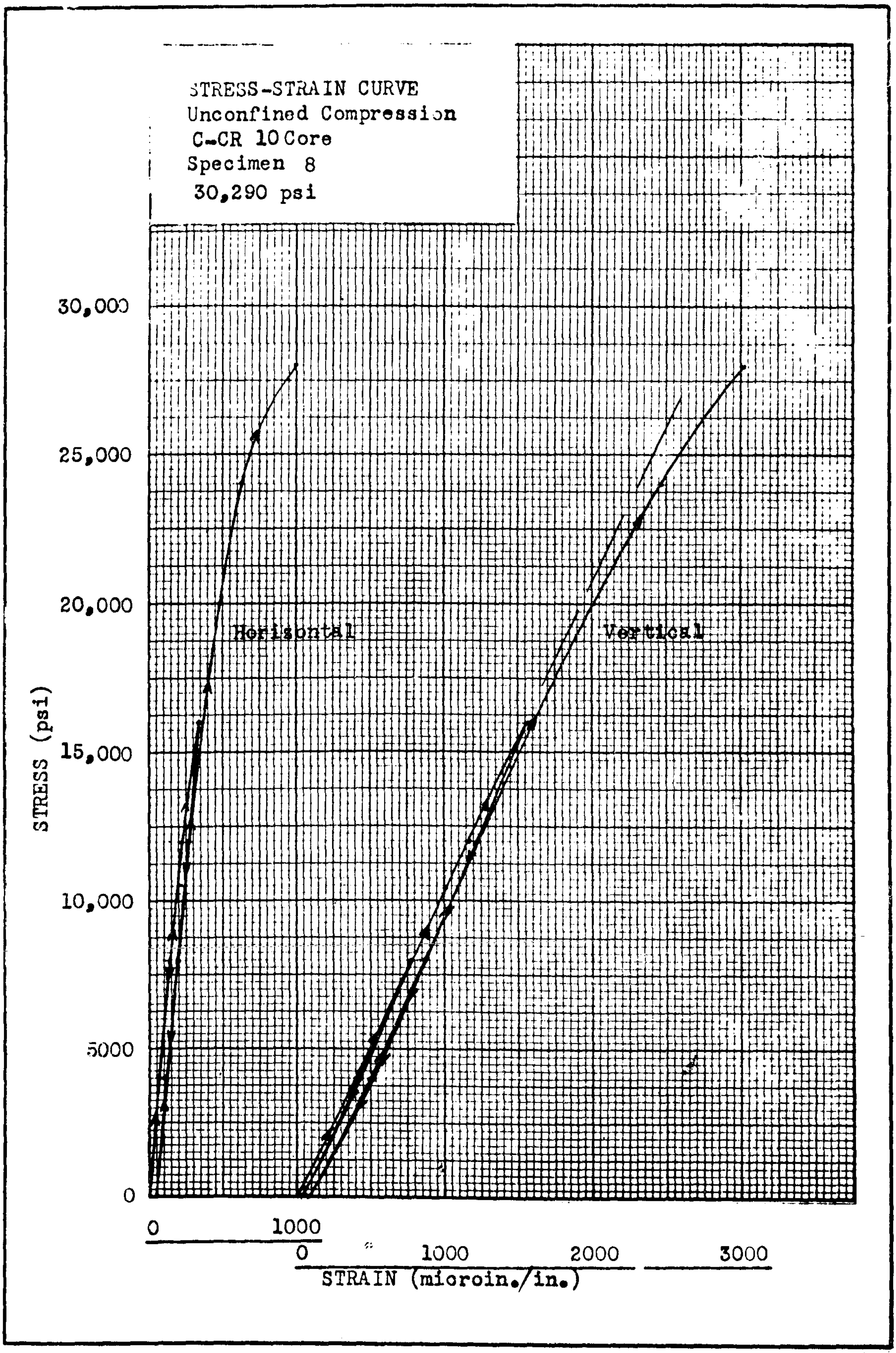

STRESS-STRAIN CURVE
Unconfined Compression
C-CR 10 Core
Specimen 8
30,290 psi
STRESS (psi)
30,000
25,000
20,000
15,000
10,000
5000
0
Horizontal
Vertical
0
1000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 4

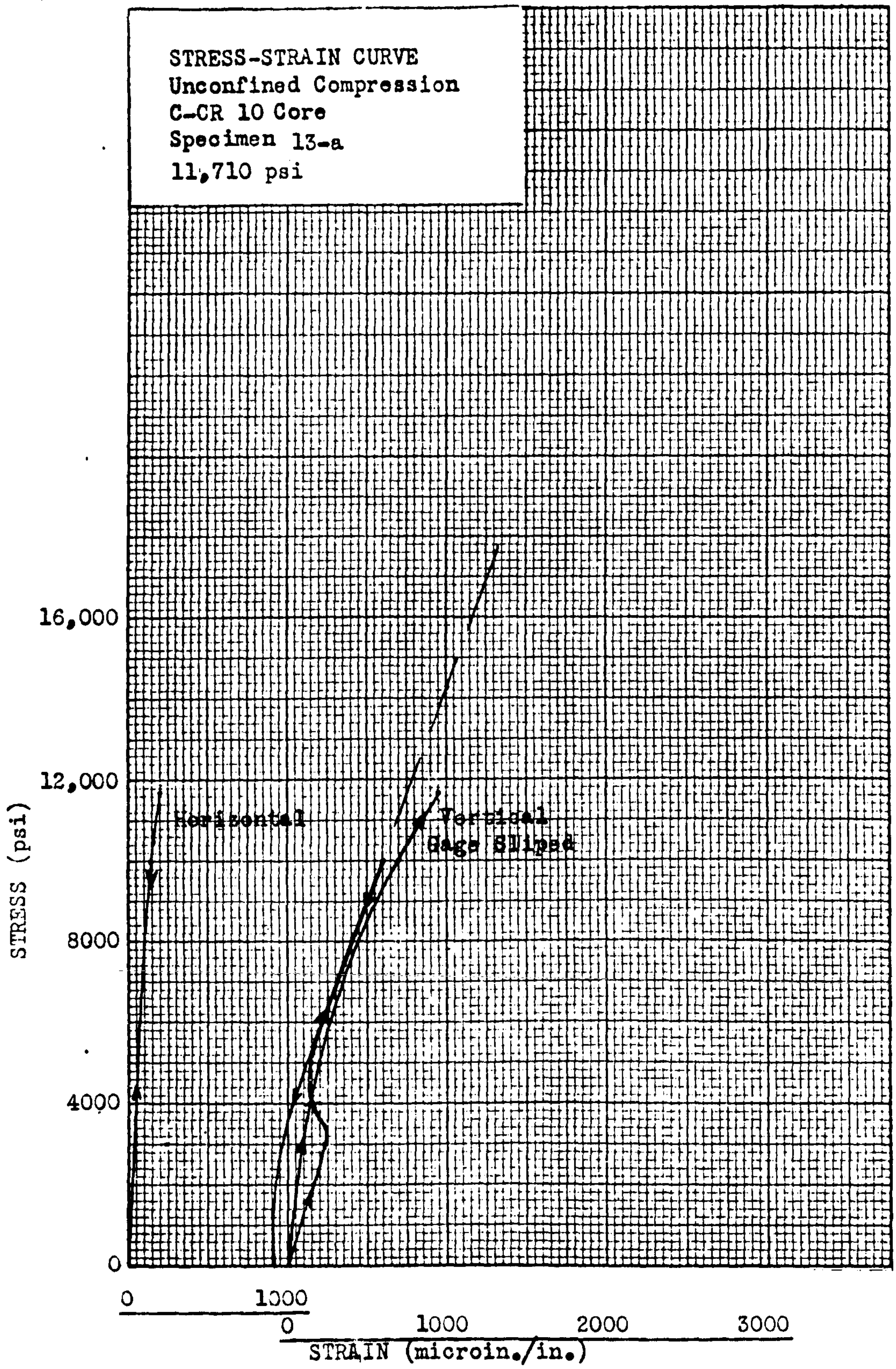

STRESS-STRAIN CURVE
Unconfined Compression
C-CR 10 Core
Specimen 13-a
11,710 psi
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
Gage Slipped
0
1000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 5

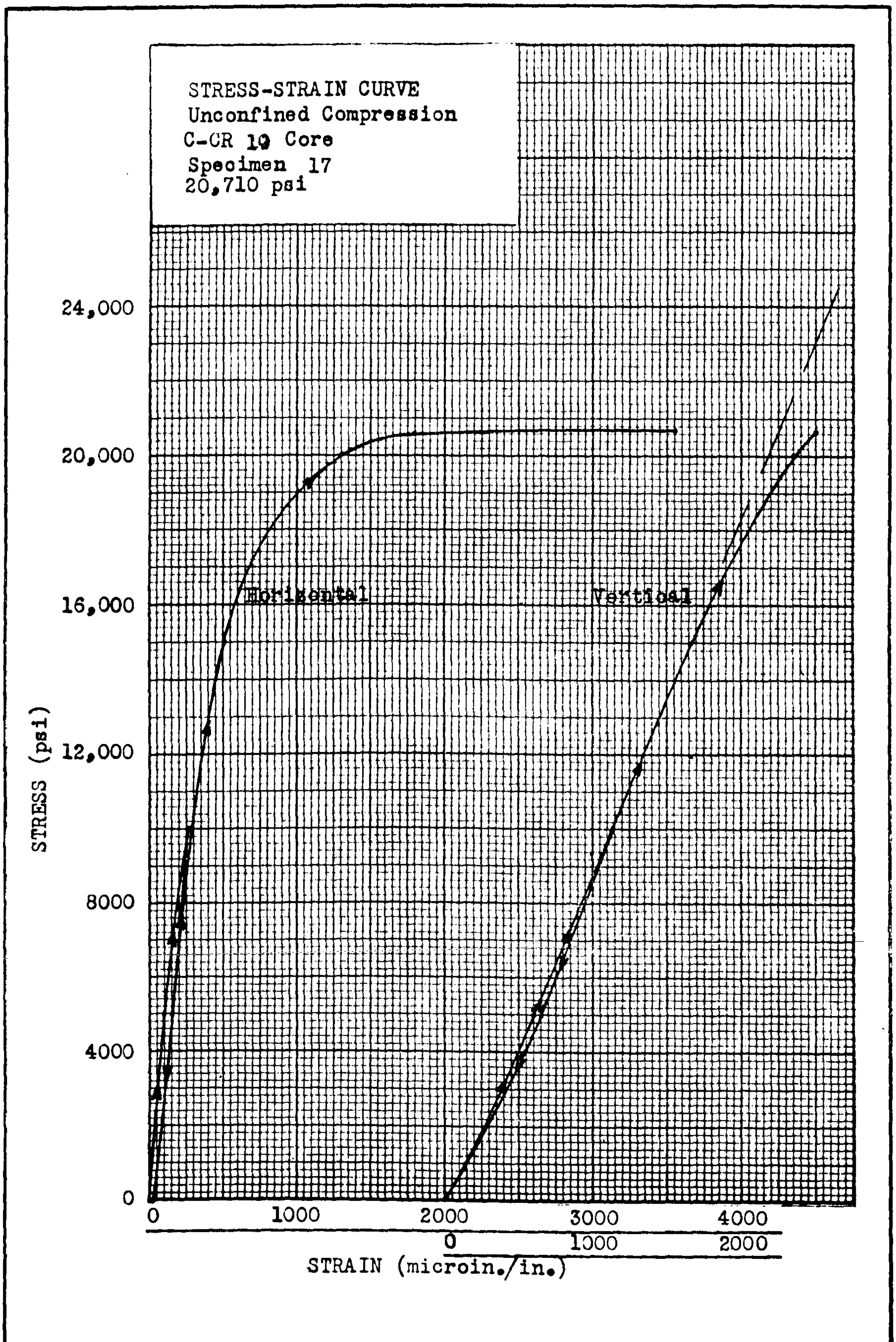

STRESS-STRAIN CURVE
Unconfined Compression
C-CR 10 Core
Specimen 17
20,710 psi
24,000
20,000
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
STRAIN (microin./in.)

PLATE 6

APPENDIX B

DATA REPORT - C-CR-19 CORES

14 March 1969

Hole Location: Madera County, California

Township 7S, Range 20E, Section 28

Core Piece No.	Approximate Depth, ft
1	20
2	32
3	37
4	50
5	58
6	67
7	76
8	82
9	84
10	99
11	107
12	126
13	142
14	153
15	167
16	177
17	190
18	198

SERIES I TESTS

Results

Core samples

1. About 17 ft of NX rock core samples from 19.0 ft to 198.7 ft deep in hole C-CR-19 were received on 19 February 1969 for testing. Field logs indicate the samples were granodiorite and granite with some aplite dike intrusions. The core appeared to be somewhat weathered throughout the depths sampled.

2. A description of the samples received is given below:

Group No.	Sample No.	Description
1	1-8, 10, 12-18	Milky white, coarse grained rock
2	9, 11, 17	Tan, medium grained; possibly dikes

A photograph of end pieces cut from representative cores is shown in plate 1.

Uniformity tests

3. To determine variations within the hole, specific gravity, compressive strength, compressional wave velocity, and Schmidt hammer tests were conducted on selected specimens. Results are given below:

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
			Group 1		
1	2.716	29.6	3.33	7,480	9,540
3a	2.728	35.1	3.51	10,895	14,940
4	2.717	34.7	3.33	11,100	11,890
7a	2.727	32.2	4.31	10,055	9,860
7b	2.742	34.9	3.17	10,250	12,910
14	2.732	42.3	3.49	14,380	13,260
16	2.720	45.1	2.77	14,960	18,860
Average	2.727	37.4	3.43	11,940	14,370

(Continued)

(Continued)

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
			Group 2		
9a	2.639	47.6	4.09	14,960	23,800
9b	2.650	46.0	3.21	14,525	13,740
11	2.666	--	--	10,605	2,700*
17a	2.605	--	--	15,300	22,890
17b	2.690	--	--	16,730	13,760**
Average	2.650	46.8	3.65	14,425	18,550

*Highly fractured; deleted from average.
**Contained joint of dike with parent rock.

4. All four tests indicate that the parent rock, group 1, is less competent than all four groups of rock from hole C-CR-10 with the exception of the specific gravity in one case (2.62 vs 2.73). The dike material of group 2 is apparently as competent as the rock of group 1. A contact surface between the intruding material and parent rock was included in specimen 17b. Significantly, the results are comparable to results on the two materials tested separately. Both materials are quite variable in strength and compressive wave velocity.

5. Porosity and tensile strength tests were conducted on selected samples as given below:

Porosity Specimen	Porosity Percent
7a	0.7
9b	0.0
Average	0.4

Tensile Strength Specimen	Tensile Strength psi
3b	620
3c	525
10a	890
10b	645
14a	735
Average	685

The tensile strength is also relatively low compared to the C-CR-10 material. Posttest photographs of the test specimens are shown in plate 2.

Moduli of deformation

6. Representative specimens for dynamic moduli tests were selected from the two groups. After the dynamic tests were completed, a portion of each sample was prepared for static compression tests. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimen. Results are given below:

Specimen No.	Modulus, psi x 10^6 Young's	Shear	Bulk	Poisson's Ratio	Wave Velocity, fps Shear	Compressional
			Dynamic			
4	3.14	1.48	1.19*	0.06*	6430	11,135
9	6.99	3.04	3.33	0.15	9330	15,225
16	6.27	2.81	2.75	0.12	8800	14,960
			Static			
4	4.00	1.57	2.89	0.25	--	--
9a	5.75	2.36	3.42	0.22	--	--
16	8.40	3.47	4.83	0.21	--	--

*Doubtful result.

7. The differences in dynamic and static moduli are probably due predominantly to differences in test methods. For a stressed rock, the static results are probably more representative since the moduli are computed at approximately half of the ultimate strength.

8. Stress-strain curves for specimens 4, 9a, and 16 are given in plates 3, 4, and 5, respectively. All specimens were cycled at 5000 and 10,000 psi. Significant hysteresis occurred only in the stress-strain curve obtained on specimen No. 4.

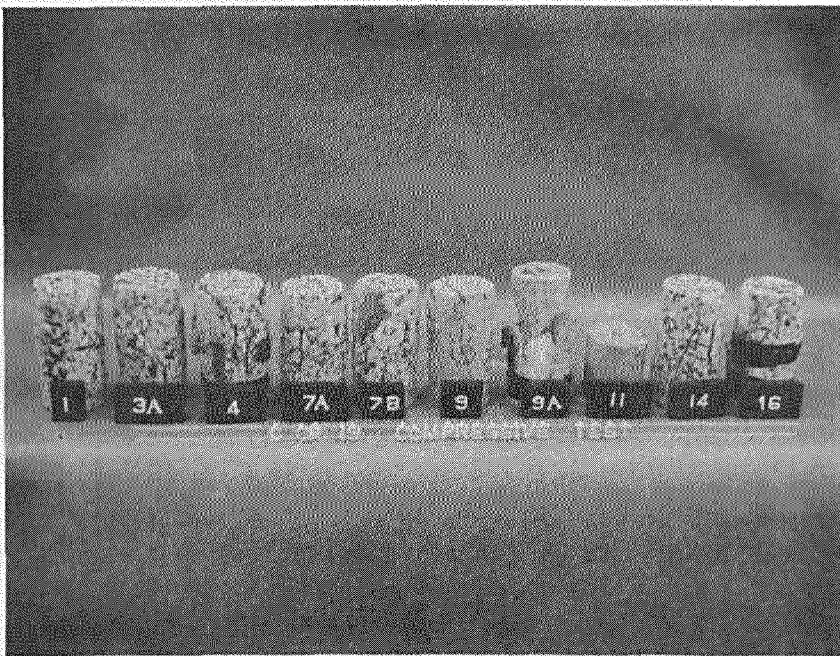
Conclusions

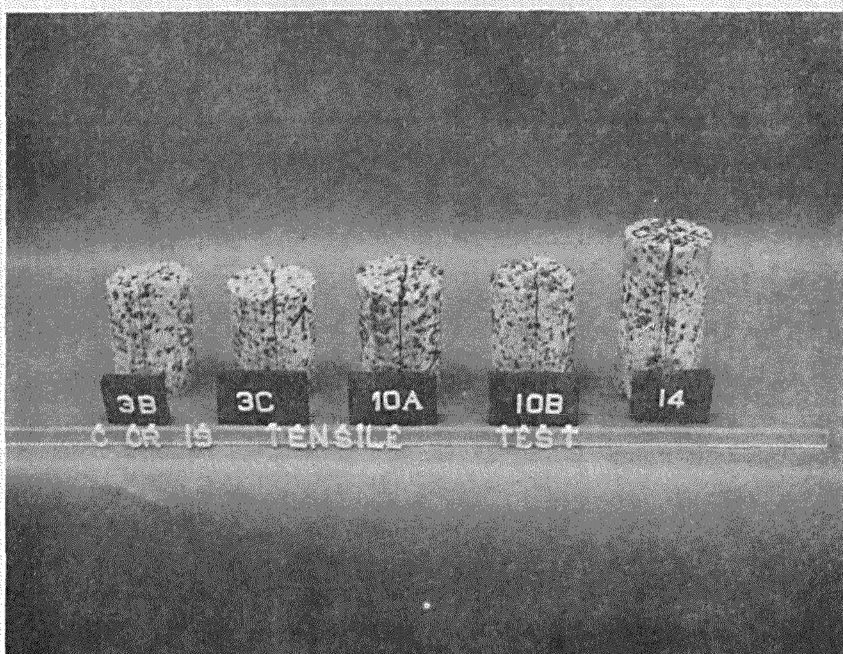
9. The core log indicated the samples received from hole C-CR-19 for testing to be granodiorite and granite. The core was divided into two groups for testing; one of the parent rock and one of possible dike intrusions. Results indicate that the C-CR-19 rock is not as competent as the rock from C-CR-10, and is not detrimentally affected by intruding dikes. Typical properties are given below:

Property	Group 1	Group 2
Description	Milky white, coarse grained	Tan, medium grained
Specific gravity	2.73	2.65
Porosity, percent	0.7	0.0
Schmidt rebound No.	37.4	46.8
Compressive strength, psi	14,370	18,550
Young's modulus, psi x 10^6	6.2	5.8
Compressional wave velocity	11,940	14,425
Tensile strength, psi	685	--

End Pieces Cut From Test Specimens

PLATE 1





Posttest Photographs of Test Specimens

PLATE 2

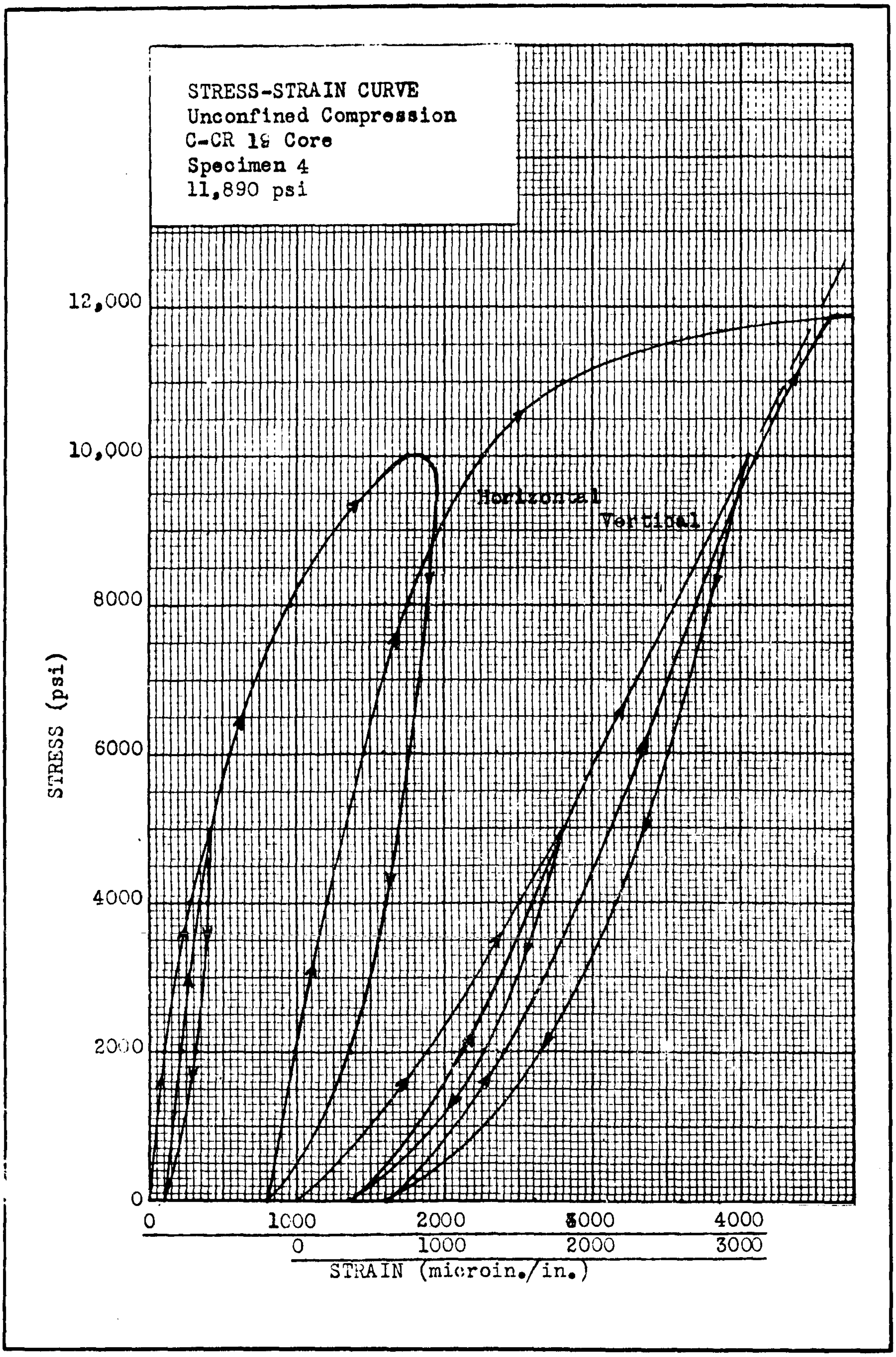
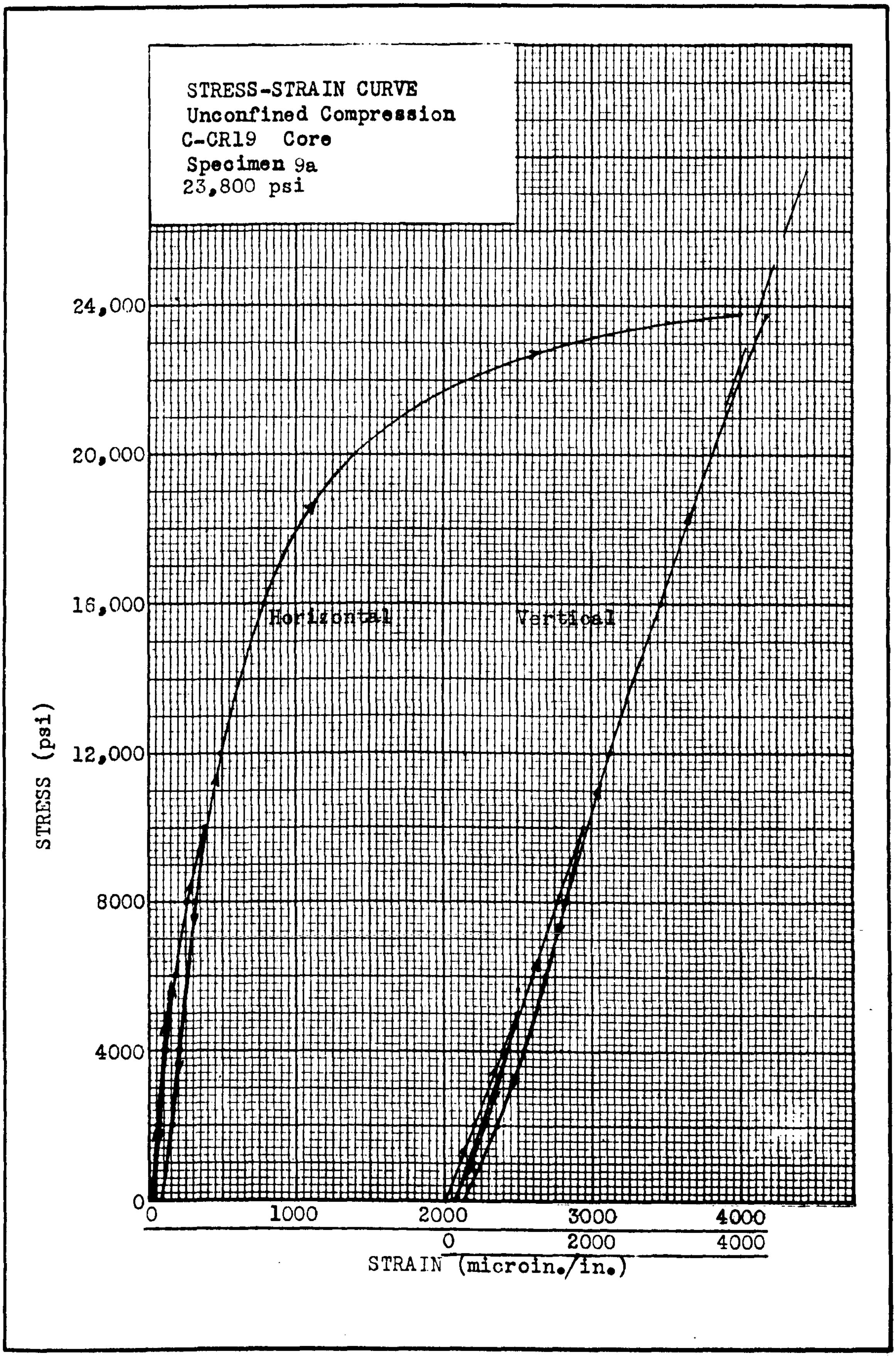

STRESS-STRAIN CURVE
Unconfined Compression
C-CR 1& Core
Specimen 4
11,890 psi
12,000
10,000
8000
6000
4000
2000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 3


STRESS-STRAIN CURVE
Unconfined Compression
C-CR19 Core
Specimen 9a
23,800 psi
24,000
20,000
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
2000
4000
STRAIN (microin./in.)

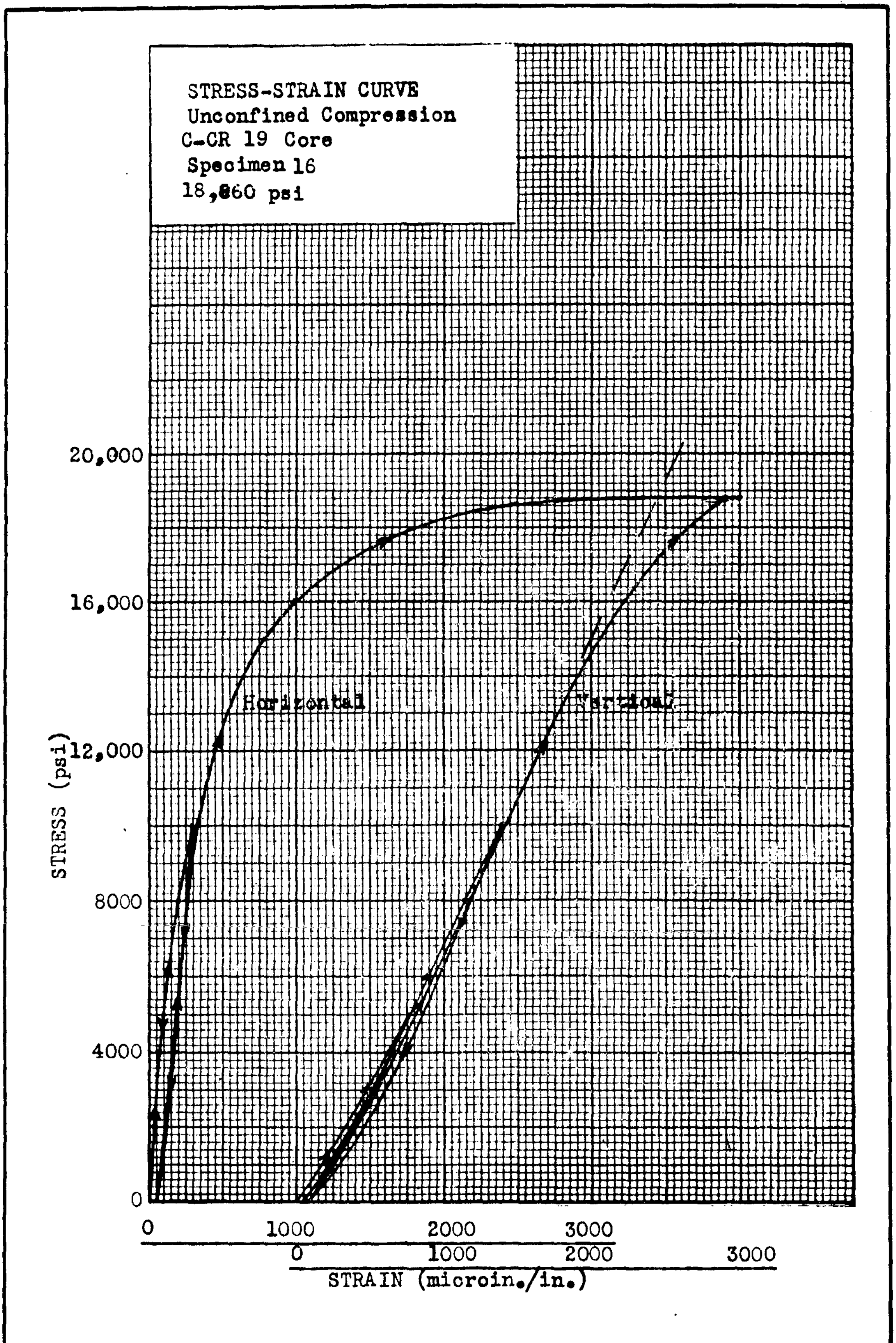

STRESS-STRAIN CURVE
Unconfined Compression
C-CR 19 Core
Specimen 16
18,860 psi
20,000
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 5

APPENDIX C

DATA REPORT - C-CR-5 CORES

19 March 1969

Hole Location: Mariposa County, California

Township 5S, Range 19E, Section 28

Core Piece No.	Approximate Depth, ft
1	15
2	28
3	37
4	45
5	48
6	65
7	76
8	86
9	115
10	140
11	161
12	179
13	199

SERIES I TEST

Results

Core samples

1. About 16 ft of NX rock core samples from 13.5 to 199.0 ft deep in hole C-CR-5 were received on 19 February 1969 for testing. Field logs indicated the samples were granodiorite with a few aplite dikes and quartz veins.

2. A description of the samples received is given below:

Sample No.	Description
1-3, 5-13	Coarse grained, light gray, salt and pepper effect. No. 9 had 2-1/2-in. wide vein or dike. No. 7 had vein at very top.
4	Fine grained, dense dark gray, entire specimen possibly quartz diabase dike.

A photograph of representative end pieces is given in plate 1.

Uniformity tests

3. To determine variations within the hole specific gravity, compressive strength, compressional wave velocity, and Schmidt hammer tests were conducted on specimens selected throughout the length of core received. Results are given below:

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
2a	2.769	43.5	2.41	14,650	14,130
4a	2.774	46.0	2.25	14,460	29,140
4b	2.792	46.9	2.55	14,650	27,430
7	2.768	54.9	2.74	17,840	22,810
9a	2.701	--	--	16,360	25,570
9b	2.788	51.4	3.37	16,830	20,210
11a	2.783	49.4	2.18	15,760	18,070
13a	2.783	47.3	3.28	14,880	22,430
Average	2.770	48.5	2.68	15,680	22,470

4. The results indicate that all of the material sampled and tested is rather competent rock. Due to the relative uniformity, grouping of results by apparent mineralogy or texture was not necessary. Some weathering is indicated in the upper area as evidenced by the lower results obtained on sample 2a. However, the obvious differences, veins or dikes in specimens 7 and 9a and the apparent dike inclusive of specimen 4, did not significantly alter the results. Like the CR-19 core and unlike the CR-10 core, the intrusions are at a relatively low angle to the axis of the core which surely affects their influence on the test properties, especially the compressive strength.

5. Porosity and tensile strength tests conducted on several specimens yielded results which correlated well with the specific gravity and compressive strength results:

Porosity		Tensile Strength	
Specimen	Percent	Specimen	psi
4b	1.1	2b	600
11	1.4	4c	1590
		11b	900
		13b	1030

Posttest photographs of test specimens are given in plate 2.

Moduli of deformation

6. Samples representative of the different materials in the hole were selected for deformation moduli tests. After dynamic tests were completed, a portion of each sample was prepared for static testing. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given below:

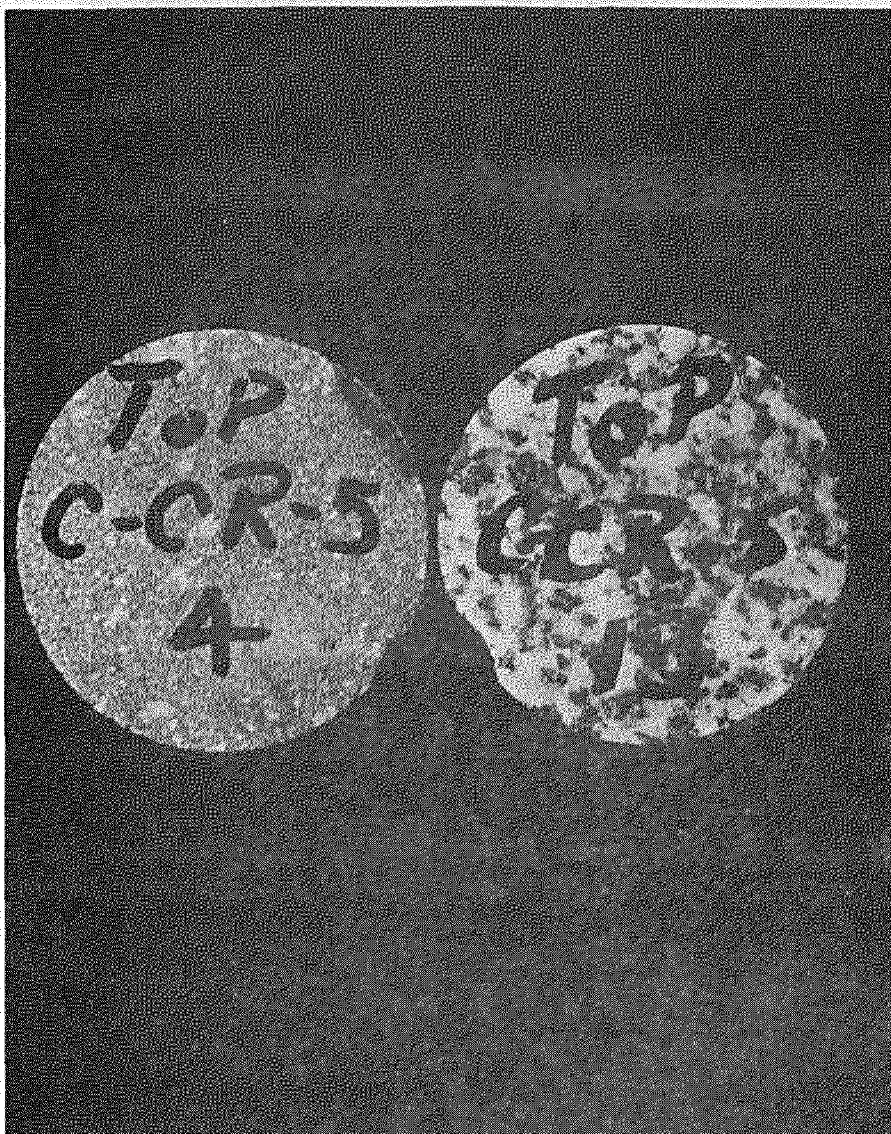
Specimen No.	Modulus, psi x 10^6 Young's	Shear	Bulk	Poisson's Ratio	Wave Velocity, fps Compressional	Shear
			Dynamic			
2	5.74	2.24	4.35	0.28	14,060	7820
4	6.54	2.88	3.03	0.14	13,910	8845
9	7.79	3.44	3.51	0.13	16,295	9665
			Static			
2a	5.20	2.02	4.13	0.29	--	--
4a	6.20	2.58	3.44	0.20	--	--
13a	8.20	3.25	5.69	0.26	--	--

7. Stress-strain curves for specimens 2a, 4a, and 13a are given in plates 3, 4, and 5, respectively. Specimen 2a was cycled at 5000 and 10,000 psi, specimen 4a at 10,000 and 20,000 psi, and specimen 13a at 8000 and 16,000 psi. All specimens exhibited a small amount of hysteresis.

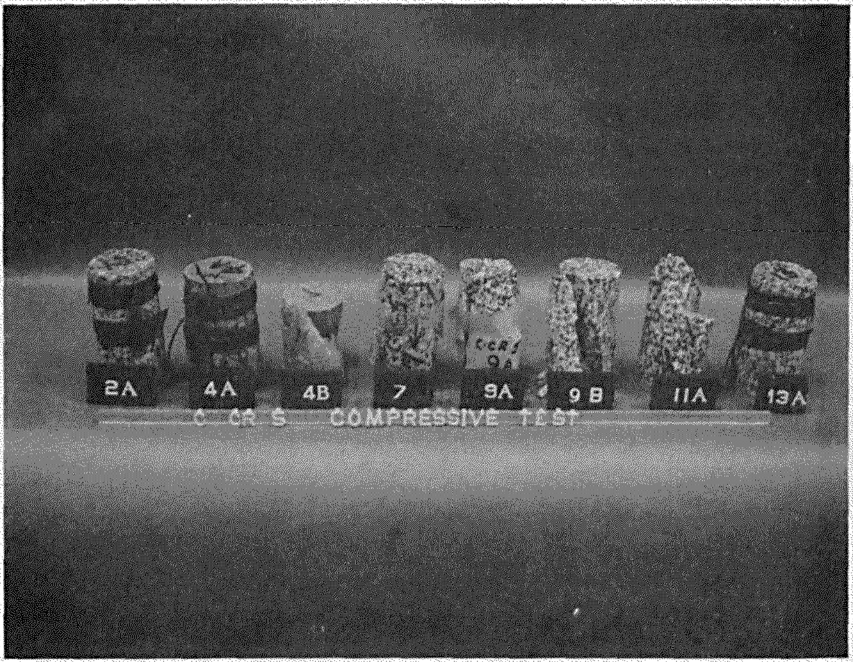
Conclusions

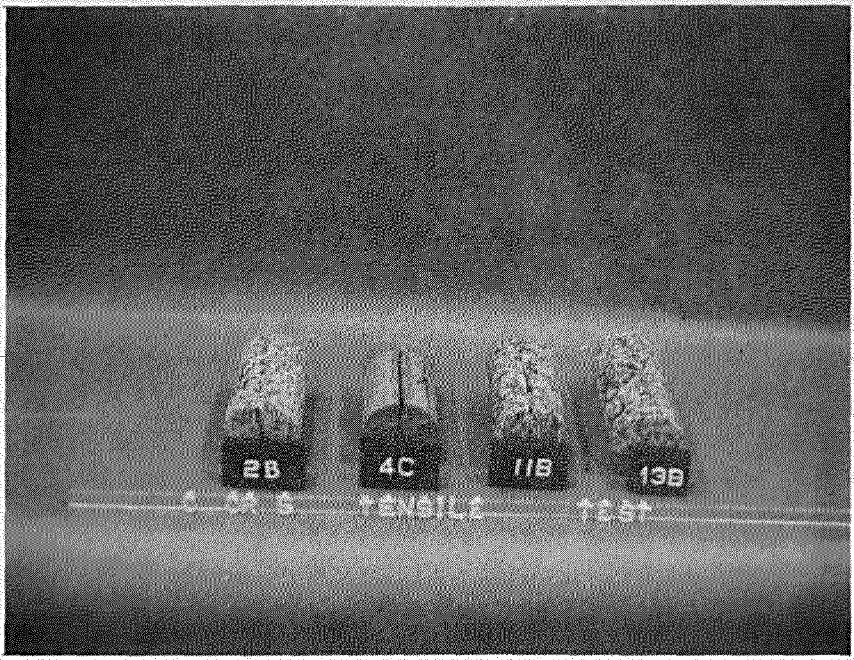
8. The core log indicated that the samples received from hole C-CR-5 for testing from 14 to 200 ft to be granodiorite with a few intrusions at low angles to the axis of the drilled core. The intruding dikes and veins did not significantly affect the test data; therefore, the test results were averaged for the entire hole:

Property	Result
Specific gravity	2.77
Porosity, percent	1.2
Schmidt rebound No.	48.5
Compressive strength, psi	22,470
Young's modulus, psi x 10^6	6.5
Compressional wave velocity, fps	15,680
Tensile strength	1,030



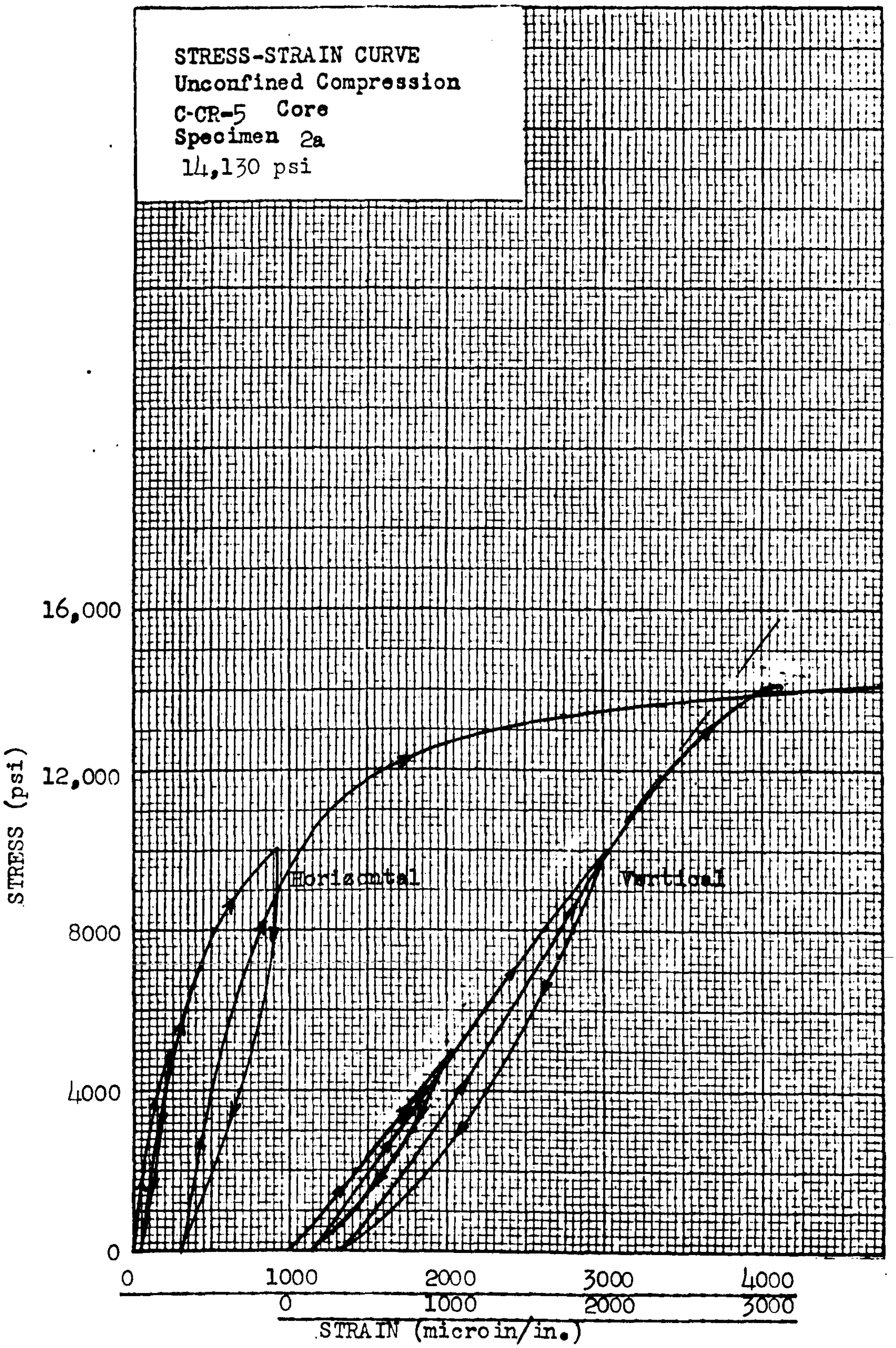
End Pieces Cut From Test Specimens





Posttest Photographs of Test Specimens

PLATE 2


STRESS-STRAIN CURVE
Unconfined Compression
C-CR-5 Core
Specimen 2a
14,130 psi
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN (microin/in.)

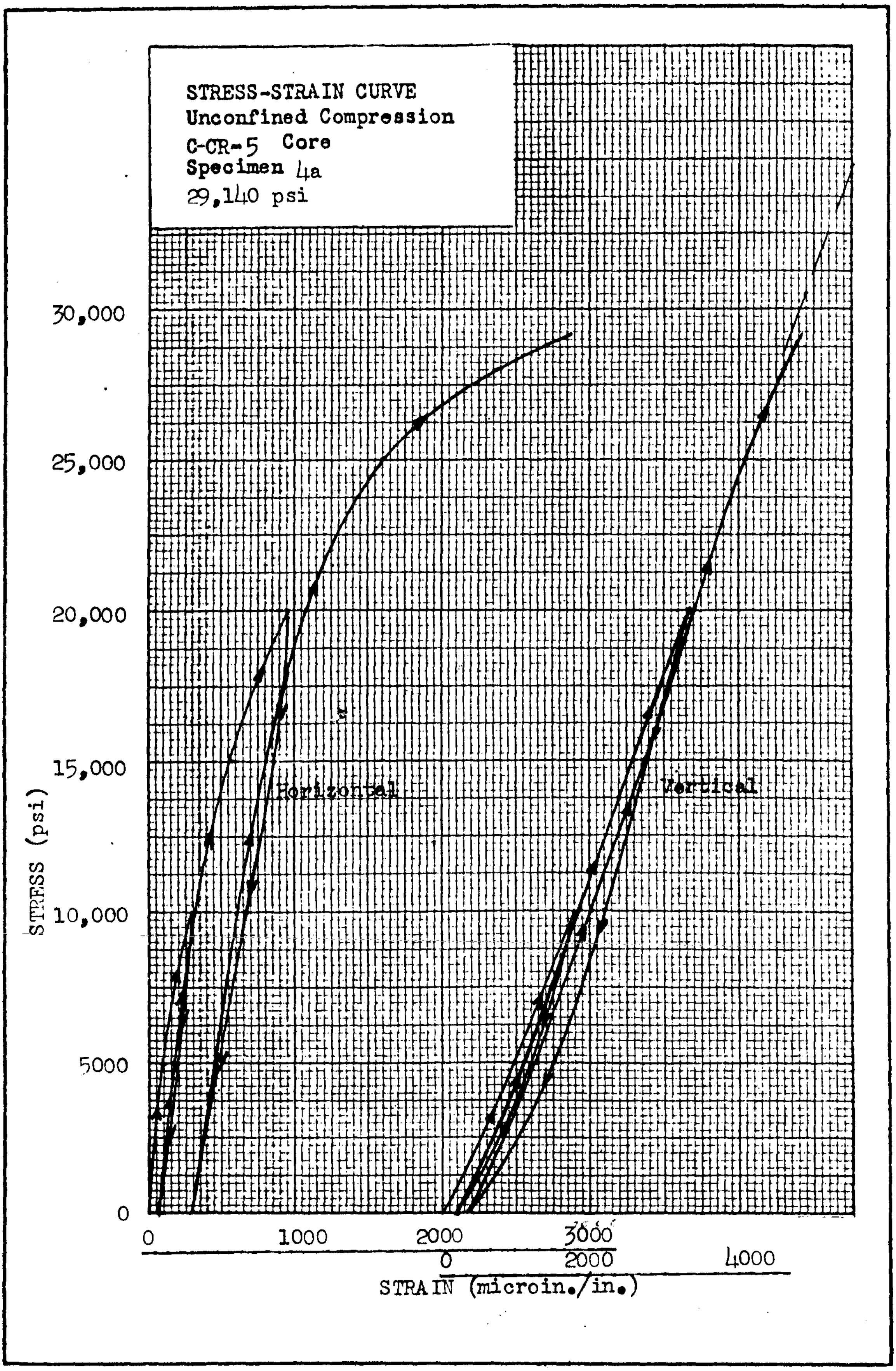

STRESS-STRAIN CURVE
Unconfined Compression
C-CR-5 Core
Specimen 4a
29,140 psi
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
0
2000
4000
STRAIN (microin./in.)

PLATE 4

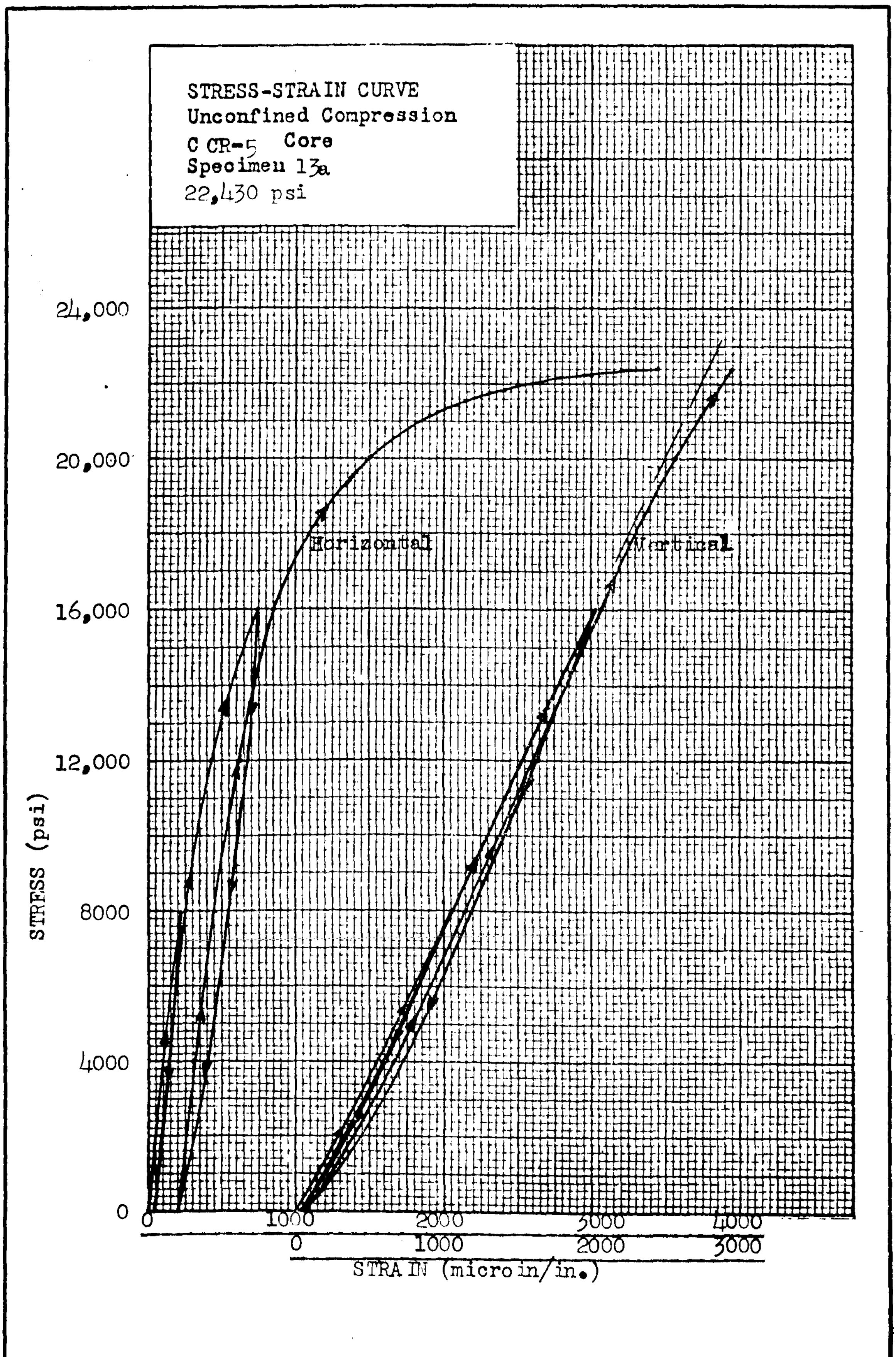

STRESS-STRAIN CURVE
Unconfined Compression
C CR-5 Core
Specimen 13a
22,430 psi
24,000
20,000
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
STRAIN (micro in/in.)

PLATE 5

APPENDIX D

DATA REPORT - C-CR-11 CORES

20 March 1969

Hole Location: Madera County, California

Township 6S, Range 21E, Section 30

Core Piece No.	Approximate Depth, ft
1	19
2	31
3	43
4	54
5	64
6	78
7	81
8	89
9	99
10	109
11	123
12	132
13	142
14	153
15	163
16	174
17	184
18	194
19	200

SERIES I TESTS

Results

Core samples

1. About 29 ft of NX rock core samples from 18.2 to 200.4 ft deep in hole C-CR-11 were received on 25 February 1969 for testing. Field logs indicated the samples were granodiorite weathered to a depth of approximately 30 ft. All of the samples received were black speckled, white rock, i.e. salt and pepper effect, with no apparent intrusions. The core pieces designated 1 and 2 appeared to be highly weathered and 5 moderately weathered. A photograph of the end pieces cut from samples 2 and 16 is given in plate 1.

Uniformity tests

2. To determine variations within the hole, specific gravity, compressive strength, compressional wave velocity, and Schmidt hammer tests were conducted on selected specimens. Results are given below:

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
			Highly Weathered Rock		
1a	2.561	13.9	2.50	4,770	1,330
1b	2.574	14.0	2.24	4,515	--
2a	2.645	--	--	4,230	3,050
2b	2.627	--	--	4,060	2,230
Average	2.602	14.0	2.37	4,390	2,200
			Moderately Weathered Rock		
5	2.702	29.9	4.83	7,250	6,170

(Continued)

(Continued)

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
		Unweathered Rock			
8	2.725	49.4	3.06	14,425	12,470
10	2.712	48.0	3.24	13,705	22,000
13a	2.727	50.5	3.56	16,205	25,090
15	2.720	49.2	3.20	13,965	12,280
16	2.721	50.2	4.11	14,250	16,510
18a	2.736	51.5	4.04	15,455	22,730
18b	2.729	51.6	3.51	15,085	22,740
19a	2.718	46.3	3.01	15,000	19,840
Average	2.724	49.6	3.47	14,760	19,210

3. The results indicate that the highly weathered rock is a very incompetent material. Apparently, some weathering existsdown to about the 60-ft depth, the approximate depth of specimen No. 5. The rock below the 60-ft level appears to be relatively competent granodiorite. No dikes or intrusions were evident in any of the cores received.

4. Porosity and tensile strength tests substantiated the findings of the uniformity tests.

Porosity Specimen	Porosity Percent	Tensile Strength Specimen	Tensile Strength psi
1b	6.5	1b	175
13b	1.4	13b	1045
19b	1.0	19b	1240

Posttest photographs of the test specimens are given in plate 2.

5. Representative specimens of weathered and unweathered rock were selected for moduli tests. Dynamic moduli tests were conducted on the entire samples as received after which a static compression test specimen

was cut from the dynamic test sample. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given below:

Specimen No.	Modulus, psi x 10^6 Young's	Shear	Bulk	Poisson's Ratio	Wave Velocity, fps Compressional	Shear
			Dynamic			
1	0.50	0.21	0.25	0.17	4,265	2500
10	6.00	2.65	2.61	0.12	13,885	8530
18	8.60	3.47	5.51	0.24	16,235	9765
			Static			
1a	0.25	*	*	*	--	--
2a	0.20	0.07	0.24	0.36	--	--
10	8.40	3.59	4.24	0.17	--	--
18a	9.00	3.75	5.00	0.20	--	--

*Doubtful results.

The moduli obtained on specimen No. 1 and 2 are the lowest recorded to date in this test program, and are indicative of the highly weathered condition of this rock.

6. Stress-strain curves for specimens 1a, 2a, 10, and 18a are given in plates 3, 4, 5, and 6, respectively. Specimens 1a and 2a were cycled at 1000 psi, specimen 10 at 10,000 psi, and specimen 18a at 10,000 and 20,000 psi. Predictably, specimens 1a and 2a exhibited considerable hysteresis.

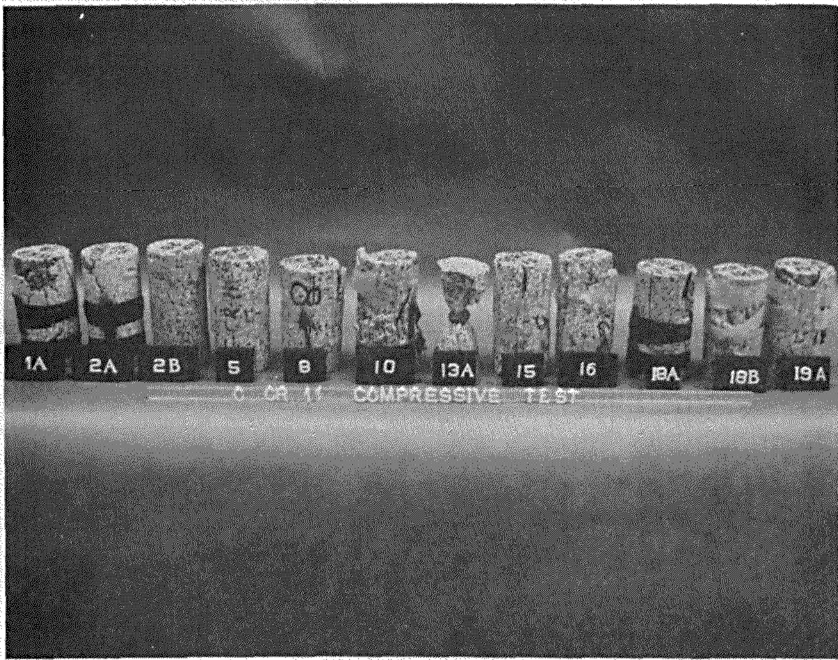
Conclusions

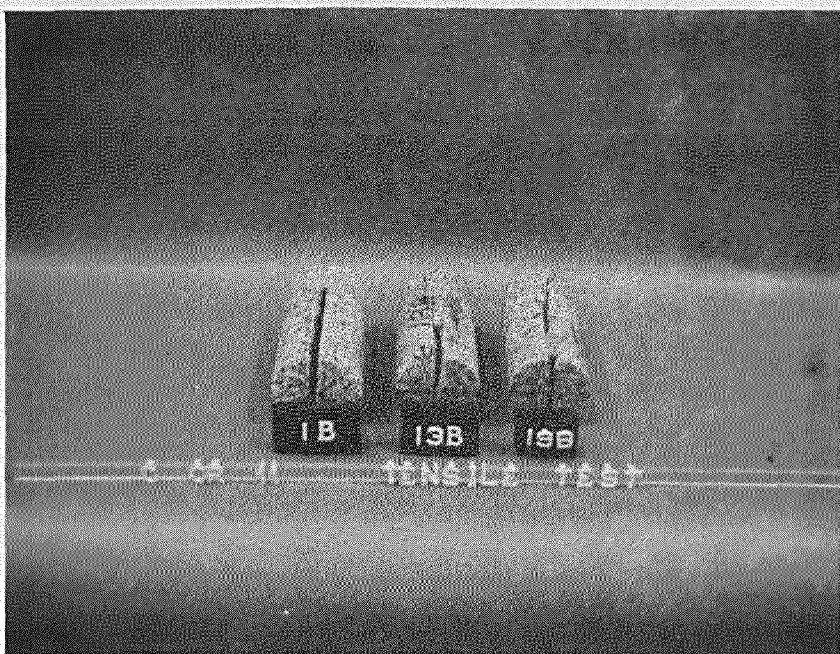
7. The core log indicated the samples received from hole C-CR-11 for testing to be salt and pepper colored granodiorite. The test

results verified the visual observation that the rock was apparently highly weathered near the surface to moderately weathered at approximately 60 ft. Typical properties are given below:

Property	Highly Weathered	Moderately Weathered	Unweathered
Specific gravity	2.60	2.70	2.72
Porosity, percent	6.5	--	1.2
Schmidt rebound No.	14	30	50
Compressive strength, psi	2200	6170	19,210
Young's modulus, psi x 10^6	0.30	--	8.00
Compressional wave velocity, fps	4390	7250	14,760
Tensile strength, psi	175	--	1,140

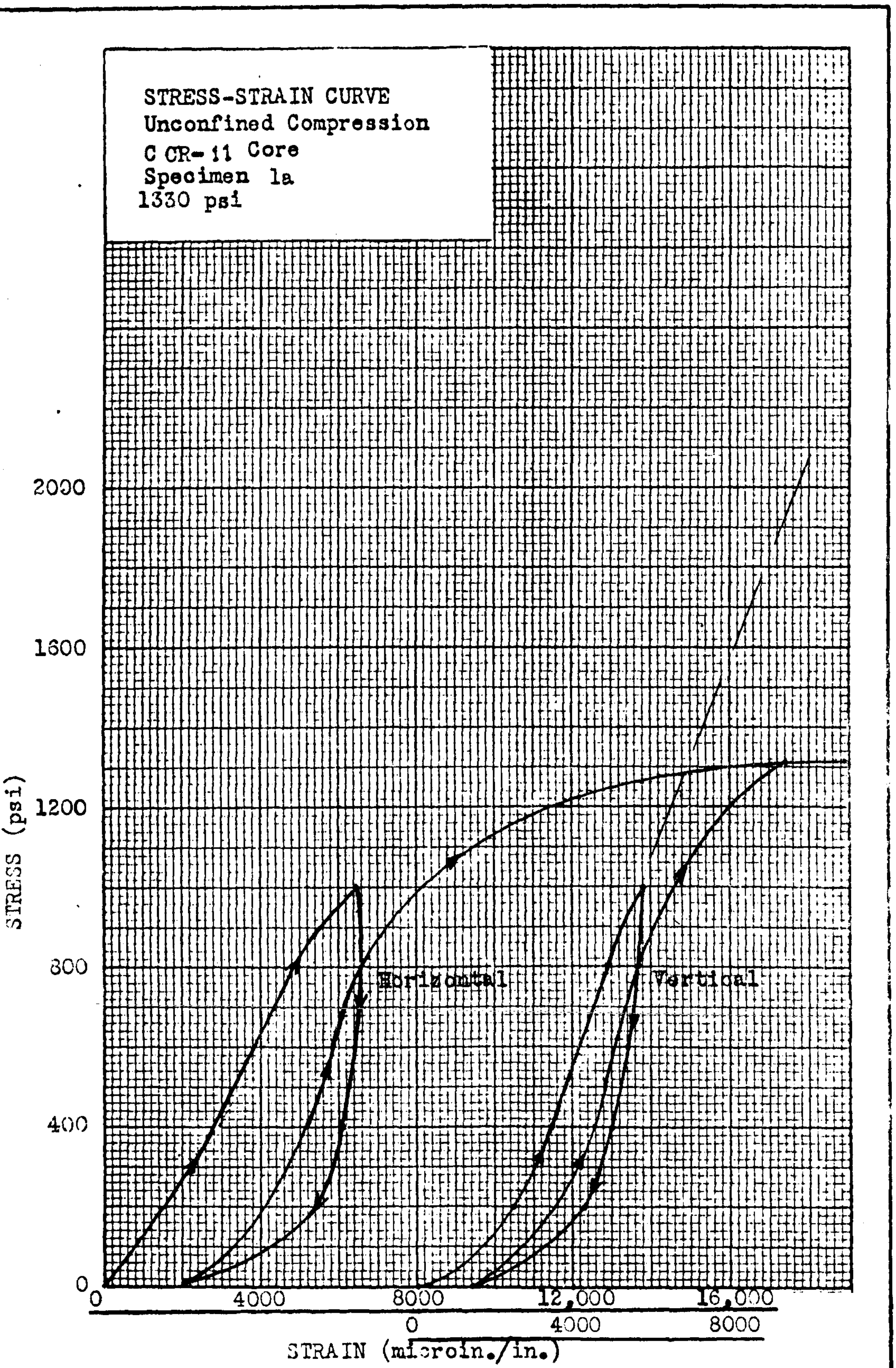
End Pieces Cut From Test Specimens





Posttest Photographs of Test Specimens

PLATE 2



STRESS-STRAIN CURVE
Unconfined Compression
C CR- 11 Core
Specimen 1a
1330 psi
STRESS (psi)
2000
1600
1200
800
400
0
Horizontal
Vertical
0
4000
8000
12,000
16,000
0
4000
8000
STRAIN (microin./in.)

PLATE 3

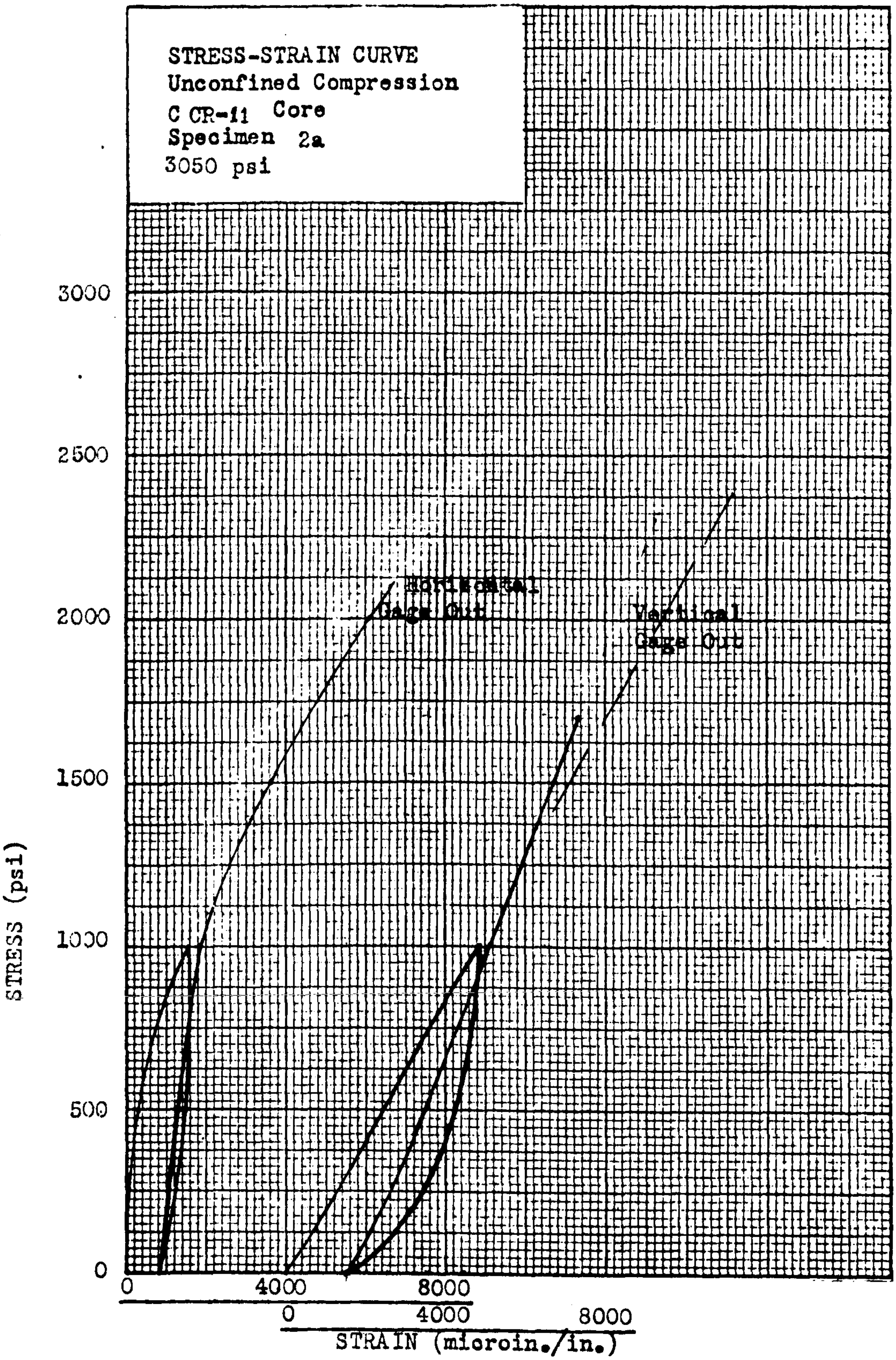

STRESS-STRAIN CURVE
Unconfined Compression
C CR-11 Core
Specimen 2a
3050 psi
Horizontal Gage Out
Vertical Gage Out
STRESS (psi)
3000
2500
2000
1500
1000
500
0
0
4000
8000
0
4000
8000
STRAIN (microin./in.)

PLATE 4

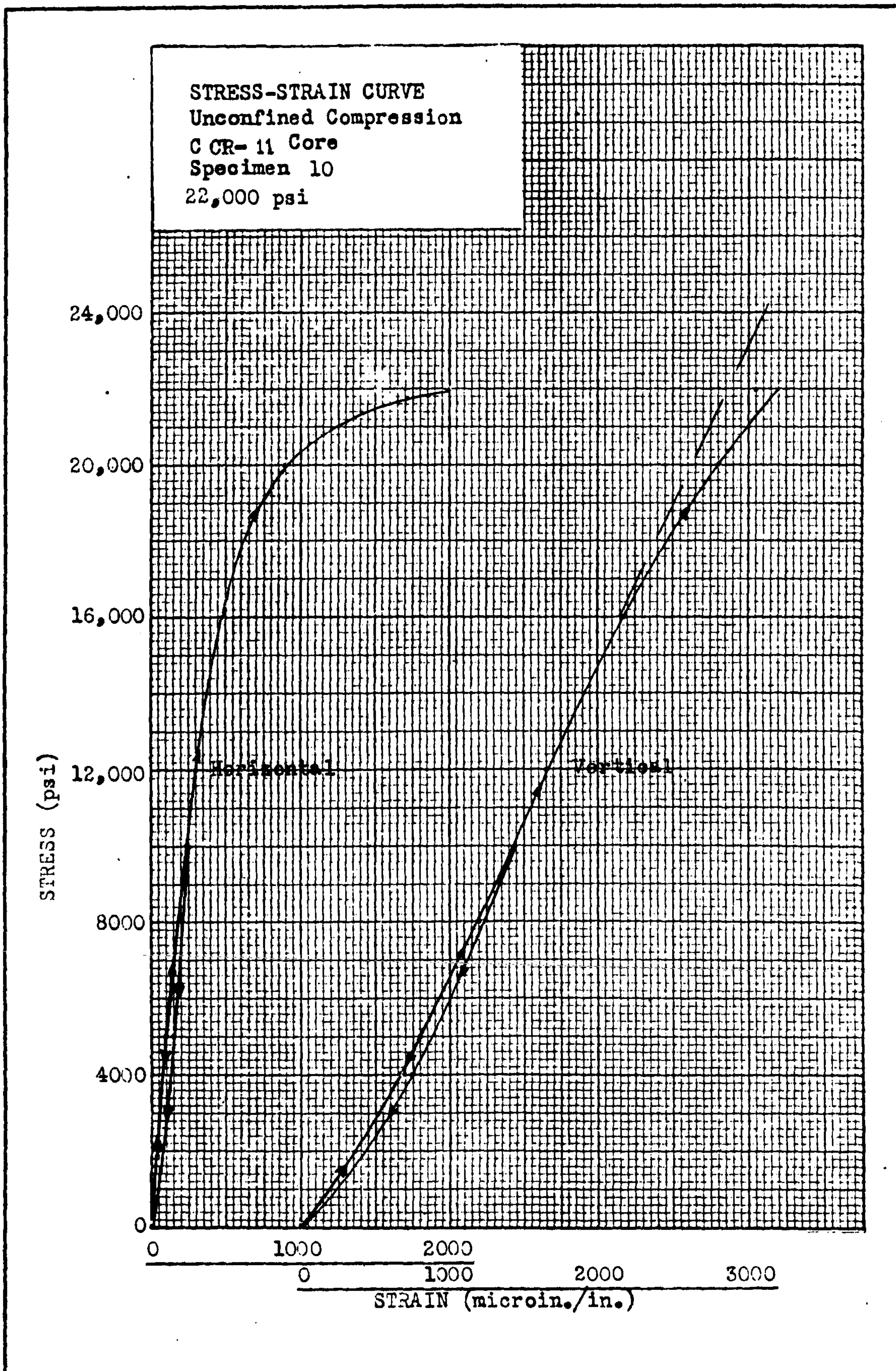

STRESS-STRAIN CURVE
Unconfined Compression
C CR- 11 Core
Specimen 10
22,000 psi
24,000
20,000
16,000
12,000
8000
4000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 5

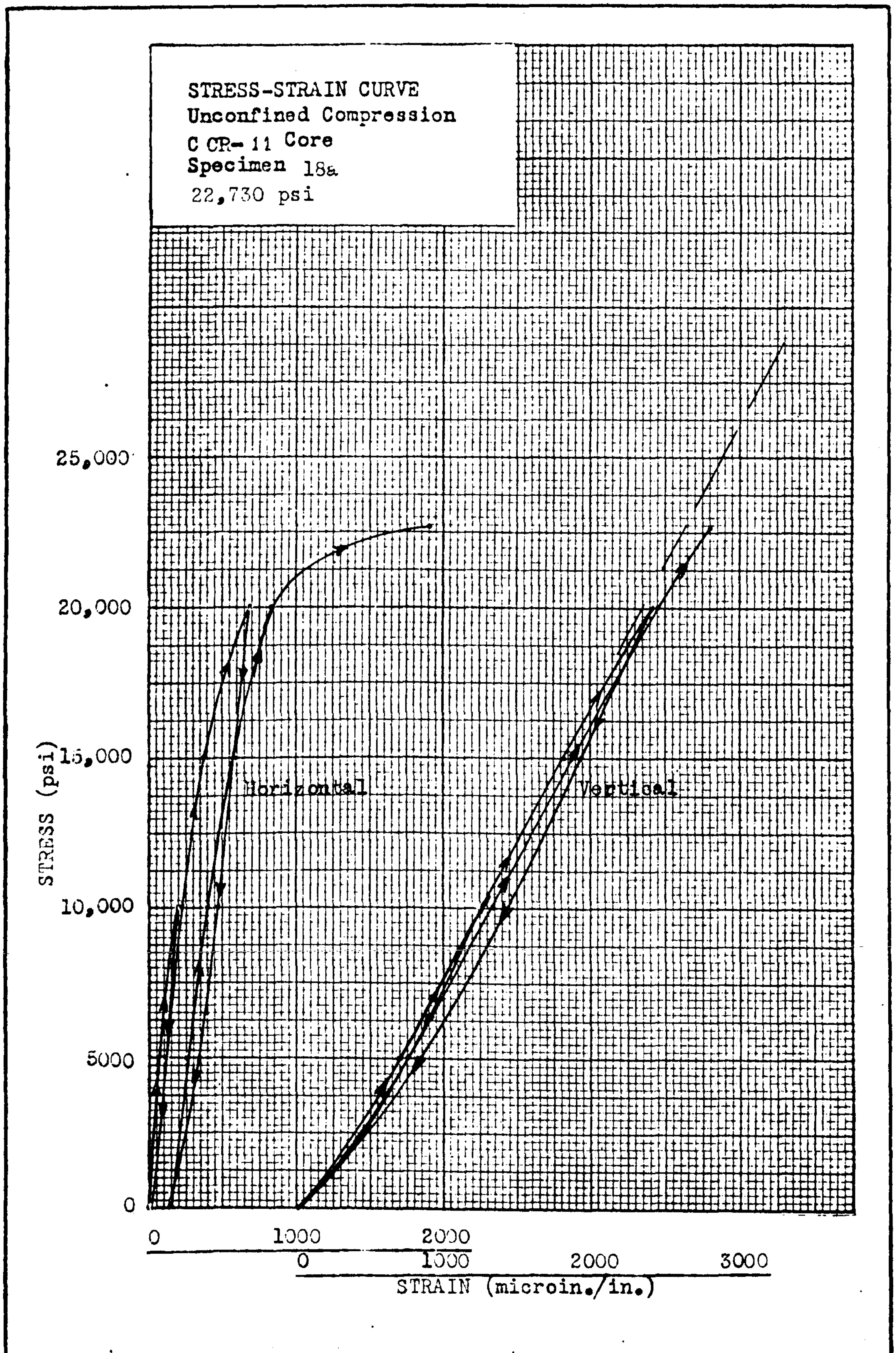

STRESS-STRAIN CURVE
Unconfined Compression
C CR- 11 Core
Specimen 18a
22,730 psi
STRESS (psi)
25,000
20,000
15,000
10,000
5000
0
Horizontal
Vertical
0
1000
2000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 6

APPENDIX E

DATA REPORT - C-CR-1 CORES

26 March 1969

Hole Location: Mariposa County, California

Township 5S, Range 17E, Section 28

Core Piece No.	Approximate Depth, ft
1	62
2	67
3	98
4	106
5	118
6	128
7	134
8	138
9	150
10	159
11	166
12	173
13	175
14	184
15	190
16	198

SERIES I TESTS

Results

Core samples

1. About 22 ft of NX rock core samples from 60.8 to 198.8 ft deep in hole C-CR-1 were received on 24 February 1969 for testing. Field logs indicated the samples were predominantly medium-grained diorite with some diabase (pieces 3, 4, and 11).

2. A description of the samples received is given below:

Sample No.	Description
1, 2	Fine to medium grained, gray
3, 4	Fine grained, light tan, numerous incipient fractures
5, 6	Fine to medium grained, light tan
7	Medium to coarse grained, light gray
8, 9, 10	Medium to coarse grained, dark gray
11	Fine grained, gray
12, 13, 14, 15, 16	Medium grained, light gray

A photograph of representative end pieces is given in plate 1.

Uniformity tests

3. To determine variations within the hole, specific gravity, compressive strength, compressional wave velocity, and Schmidt hammer tests were conducted on specimens selected throughout the length of cores received. The results were grouped according to strength levels and fracture pattern: (a) very incompetent rock with many apparent fractures (specimens 3 and 4 only), (b) apparently competent material which failed on high angle, closed seams some of which were not apparent until after the compressive tests were completed, and (c) competent rock which failed in the familiar shearing or coning mode. Results are given below:

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
			Highly Fractured Rock		
3	2.485	--	--	8,780	600
4	2.602	--	--	6,795	2,060
Average	2.544	--	--	7,790	1,330
			Competent Rock Which Failed on Closed Seams		
5a	2.914	--	--	18,940	16,940
5b	2.932	56.8	4.29	20,555	21,710
7	2.882	55.6	3.17	19,135	17,940
8	2.870	--	--	21,550	15,860
12b	2.866	59.3	5.58	19,070	11,430
16	2.872	57.8	4.94	20,880	12,140
Average	2.889	57.4	4.50	20,020	16,000
			Competent Rock Which Failed in Normal Shear		
2a	2.842	--	--	21,305	38,570
2b	2.856	59.8	3.89	21,800	45,000
10	2.902	59.5	4.26	22,590	36,570
11a	2.884	--	--	19,010	32,000
11b	2.882	51.0	3.08	18,060	39,860
14	2.875	56.3	5.24	21,000	25,860
Average	2.874	56.7	4.12	20,630	36,310

4. The unusually high specific gravity and compressional wave velocity obtained on the more competent material indicate that the seams were very tight. Predictably, the compressive strength was considerably reduced due not only to the presence of the seams, but also to the critical angle of intersection of the seams with the test axis (approximately 30 deg).

5. Porosity and tensile strength tests were conducted on several specimens as given below. The tensile specimens did not fail on seams; therefore, the tensile strengths should be correlated with the compressive strength of the intact rock.

Porosity		Tensile Strength	
Specimen	Percent	Specimen	psi
4	4.0	5c	2410
12a	0.2	11c	1330
		11d	1330
		12a	2460

Posttest photographs of test specimens are given in plate 2.

Moduli of deformation

6. Samples representative of the different materials in the hole were selected for deformation moduli tests. After dynamic tests were completed, a portion of each sample was prepared for static testing. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given below:

Specimen No.	Modulus, psi x 10^6			Poisson's Ratio	Wave Velocity, fps	
	Young's	Shear	Bulk		Compressional	Shear
			Dynamic			
2	13.23	5.45	7.60	0.21	20,730	11,980
5	12.05	4.89	7.44	0.23	19,420	11,255
11	8.33	3.69	3.75	0.13	17,120	9,835
14	11.81	4.93	6.56	0.20	19,530	11,425
			Static			
2b	12.6	5.16	7.50	0.22	--	--
5b	10.0	4.17	5.56	0.20	--	--
11b	10.5	4.45	5.47	0.18	--	--
14	10.7	4.46	5.94	0.20	--	--

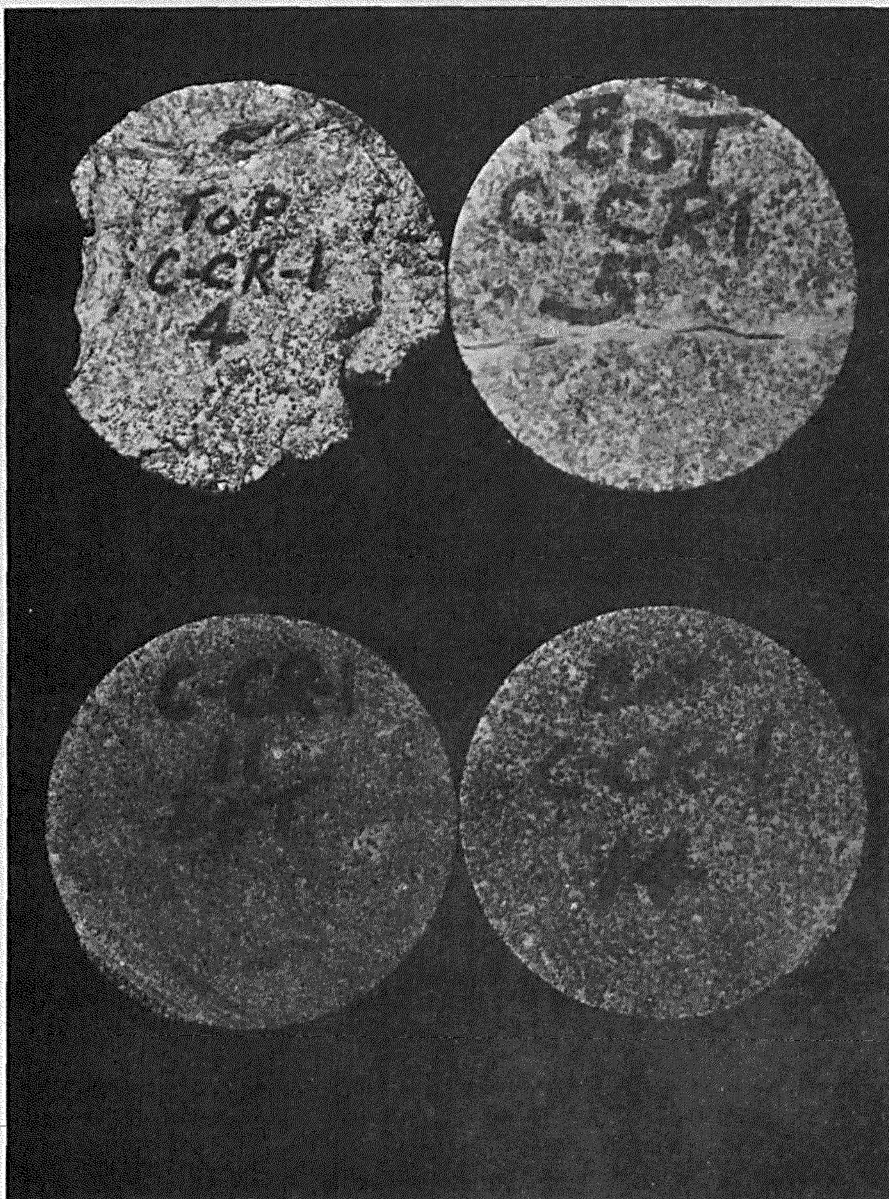
7. Stress-strain curves for specimens 2b, 5b, 11b, and 14 are given in plates 3, 4, 5, and 6, respectively. All specimens were cycled at 10,000 and 20,000 psi and exhibited negligible hysteresis.

Conclusions

8. The core log indicated that the samples received from hole C-CR-1 for testing were predominantly medium-grained diorite with some diabase. Two of the diabase samples were highly fractured and several of the diorite specimens failed on closed seams. The results were grouped according to indicated strength as given below:

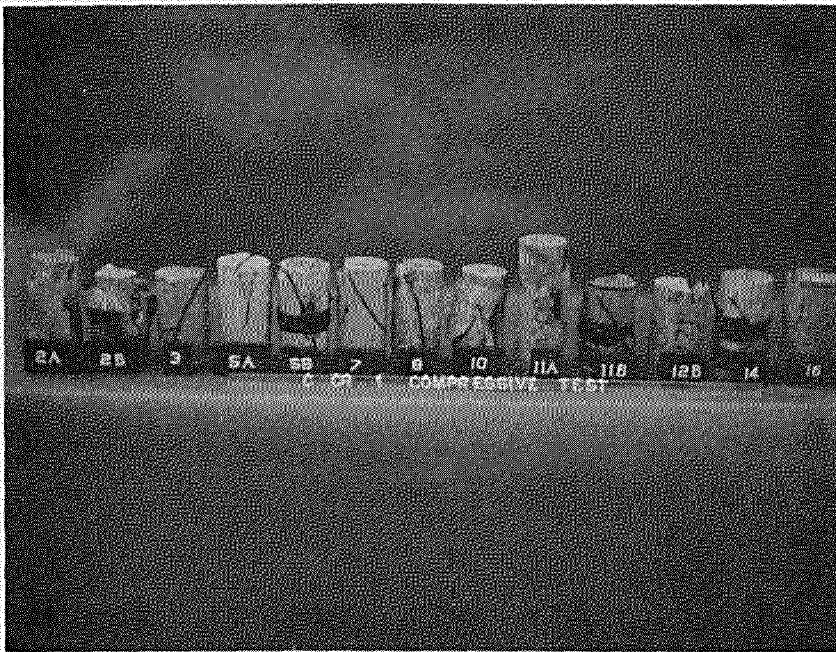
Property	Highly Fractured Rock	Competent Rock Which Failed on Seams	Competent Rock Which Failed on Shear Planes
Specific gravity	2.54	2.89	2.87
Porosity, percent	4.0	--	0.2
Schmidt rebound No.	--	57.4	56.7
Compressive strength, psi	1330	16,000	36,310
Young's modulus, psi x 10^6	--	10.0	11.3
Compressional wave velocity, fps	7790	20,020	20,630
Tensile strength, psi	--	1,330*	2,430**

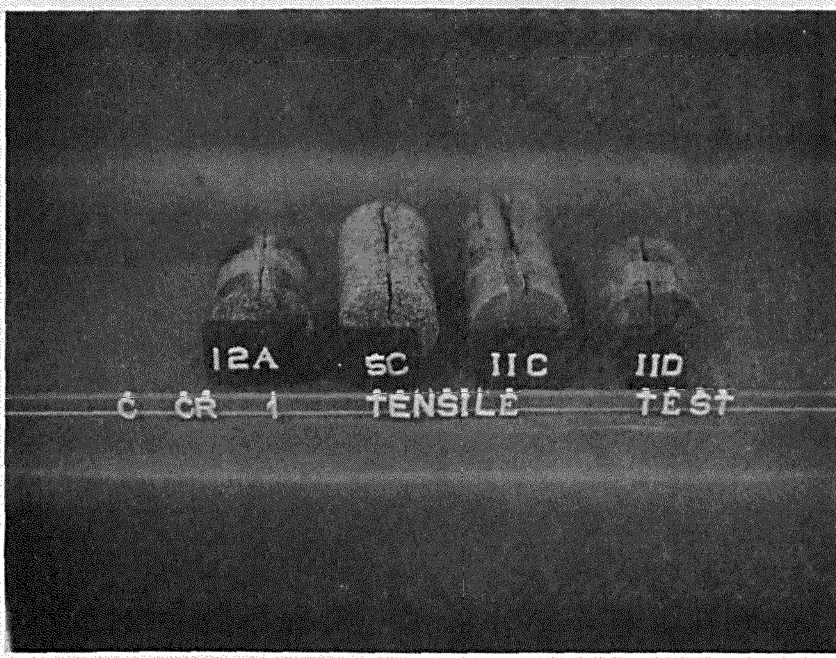
*Diabase
**Diorite



End Pieces Cut From Test Specimens

PLATE 1





Posttest Photographs of Test Specimens

Plate 2

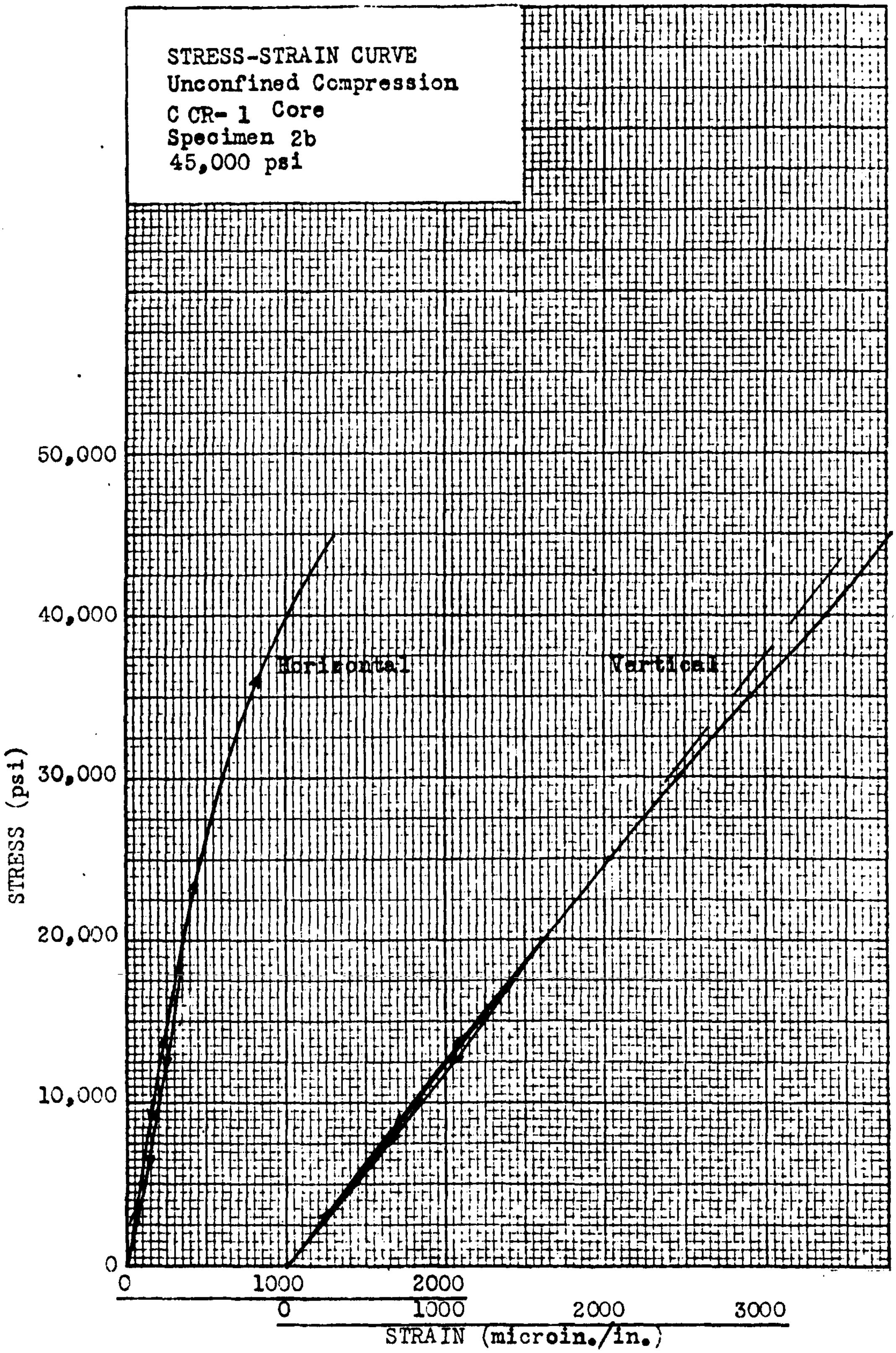

STRESS-STRAIN CURVE
Unconfined Compression
C CR- 1 Core
Specimen 2b
45,000 psi
Horizontal
Vertical
50,000
40,000
30,000
20,000
10,000
0
STRESS (psi)
0
1000
2000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 3

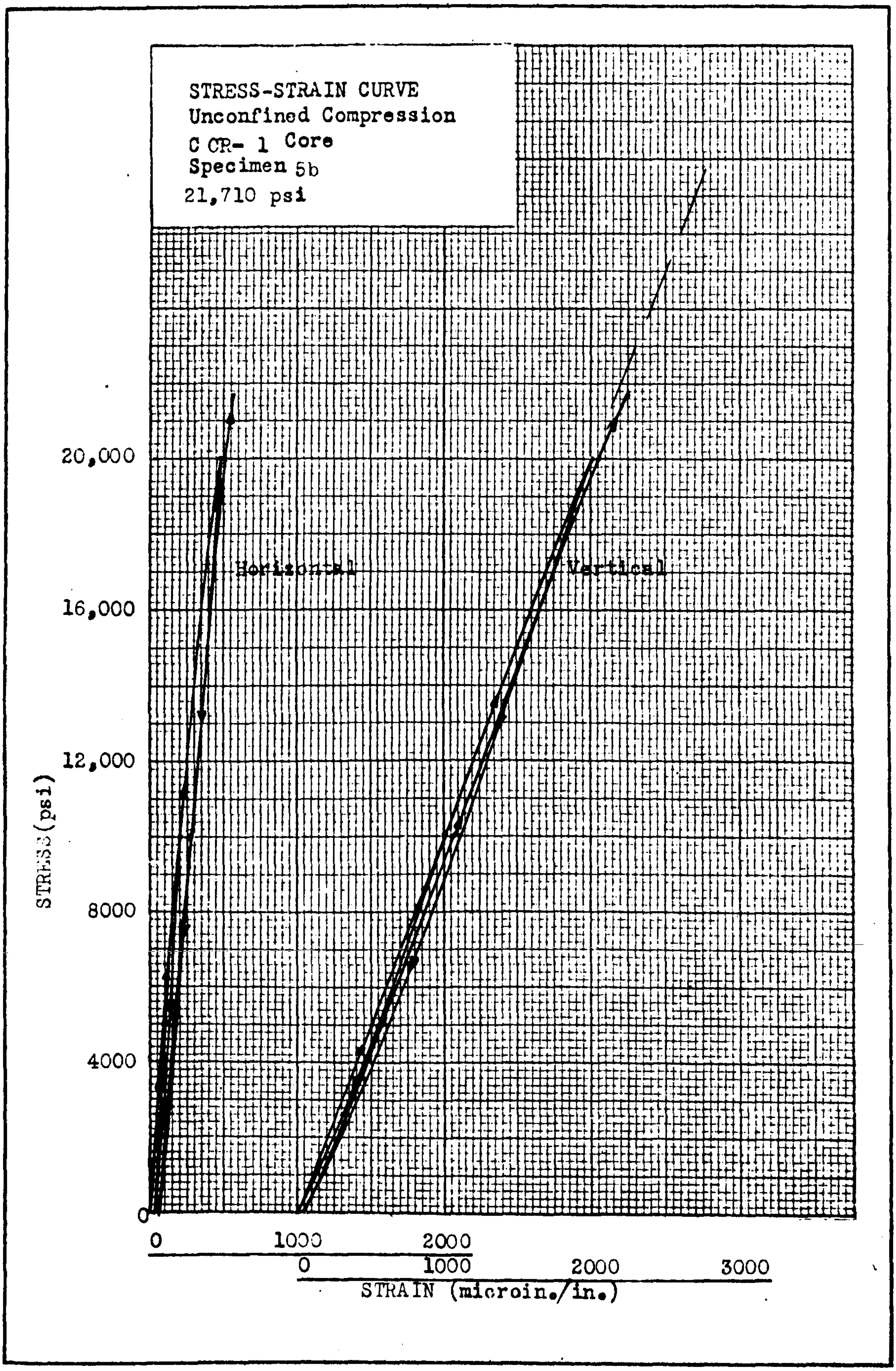
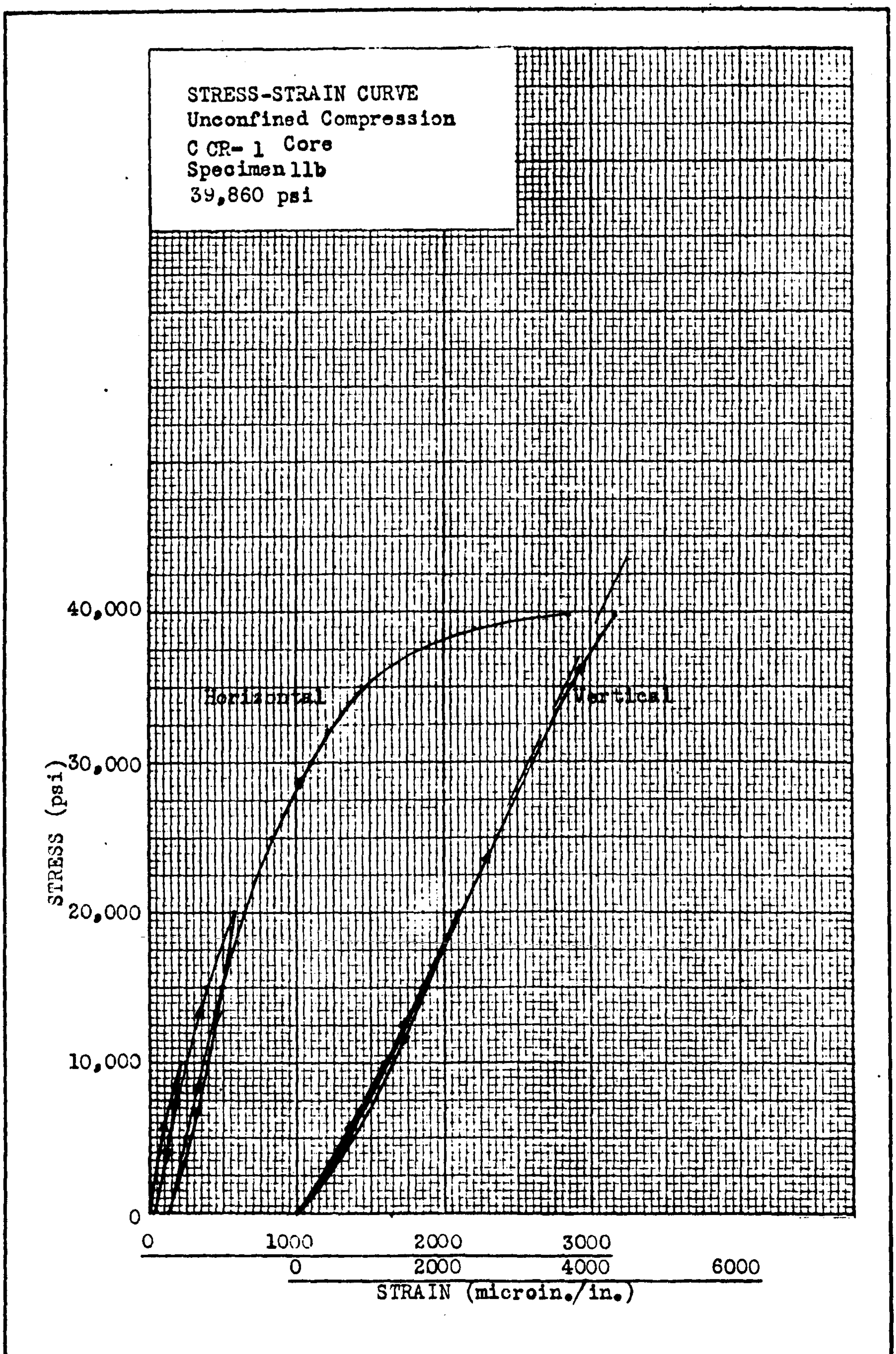

STRESS-STRAIN CURVE
Unconfined Compression
C CR- 1 Core
Specimen 5b
21,710 psi
Horizontal
Vertical
20,000
16,000
12,000
8000
4000
0
STRESS (psi)
0
1000
2000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 4



STRESS-STRAIN CURVE
Unconfined Compression
C CR- 1 Core
Specimen 11b
39,860 psi
Horizontal
Vertical
STRESS (psi)
40,000
30,000
20,000
10,000
0
0
1000
2000
3000
0
2000
4000
6000
STRAIN (microin./in.)

PLATE 5

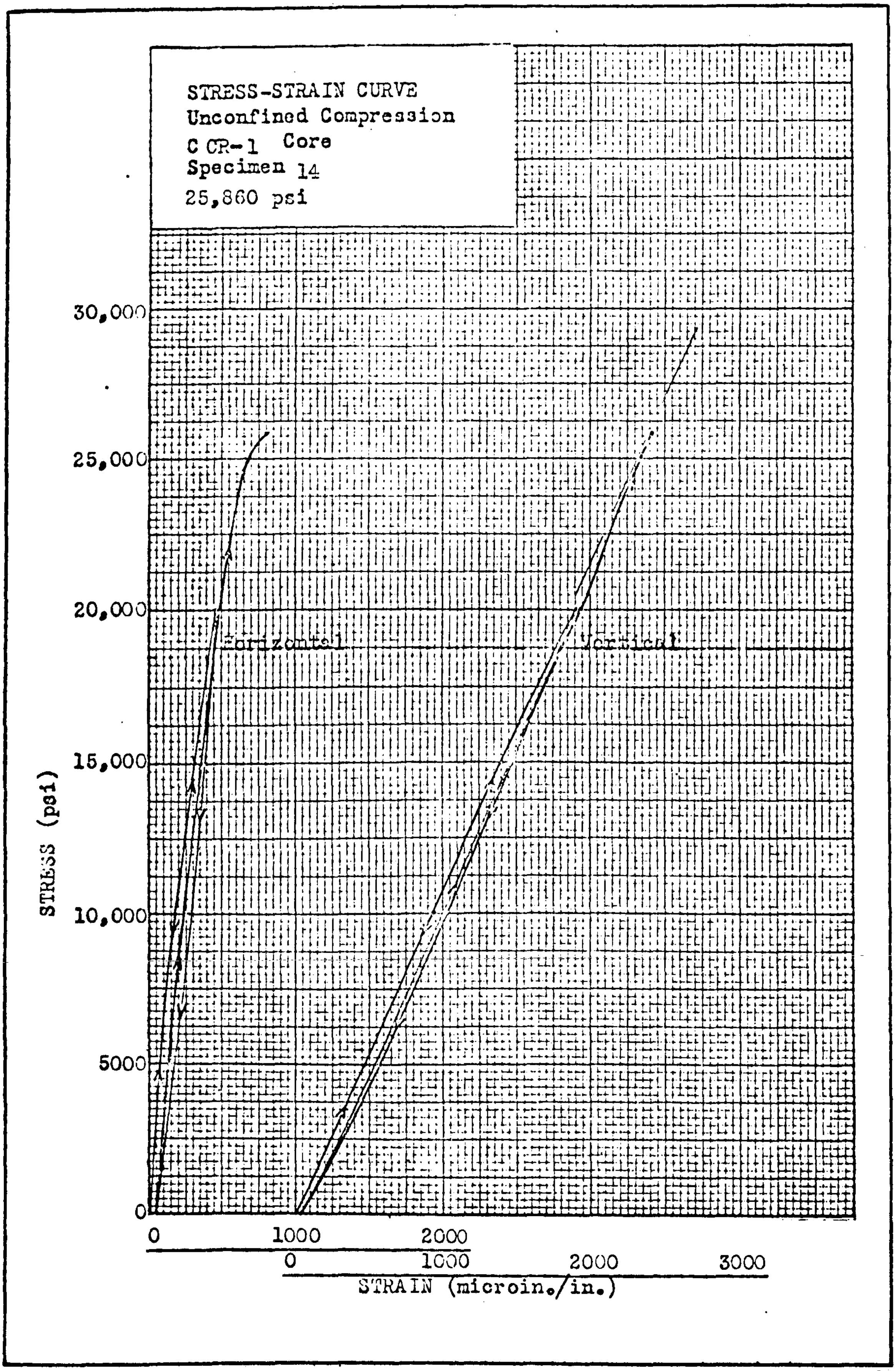

STRESS-STRAIN CURVE
Unconfined Compression
C CR-1 Core
Specimen 14
25,860 psi
30,000
25,000
20,000
15,000
10,000
5000
0
STRESS (psi)
Horizontal
Vertical
0
1000
2000
0
1000
2000
3000
STRAIN (microin./in.)

PLATE 6

APPENDIX F

DATA REPORT - C-CR-14 CORES

28 March 1969

Hole Location: Madera County, California

Township 7S, Range 21E, Section 9

Core Piece No.	Approximate Depth, ft
1	51
2	60
3	74
4	80
5	93
6	103
7	115
8	122
9	127
10	130
11	138
12	146
13	151
14	155
15	168
16	176
17	184
18	190
19	200

SERIES I TESTS

Results

Core samples

1. About 15 ft of NX rock core samples from 50.7 to 200.5 ft deep in hole C-CR-14 were received on 25 February 1969 for testing. Field logs indicated the samples were predominantly granite with some granodiorite. All samples were coarse grained with a light gray, salt and pepper appearance. Four of the samples, Nos. 1, 2, 3, and 14, had a brownish, weathered appearance. A photograph of representative end pieces is given in plate 1.

Uniformity tests

2. To determine variations within the hole, specific gravity, compressive strength, compressional wave velocity, and Schmidt hammer tests were conducted on specimens selected throughout the length of core received. Results are given below:

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
		Highly Weathered Rock			
2	2.649	13.7	2.06	3,495	220
3	2.608	14.6	2.39	4,555	940
14	2.620	15.9	2.87	7,360	1,710
Average	2.626	14.7	2.44	5,135	960

(Continued)

(Continued)

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
		Moderately Weathered Rock			
4	2.703	26.7	3.01	7,635	4,090
6a	2.671	--	--	6,805	2,710
9	2.715	25.7	3.34	9,975	7,060
11	2.710	--	--	8,750	5,160
13	2.715	29.3	2.94	10,270	6,140
16	2.697	30.5	3.39	8,930	3,860
Average	2.704	28.0	3.17	8,730	4,840
		Relatively Unweathered Rock			
18a	2.735	51.9	2.40	17,735	22,170

3. The results were grouped according to the degree of weathering. Like the C-CR-11 core, the highly weathered rock is obviously a very incompetent material and the moderately weathered rock is, at least, only mediocre. Apparently, unweathered rock is present near the bottom of the hole.

4. Porosity and tensile strength tests conducted on several specimens yielded results which correlated well with the specific gravity and compressive strength results:

Specimen No.	Porosity percent	Tensile Strength, psi
1	2.8	120
3b	2.4	120
6b	2.4	140
18b	0.3	1270

Posttest photographs of test specimens are given in plate 2.

Moduli of deformation

5. Samples representative of the different materials in the hole were selected for deformation moduli tests. After dynamic tests were completed, a portion of each sample was prepared for static testing. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given below:

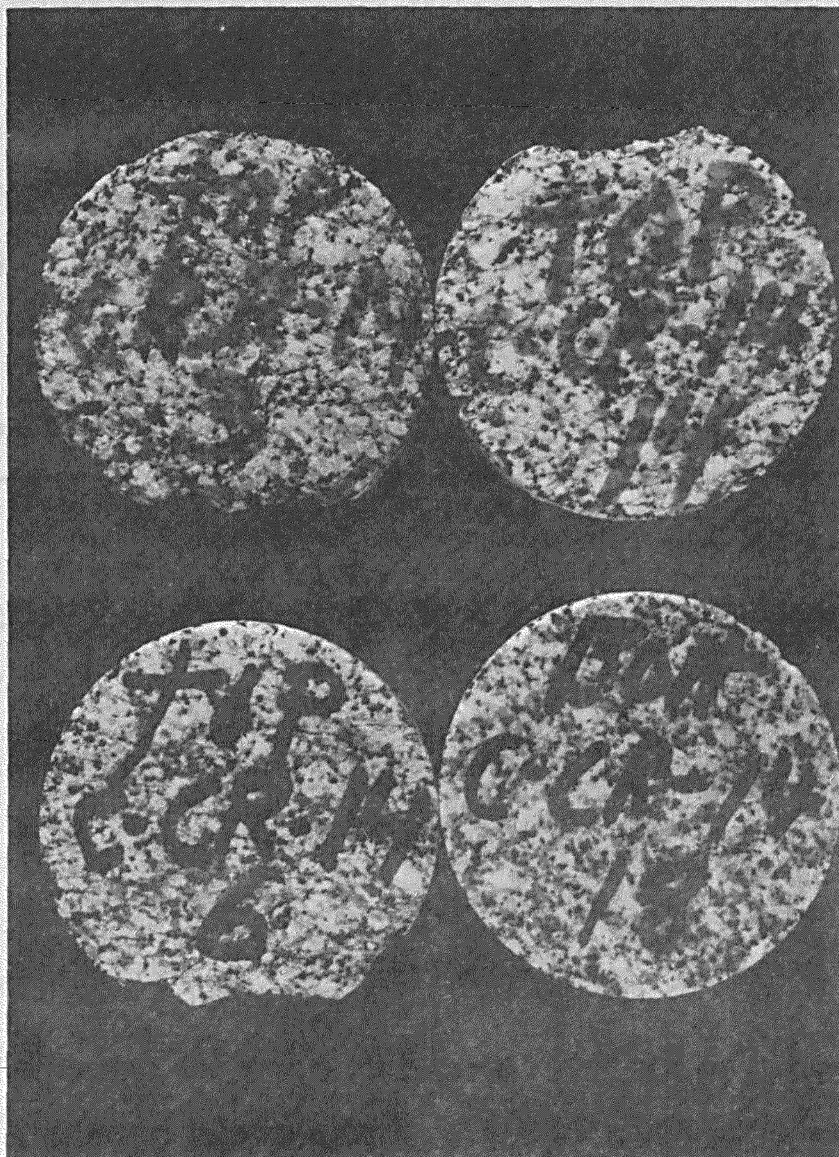
Specimen No.	Modulus, psi x 10^6 Young's	Shear	Bulk	Poisson's Ratio	Wave Velocity, fps Compressional	Shear
			Dynamic			
6	0.6	--	--	--	6,250	3,160
16	1.0	--	--	--	8,110	5,040
18	9.5	4.1	4.8	0.17	18,260	10,545
			Static			
6a	0.8	0.3	0.9	0.35	--	--
16	0.8	0.3	0.5	0.21	--	--
18a	8.0	3.3	4.4	0.20	--	--

6. Core Nos. 6 and 16 responded erratically to tests. Except for the velocities, the dynamic data reported on these specimens are questionable. Due to the poor condition of the highly weathered specimens, no attempt was made to affix strain gages to these specimens. Stress-strain curves for specimens 6a, 16, and 18a are given in plates 3, 4, and 5, respectively. Specimens 6a and 16 were cycled at 2000 psi, and specimen 18a at 10,000 psi. All specimens exhibited some hysteresis.

Conclusions

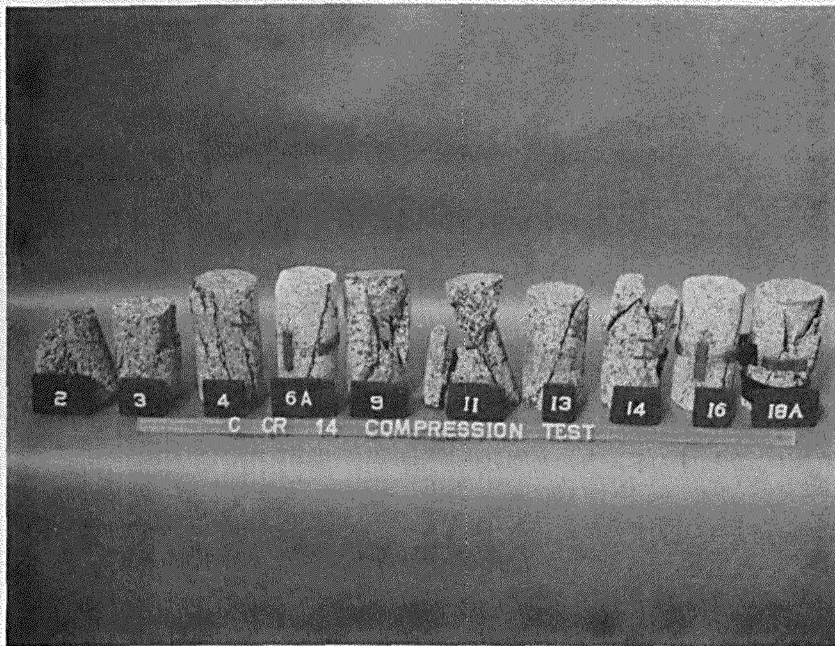
7. The core log indicated that the samples received from hole C-CR-14 for testing from 50 to 200 ft were predominantly weathered granite with some granodiorite. Much of the core was relatively incompetent due to various degrees of weathering. Apparently, unweathered rock was not reached until near the bottom of the hole. Results were grouped according to degree of weathering:

Property	Highly Weathered Rock	Moderately Weathered Rock	Unweathered Rock
Specific gravity	2.63	2.70	2.74
Porosity, percent	2.8	2.4	0.3
Schmidt rebound number	14.7	28.0	51.9
Compressive strength, psi	960	4840	22,170
Young's modulus, psi x 10^6	0.8	0.8	8.0
Compressional wave velocity, fps	5135	8730	17,735
Tensile strength	120	140	1,270

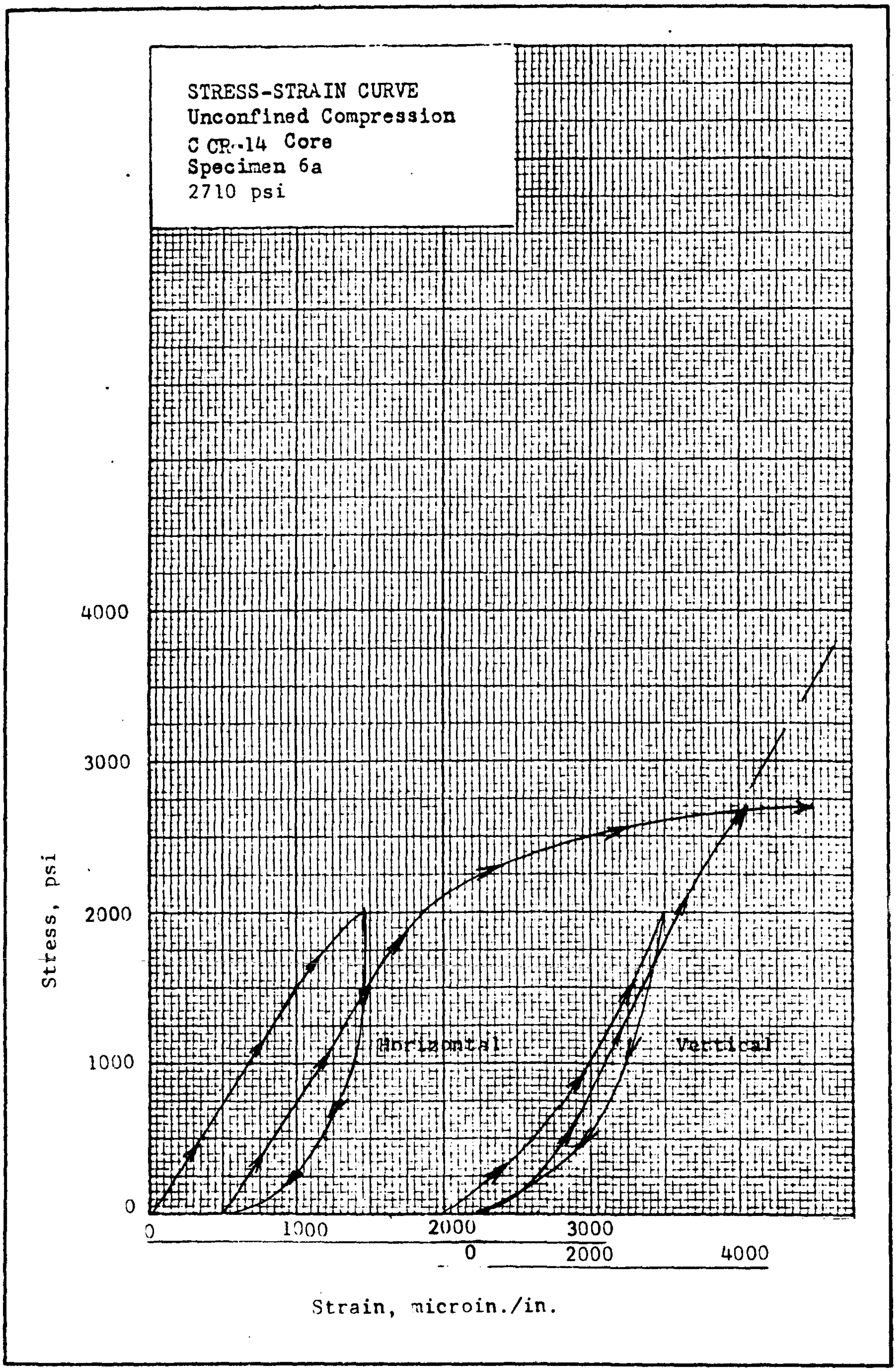


End Pieces Cut From Test Specimens

PLATE 1



Posttest Photographs of Test Specimens



STRESS-STRAIN CURVE
Unconfined Compression
C CR-14 Core
Specimen 6a
2710 psi
Horizontal
Vertical
Stress, psi
4000
3000
2000
1000
0
0
1000
2000
3000
0
2000
4000
Strain, microin./in.

PLATE 3

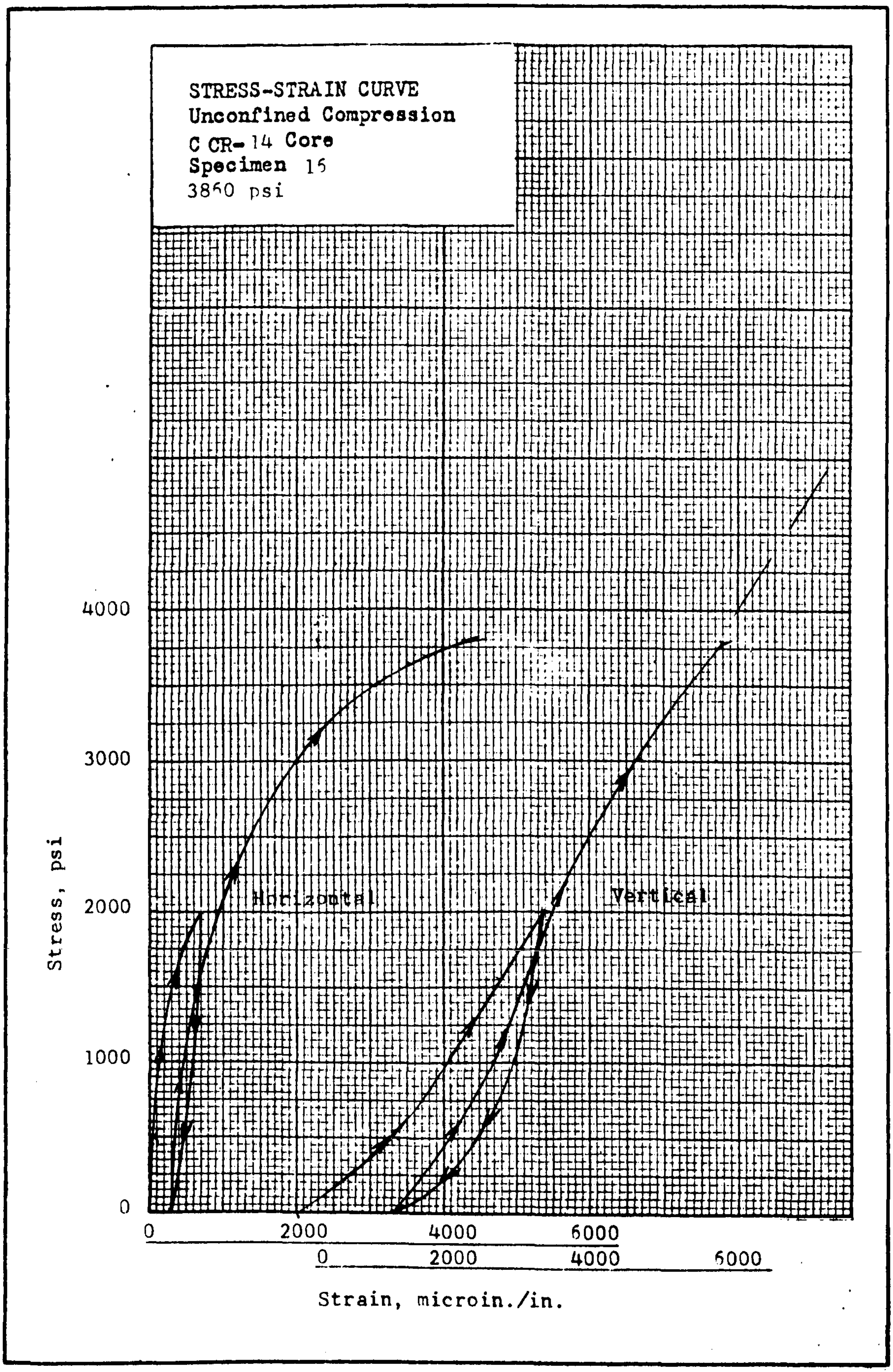

STRESS-STRAIN CURVE
Unconfined Compression
C CR-14 Core
Specimen 15
3860 psi
Horizontal
Vertical
Stress, psi
4000
3000
2000
1000
0
0
2000
4000
6000
0
2000
4000
6000
Strain, microin./in.

PLATE 4

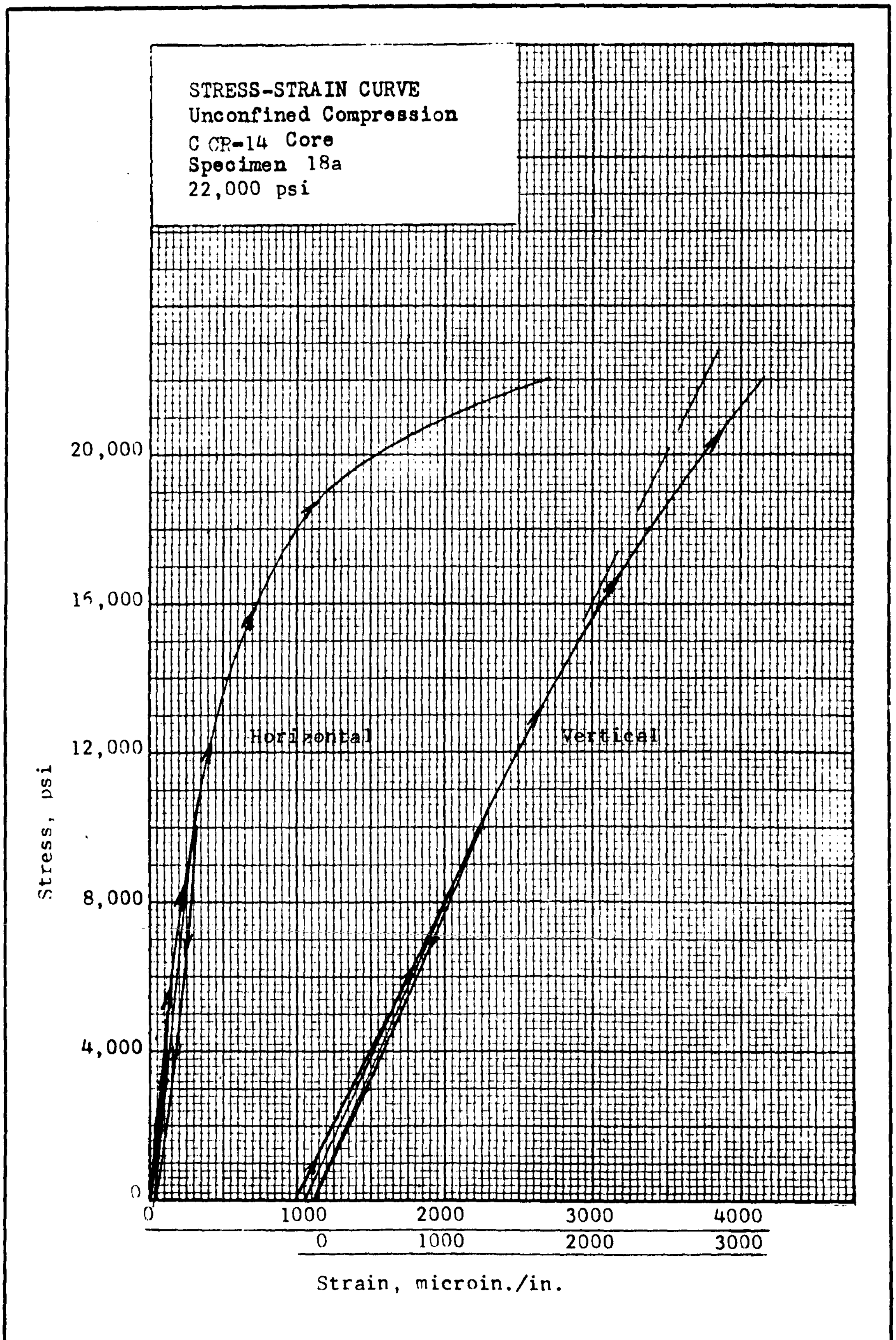

STRESS-STRAIN CURVE
Unconfined Compression
C CR-14 Core
Specimen 18a
22,000 psi
20,000
16,000
12,000
8,000
4,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 5

APPENDIX G

DATA REPORT - C-CR-27 CORES

3 April 1969

Hole Location: Madera County, California

Township 9S, Range 19E, Section 17

Core Piece No.	Approximate Depth, ft
1	21
2	32
3	41
4	51
5	62
6	74
7	84
8	96
9	102
10	112
11	124
12	139
13	156
14	166
15	176
16	182
17	190
18	198

SERIES I TESTS

Results

Core samples

1. About 20 ft of NX rock core samples from 21.4 to 198.9 ft deep in hole C-CR-27 were received on 25 February 1969 for testing. Field logs indicated the samples were predominantly granodiorite with some quartz diorite in the upper elevations and granodiorite with high quartz content in the lower portion of the hole. There was a tendency to high angle banding in many of the samples.

2. A description of the samples received is given below.

Sample No.	Description
1, 2, 3, 4	Coarse grained, gold to gray colored, decreasing weathering 1 through 3
5, 6	Gray, indicated to be quartz diorite
7-12	Gray, medium to coarse grained
13-18	Salt and pepper appearance, some incipient fractures

A photograph of representative end pieces is given in plate 1. The incipient fracture is visible in specimen 16.

Uniformity tests

3. To determine variations within the hole, specific gravity, compressive strength, compressional wave velocity, and Schmidt hammer tests were conducted on specimens selected throughout the length of core received. Results are grouped according to condition of rock or mode of failure.

Specimen No.	Specific Gravity	Schmidt Hammer Rebound No.	Schmidt Hammer Standard Deviation	Compressional Wave Velocity fps	Compressive Strength psi
		Slightly Weathered Rock			
1a	2.729	30.7	2.78	10,785	4,240
3	2.780	44.6	3.39	16,130	9,480
Average	2.754	37.6	3.08	13,460	6,860
		Rock Which Failed on Incipient Fractures			
14	2.722	54.2	3.21	16,900	9,970
16b	2.688	--	--	16,025	7,580
Average	2.705	54.2	3.21	16,460	8,780
		Rock Which Failed Predominantly on Bands			
5a	2.817	53.2	3.08	17,385	14,670
7	2.765	55.4	4.21	17,525	17,090
9	2.825	55.3	3.11	18,365	18,970*
10	2.764	55.5	3.18	17,385	18,530
12a	2.769	58.0	3.84	17,525	19,700
18	2.726	53.8	3.56	16,000	15,450
Average	2.777	55.4	3.50	17,360	17,400

* No banding; conical failure.

4. The weathered rock is apparently not as incompetent as a majority of the material from hole C-CR-14 nor is the weathered zone as deep. The compressive strength is predictably lower where incipient fractures were present. The strength of the rock which failed predominantly on banding is also slightly lower than other comparatively dense material from the Castle area.

5. Porosity and tensile strength tests conducted on several specimens yielded results which correlated well with the specific gravity and compressive strength results.

Porosity		Tensile Strength	
Specimen	Percent	Specimen	psi
1b	0.2	1b	450
12b	0.2	5b	1210
		12b	1180
		16a	1000

Posttest photographs of test specimens are given in plate 2.

Moduli of deformation

6. Samples representative of the different materials in the hole were selected for deformation moduli tests. After dynamic tests were completed, a portion of each sample except No. 1 was prepared for static testing. Static moduli were computed from measurements taken from electrical resistance strain gages affixed to the specimens. Results are given below:

Specimen No.	Modulus, psi x 10^6 Young's	Shear	Bulk	Poisson's Ratio	Wave Velocity, fps Compressional	Shear
			Dynamic			
1	3.55	1.74	1.23	0.02*	12,500	7,040
5	11.00	4.62	5.91	0.19	19,195	11,240
12	11.06	4.71	5.59	0.17	19,455	11,410
16	8.37	3.57	4.23	0.17	17,395	10,100
			Static			
5a	9.5	3.83	6.09	0.24	--	--
12a	10.8	4.50	6.00	0.20	--	--
16b	7.6	3.22	3.96	0.18	--	--

* Doubtful result.

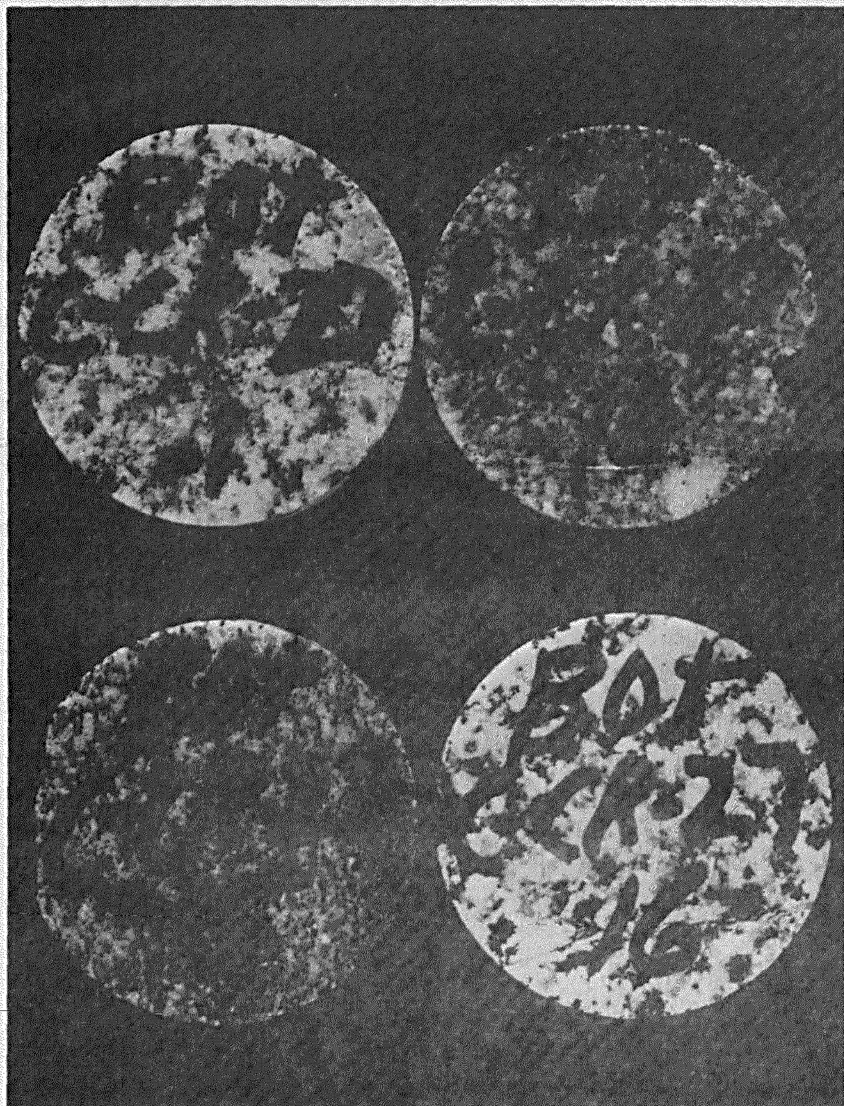
7. Stress-strain curves for specimens 5a, 12a, and 16b are given in plates 3, 4, and 5, respectively. Specimens 5a and 12a were cycled

at 5000 and 10,000 psi and specimen 16b at 5000 psi. The strain gages on specimen 5a behaved erratically on the second and third loading cycles. All specimens exhibited negligible hysteresis.

Conclusions

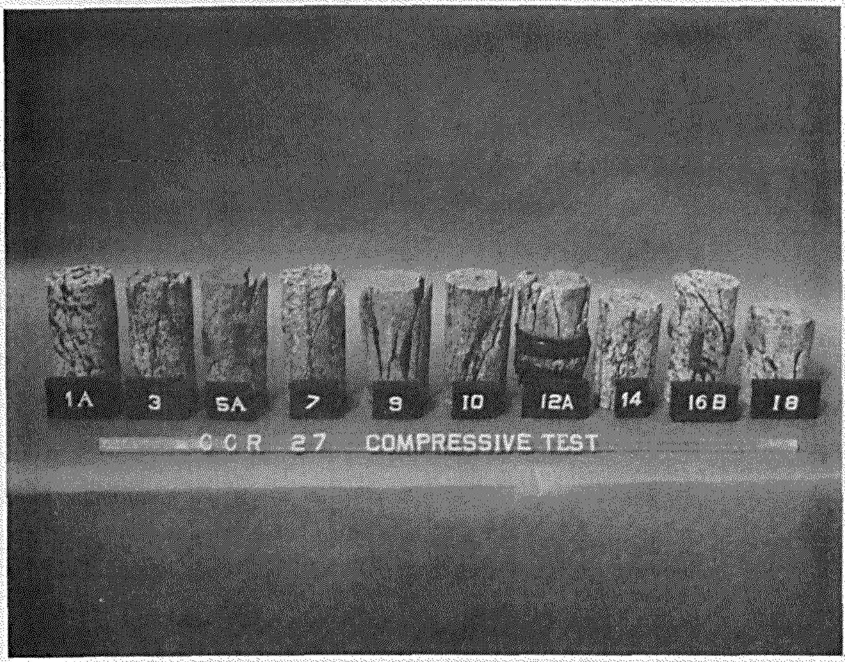
8. The core log indicated that the samples received from hole C-CR-27 for testing from 21 to 198 ft were predominantly granodiorite with some quartz diorite. A slightly weathered zone was indicated near the top of the hole. The more competent rock failed along either incipient fractures or bands; results were grouped accordingly.

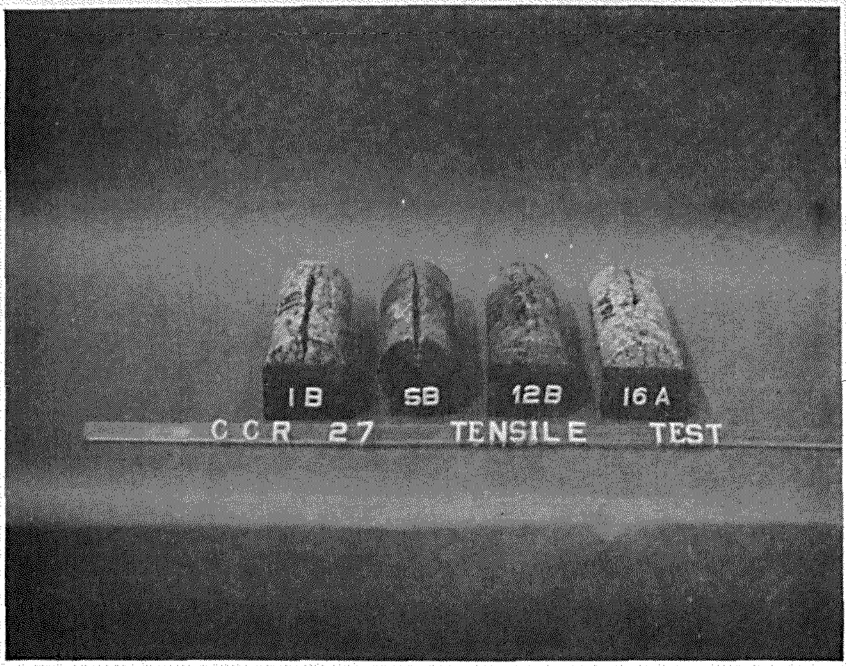
Property	Slightly Weathered Rock	Rock Which Failed On: Incipient Fractures	Rock Which Failed On: Bands
Specific gravity	2.75	2.70	2.78
Porosity, percent	0.2	--	0.2
Schmidt rebound number	37.6	54.2	55.4
Compressive strength, psi	6,860	8,780	17,400
Young's modulus, psi x 10^6	3.6	8.0	10.0
Compressional wave velocity, fps	13,460	16,460	17,360
Tensile strength, psi	450	1,000	1,200



End Pieces Cut From Test Specimens

PLATE 1





Posttest Photographs of Test Specimens

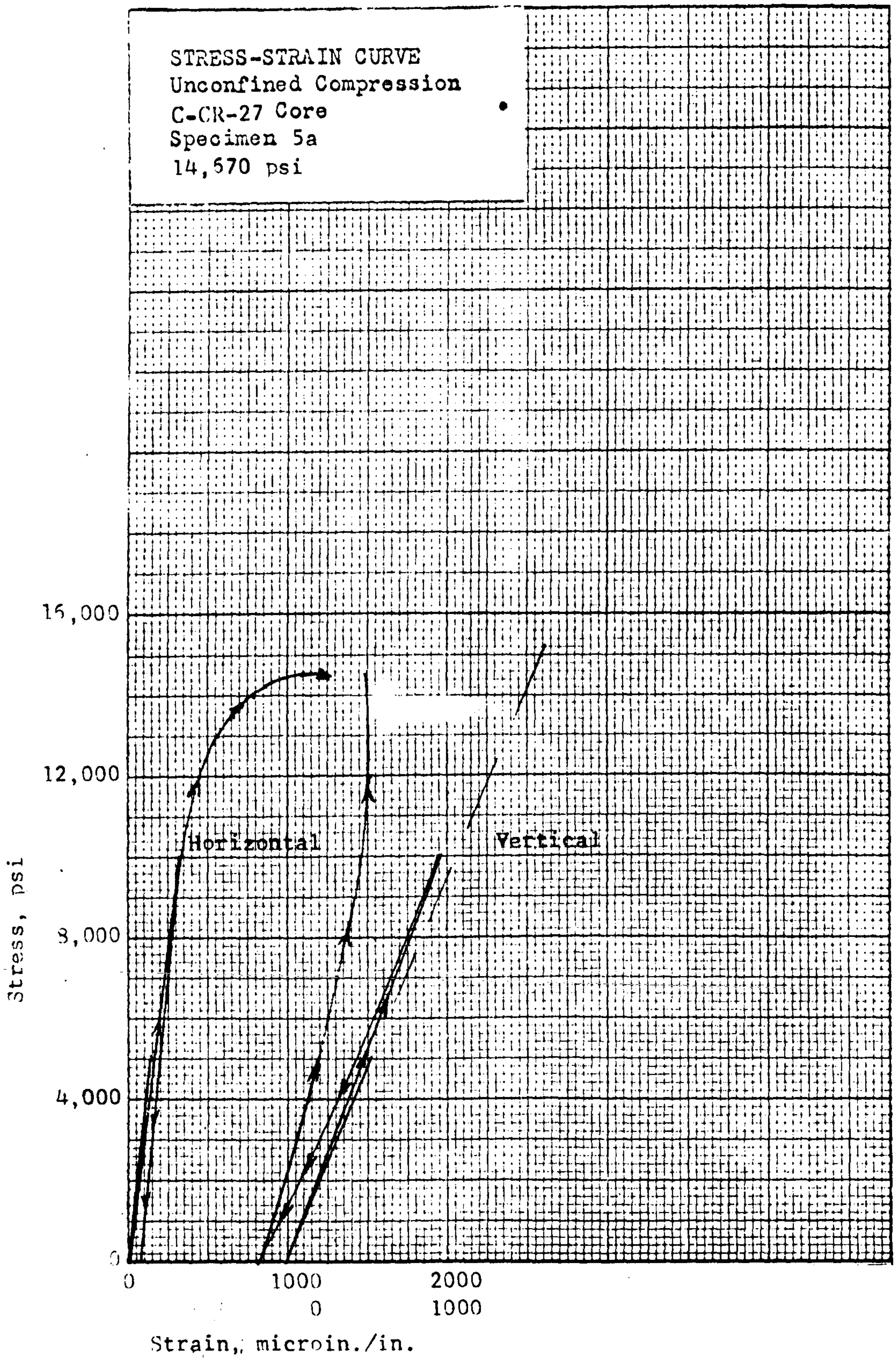
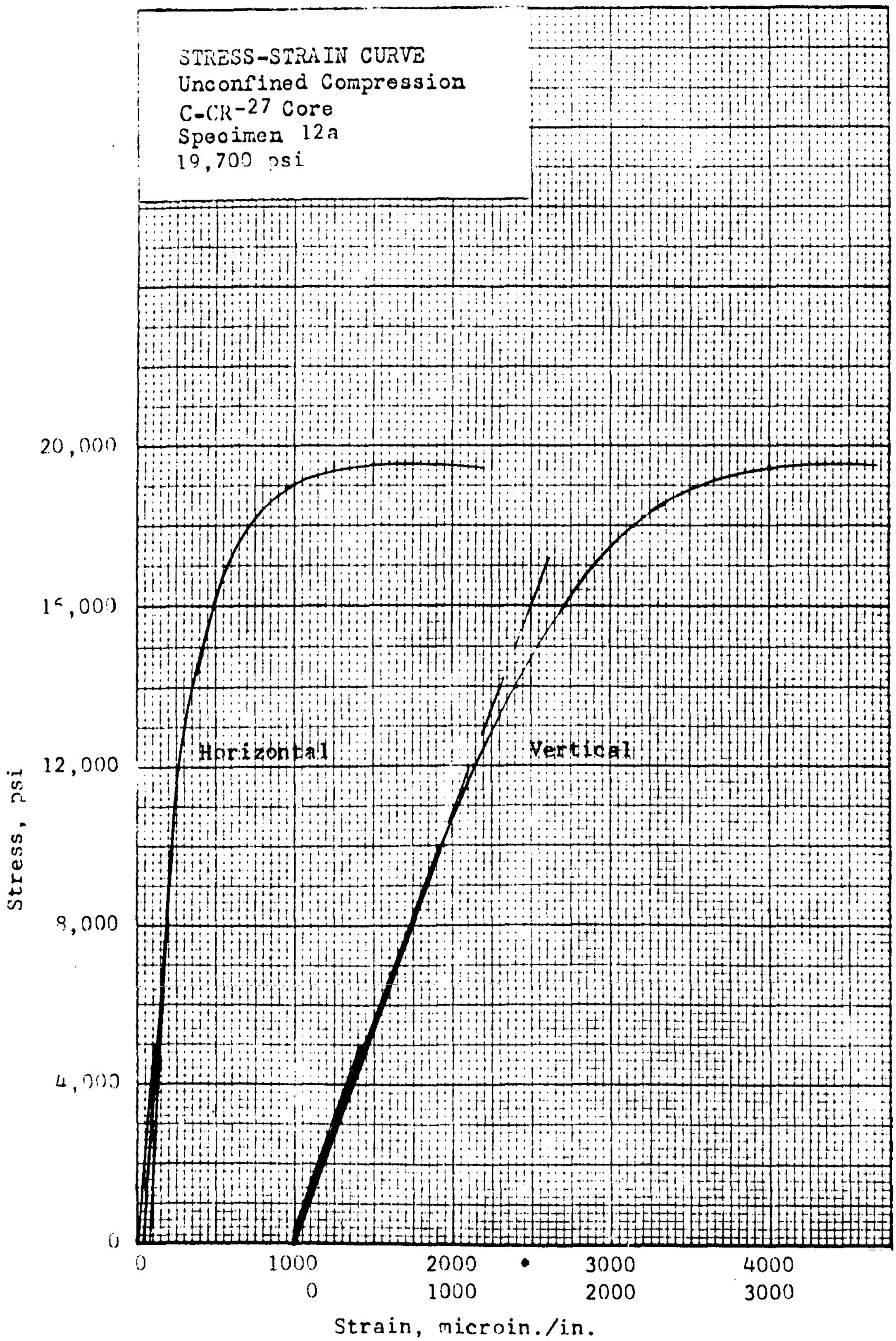

STRESS-STRAIN CURVE
Unconfined Compression
C-CR-27 Core
Specimen 5a
14,570 psi
16,000
12,000
8,000
4,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
0
1000
Strain, microin./in.

PLATE 3



STRESS-STRAIN CURVE
Unconfined Compression
C-CR-27 Core
Specimen 12a
19,700 psi
20,000
16,000
12,000
8,000
4,000
0
Stress, psi
Horizontal
Vertical
0
1000
2000
3000
4000
0
1000
2000
3000
Strain, microin./in.

PLATE 4

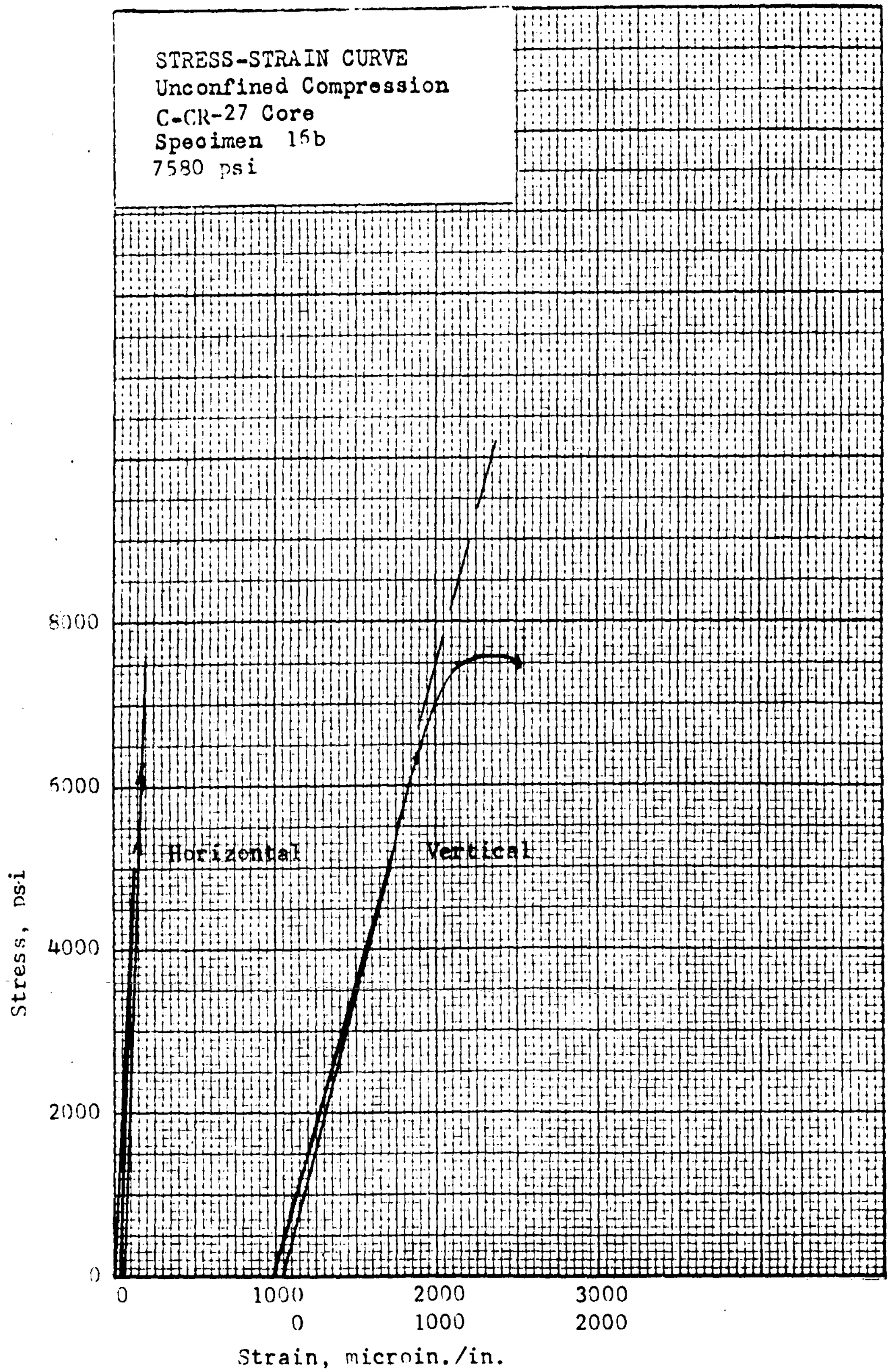

STRESS-STRAIN CURVE
Unconfined Compression
C-CR-27 Core
Specimen 16b
7580 psi
Horizontal
Vertical
Stress, psi
8000
6000
4000
2000
0
0
1000
2000
3000
0
1000
2000
Strain, microin./in.

PLATE 5

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13. ABSTRACT

Laboratory tests were conducted on rock core samples received from seven core holes in the Castle area of Mariposa and Madera Counties, California. The results were used to determine the quality and uniformity of the rock to depths of 200 feet below ground surface. Specific gravity, Schmidt hardness, wave velocity, and compressive strength tests indicated the rock to be highly variable in physical properties. The core was identified as predominantly soda tonalite. Approximately one-third of the rock tested was sufficiently weathered and fractured to be classed as incompetent material. An assessment of the area on a hole-to-hole basis indicates that the area in the vicinity of only two of the seven holes appears to offer possibilities as a uniform, competent hard rock medium.

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