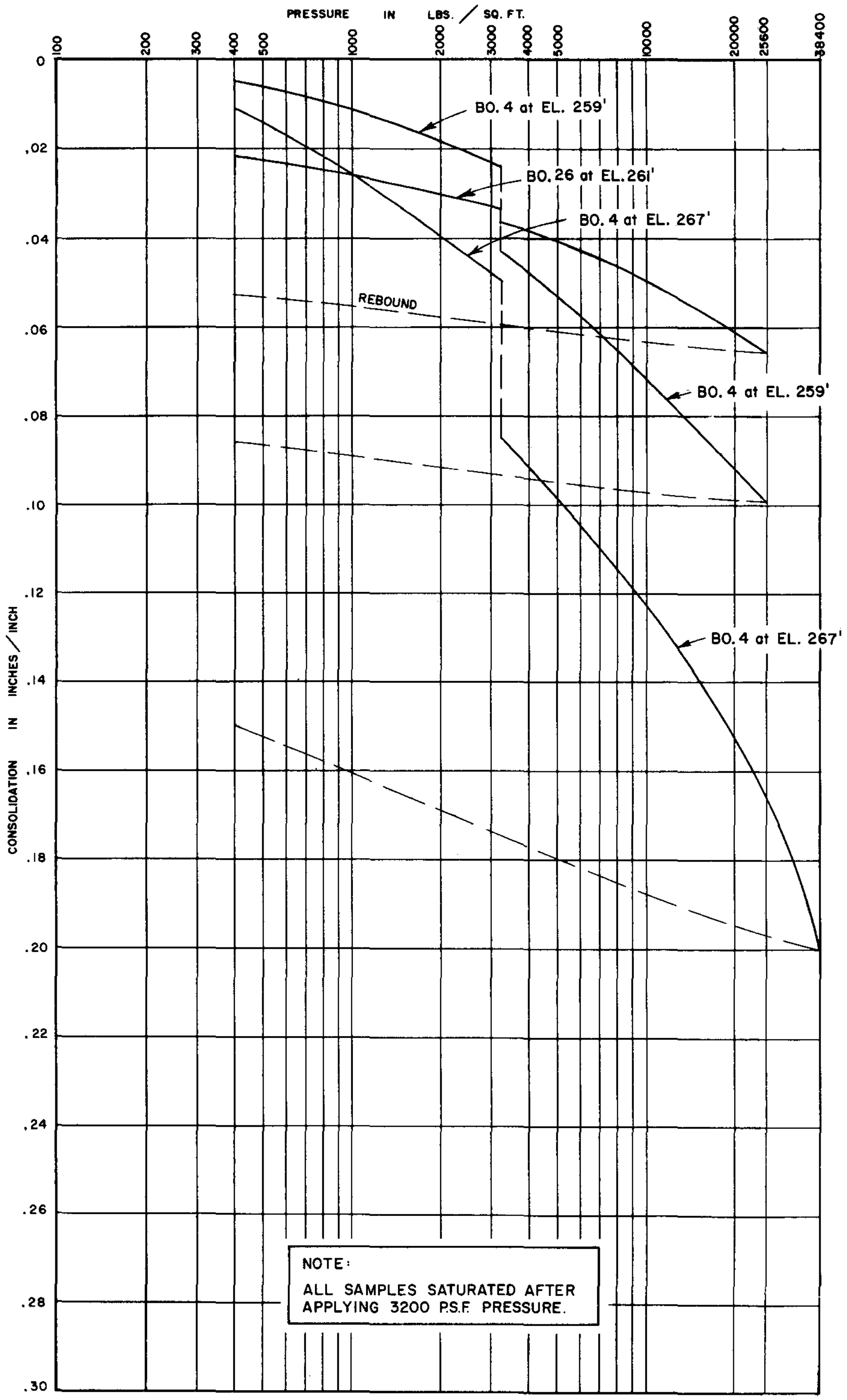
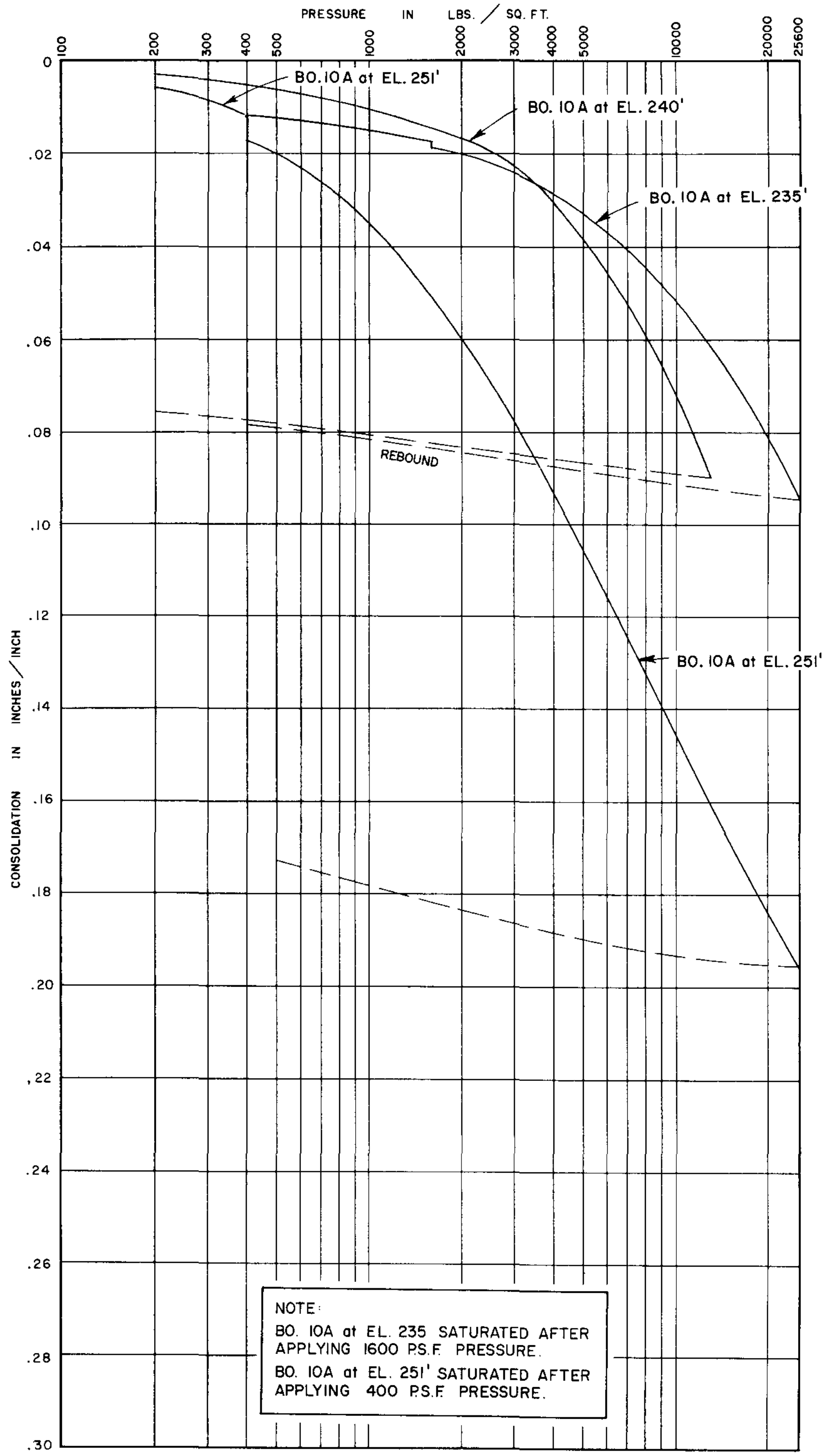


BORING NO.	ELEVATION FT.	SOIL OR ROCK TYPE	MOISTURE CONTENT, %		DRY DENSITY, P.C.F.
			before test	after test	
4	267	GRAYISH-BLACK FRACTURED SHALE	8	12	121
26	261	LIGHT BROWN FINE GRAINED SANDSTONE	14	17	109
4	259	GRAY FINE GRAINED SANDSTONE	8	11	120

CONSOLIDATION TEST DATA

DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A3A

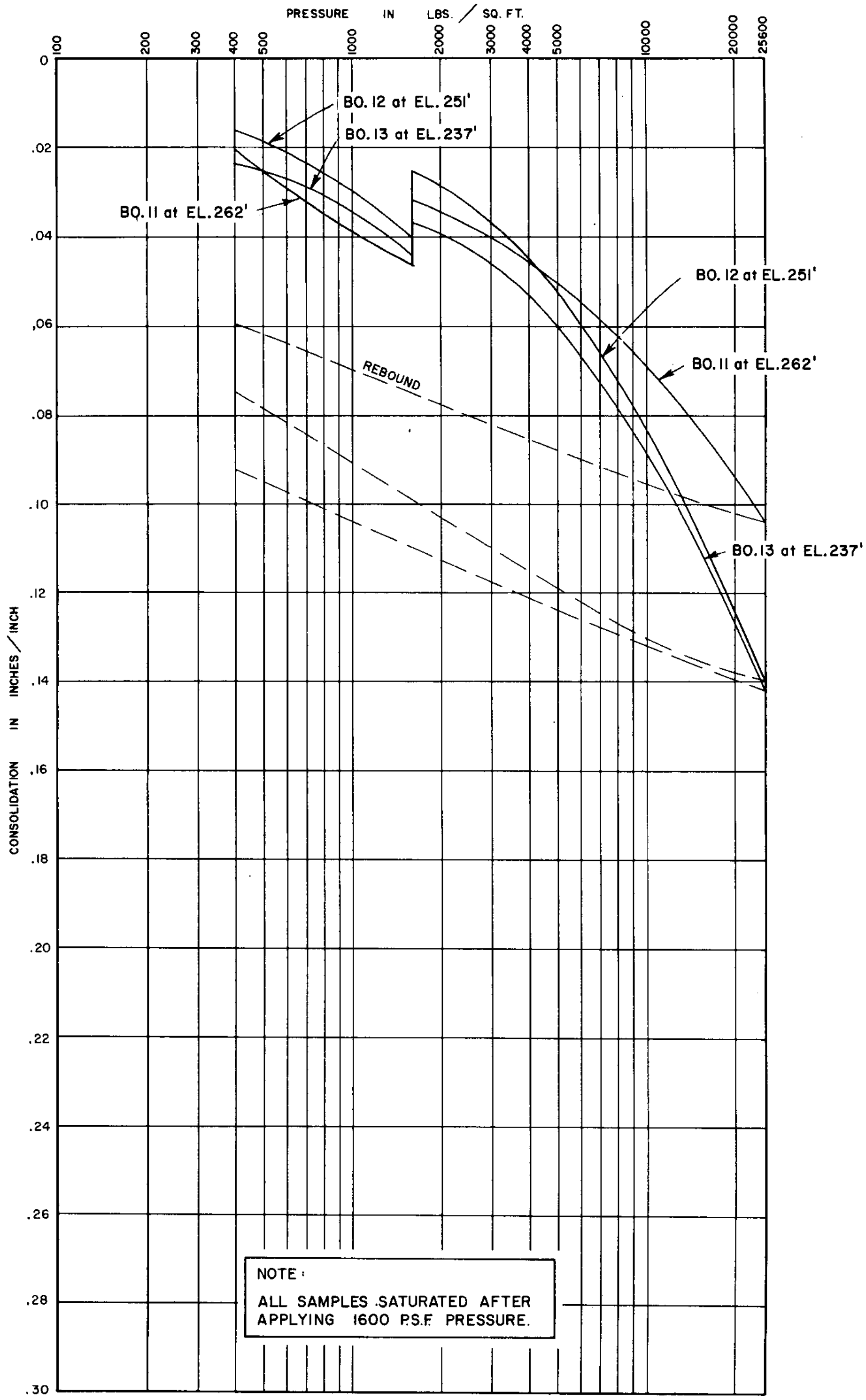


BORING NO.	ELEVATION FT.	SOIL OR ROCK TYPE	MOISTURE CONTENT, % before test	MOISTURE CONTENT, % after test	DRY DENSITY, P.C.F.
10A	251	DARK BROWN SANDY CLAY (CL)	15	17	97
10A	240	DARK BROWN SANDY CLAY (CL)	18	21	98
10A	235	DARK BROWN SANDY CLAY (CL)	15	17	104

CONSOLIDATION TEST DATA

DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A3B



BORING NO.	ELEVATION FT.	SOIL OR ROCK TYPE	MOISTURE CONTENT, %		DRY DENSITY, P.C.F.
			before test	after test	
11	262	BROWN FRACTURED SHALE	32	31	92
12	251	DARK BROWN CLAY WITH SOME SAND (CL)	25	23	100
13	237	BROWN & GRAY SANDY CLAY WITH DISPERSED GYPSUM	25	29	94

CONSOLIDATION TEST DATA

DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A3C

REVISIONS
BY ____ DATE ____
BY ____ DATE ____
PLATE ____ OF ____

FILE ____
BY ____ DATE ____
CHECKED BY ____ DATE ____

SAMPLE NO. 1 ELEVATION 275'

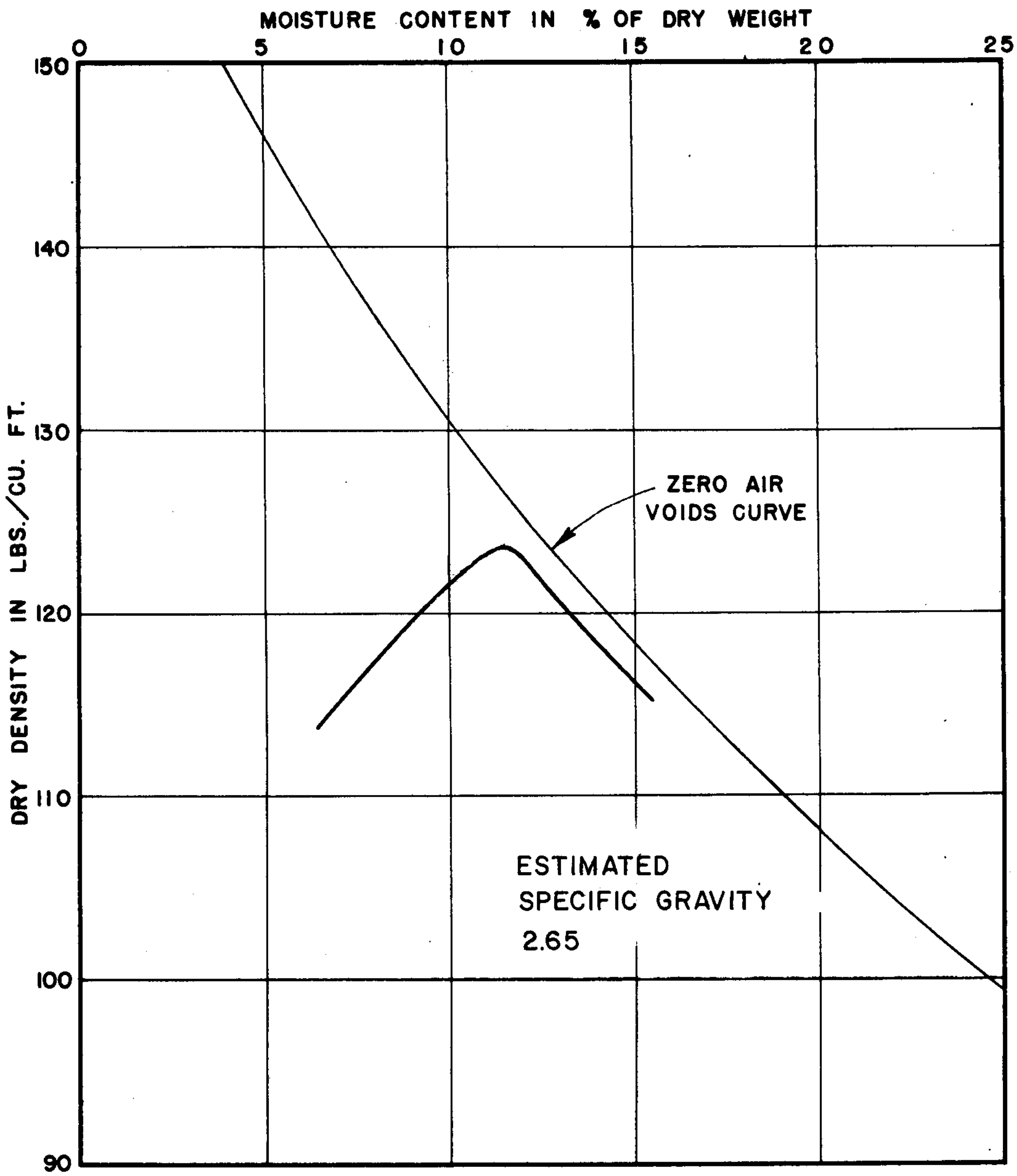
SOIL BROWNISH-GRAY SHALE

LOCATION BORING 4

OPTIMUM MOISTURE CONTENT 11 %

MAXIMUM DRY DENSITY 124 P.C.F.

METHOD OF COMPACTION MODIFIED AASHO



COMPACTION TEST DATA

DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A4A 297

DRAWN BY ______ DATE ______

CHECKED BY CLN DATE 1-?-6?

REVISION 2 BY ______ DATE ______

REVISION 1 BY ______ DATE ______

FILE 651-81

SAMPLE NO. 2 ELEVATION 266'

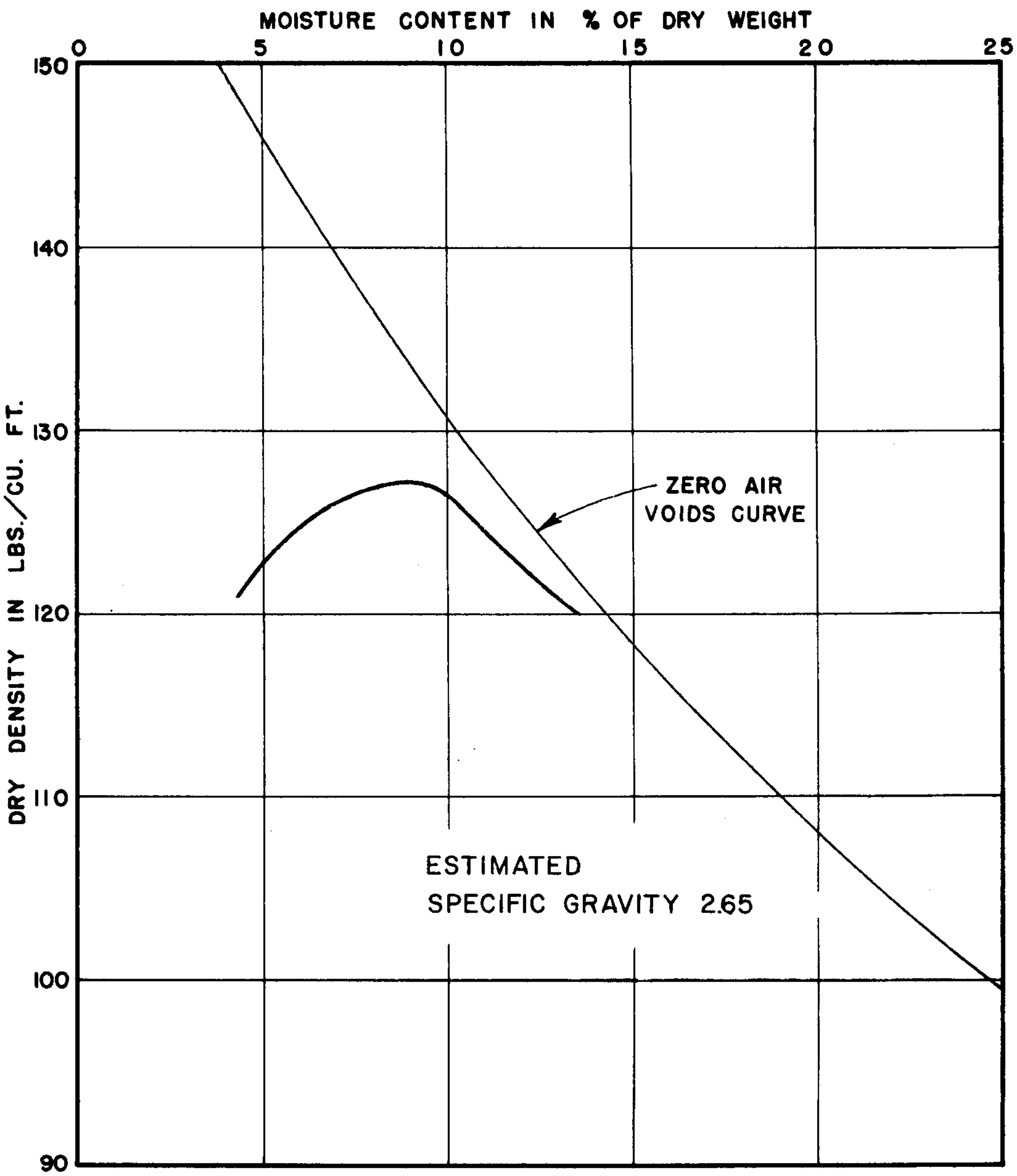
SOIL GRAYISH-BLACK SHALE

LOCATION BORING 4

OPTIMUM MOISTURE CONTENT 9%

MAXIMUM DRY DENSITY 127 P.C.F.

METHOD OF COMPACTION MODIFIED AASHO



COMPACTION TEST DATA

DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A4B

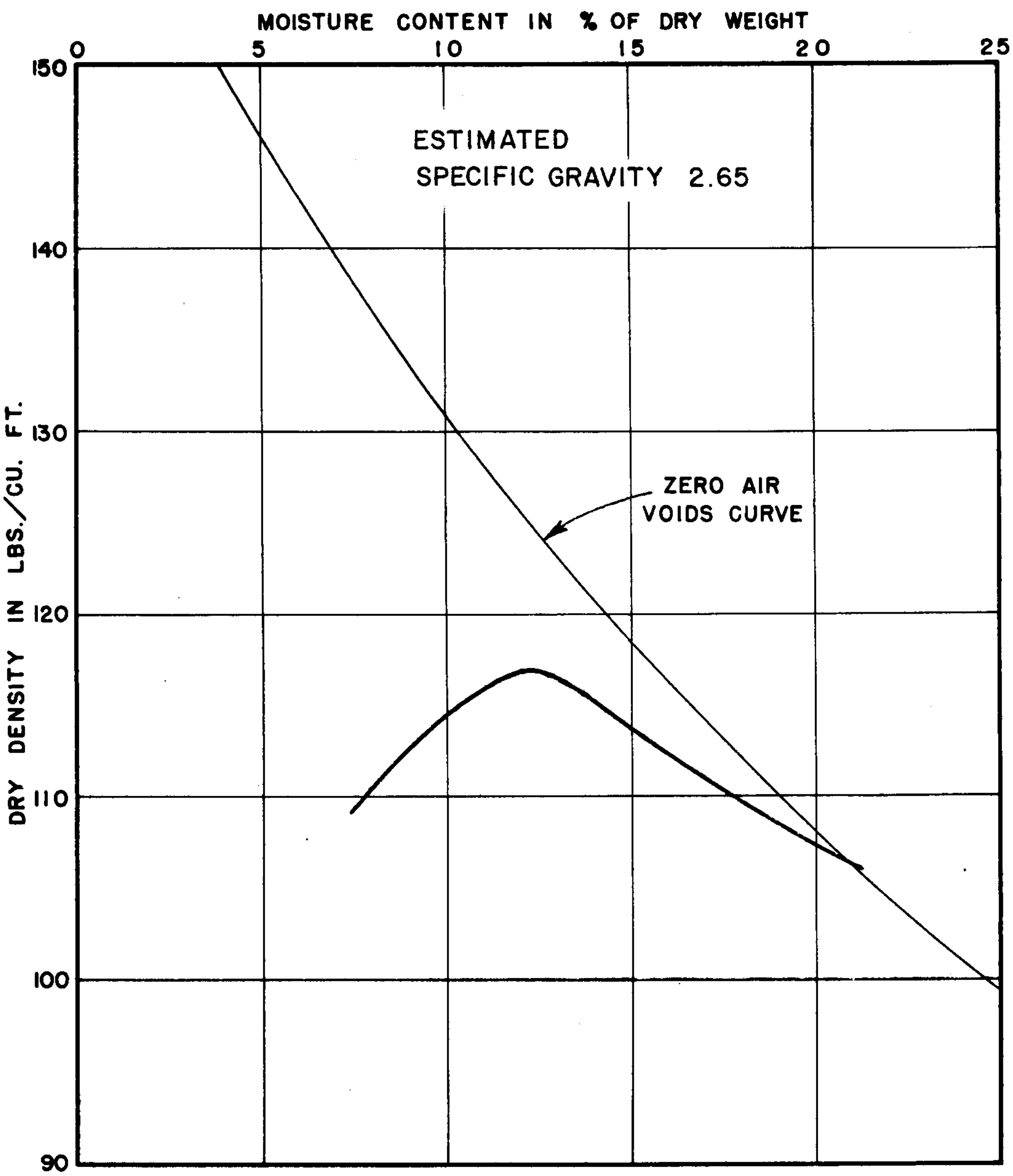
DRAWN BY ____ DATE ____
CHECKED BY ____ DATE ____

REVISION 2 BY ____ DATE ____

REVISION 1 BY ____ DATE ____

FILE 651-BI

SAMPLE NO. 3 ELEVATION 274'
SOIL LIGHT BROWN SILTY FINE SAND WI. GRAVEL (FINE GRAINED SANDSTONE)
LOCATION BORING 20
OPTIMUM MOISTURE CONTENT 12%
MAXIMUM DRY DENSITY 117 P.C.F.
METHOD OF COMPACTION MODIFIED AASHO



COMPACTION TEST DATA

DAMES & MOORE
SOIL MECHANICS ENGINEERS

PLATE A4C

DRAWN BY ____ DATE ____
CHECKED BY CLN DATE 11-9-60
REVISION 2 BY ____ DATE ____
REVISION 1 BY ____ DATE ____
FILE 651-81

SHEAR TEST DATA, COMPACTED CORES

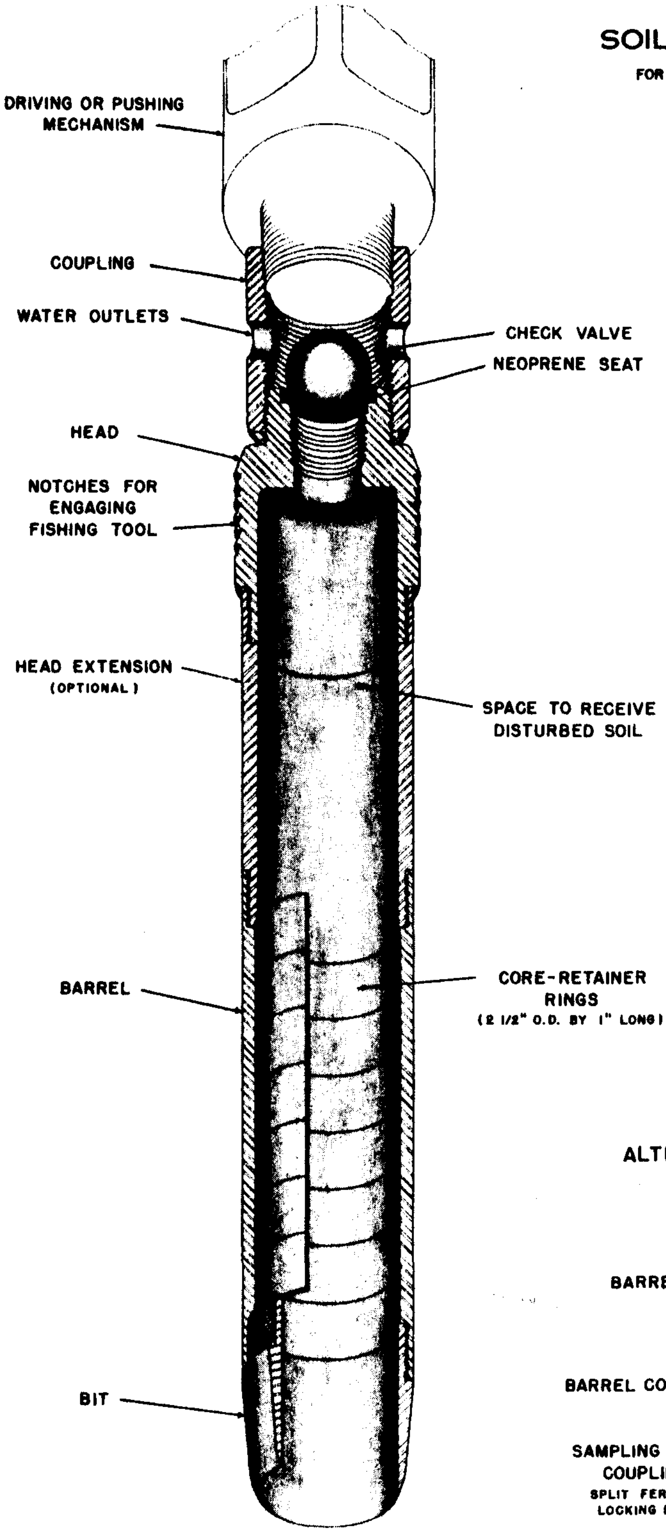
Boring	Depth (Ft.)	Soil Type	% Moisture*	% Moisture (Increased)**	Dry Density Lbs./Cu.Ft.	Normal Pressure Lbs./Sq.Ft.	Direct Shear Strength Lbs./Sq.Ft. Peak	Ultimate
20	10	Sandstone	18	--	101	200	1500	500
		"	17	--	105	2000	2000	2000
		"	17	--	103	8000	5600	5600
		"	17	23	110	200	700	700
		"	12	23	108	200	600	450
		"	18	19	111	2000	2600	2100
		"	14	21	106	2000	2000	1900
		"	16	21	105	5000	2600	2600
		"	18	22	104	5000	2800	2800
		"	16	18	115	5000	5000	4200
		"	17	20	103	8000	4200	4200
4	28	Shale	13	--	113	200	850	600
		"	11	--	122	2000	2500	2200
		"	13	--	112	2000	2200	2200
		"	11	--	120	5000	3100	3100
		"	14	--	113	5000	2400	2400
		"	12	--	114	8000	5500	5500
		"	11	12	132	200	1400	500
		"	12	15	115	200	450	450
		"	11	14	114	2000	2000	2000
		"	12	13	125	2000	2800	2800
		"	10	14	115	5000	3100	3100
		"	10	12	126	5000	5400	4300
		"	10	11	131	5000	6200	4300
		"	13	13	113	8000	4500	4500

*Specimen was compacted at this moisture.

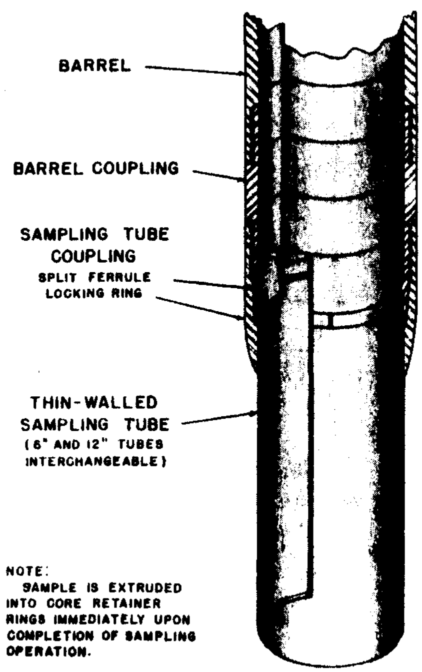
**Moisture was increased to this value under normal pressure indicated for given test.

SOIL SAMPLER TYPE D

FOR SOILS EASY TO RETAIN IN SAMPLER



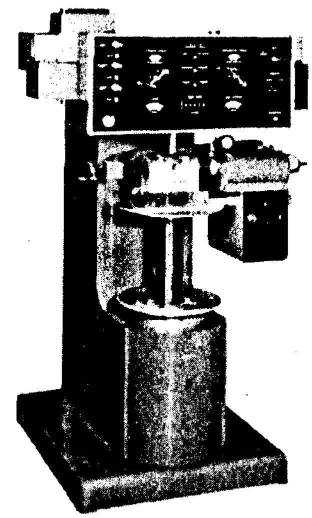
ALTERNATE ATTACHMENTS



NOTE:
SAMPLE IS EXTRUDED INTO CORE RETAINER RINGS IMMEDIATELY UPON COMPLETION OF SAMPLING OPERATION.

METHOD OF PERFORMING DIRECT SHEAR AND FRICTION TESTS

Direct shear tests are performed to determine the shearing strengths of soils. Friction tests are performed to determine the frictional resistances between soils and various other materials such as wood, steel, or concrete. The tests are performed in the laboratory to simulate anticipated field conditions.



DIRECT SHEAR TESTING MACHINE

Each sample is tested within three brass rings, two and one-half inches in diameter and one inch in length. Undisturbed samples of in-place soils are tested in rings taken from the sampling tool in which the samples were obtained. Loose samples of soils to be used in constructing earth fills are compacted in rings to predetermined conditions and tested.

Direct Shear Tests

A three-inch length of the sample is tested in direct double shear. A constant pressure, appropriate to the conditions of the problem for which the test is being performed, is applied normal to the ends of the sample through porous stones. A shearing failure of the sample is caused by moving the center ring in a direction perpendicular to the axis of the sample. Transverse movement of the outer rings is prevented.

The shearing failure may be accomplished by applying to the center ring either a constant rate of load, a constant rate of deflection, or increments of load or deflection. In each case, the shearing load and the deflections in both the axial and transverse directions are recorded and plotted. The shearing strength of the soil is determined from the resulting load-deflection curves.

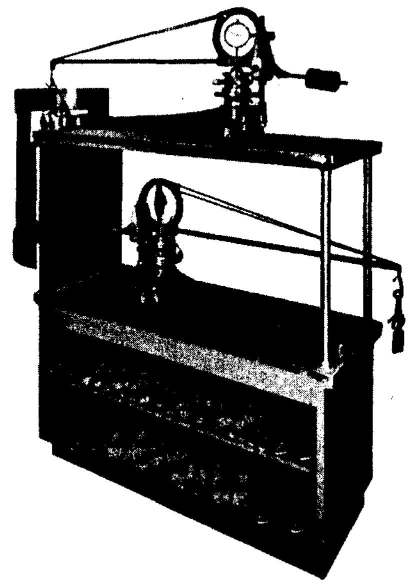
Friction Tests

In order to determine the frictional resistance between soil and the surfaces of various materials, the center ring of soil in the direct shear test is replaced by a disk of the material to be tested. The test is then performed in the same manner as the direct shear test by forcing the disk of material from the soil surfaces.

METHOD OF PERFORMING CONSOLIDATION TESTS

Consolidation tests are performed to evaluate the volume changes of soils subjected to increased loads. Time-consolidation and pressure-consolidation curves may be plotted from the data obtained in the tests. Engineering analyses based on these curves permit estimates to be made of the probable magnitude and rate of settlement of the tested soils under applied loads.

Each sample is tested within a brass ring two and one-half inches in diameter and one inch in length. Undisturbed samples of in-place soils are tested in rings taken from the sampling tool in which the samples were obtained. Loose samples of soils to be used in constructing earth fills are compacted in rings to predetermined conditions and tested.

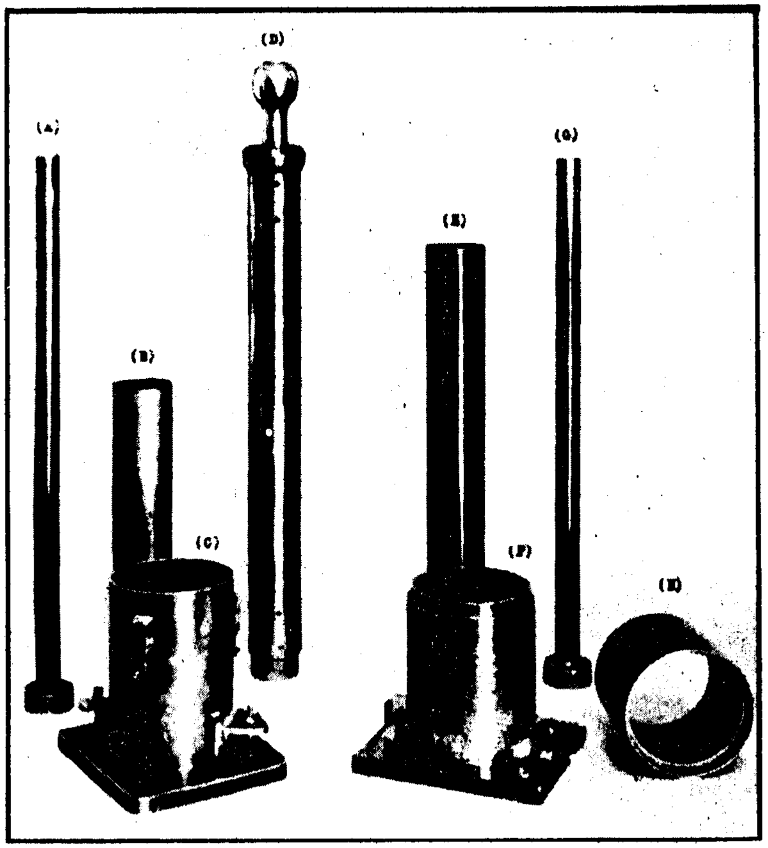

CONSOLIDATION MACHINES

In testing, the sample is rigidly confined laterally by the brass ring. Axial loads are transmitted to the ends of the sample by porous disks. The disks allow drainage of the loaded sample. The axial compression or expansion of the sample is measured by a micrometer dial indicator at appropriate time intervals after each load increment is applied. Each load is ordinarily twice the preceding load. The increments are selected to obtain consolidation data representing the field loading conditions for which the test is being performed. Each load increment is allowed to act over an interval of time dependent on the type and extent of the soil in the field.

Soils saturated in the field are tested submerged in water. The effect of increased moisture content on partially saturated soils is determined by adding water to the sample during the test.

METHOD OF PERFORMING COMPACTION TESTS

It has been established that, when compacting effort is held constant, the density of a rolled earth fill increases with added moisture until a maximum dry density is obtained at a moisture content termed the "optimum moisture content", after which the dry density decreases. The compaction curve showing the relationship between density and moisture content for a specific compacting effort is determined by experimental methods -- the most commonly used methods are described in the following paragraph.



APPARATUS FOR PERFORMING COMPACTION TESTS
(A), 5½-pound rammer; (B), sleeve controlling 12" height of drop; (C), 1/30-cubic-foot cylinder with removable collar and base plate, (D), 10-pound rammer within sleeve; (E), sleeve controlling 18" height of drop; (F), 1/20-cubic-foot cylinder and removable base plate; (G), 5½-pound rammer; (H), removable collar.

For the "Standard A.A.S.H.O." method of compaction, the soil sample is compacted in accordance with the "Standard Laboratory Method of Test for the Compaction and Density of Soil" as specified by the American Association of State Highway Officials under Designation T99-38. In this method of testing, a portion of the soil sample is compacted at a specific moisture content in three equal layers in a standard compaction cylinder having a volume of 1/30 cubic foot, using twenty-five 12-inch blows of a standard 5½-pound rammer to compact each layer. In the "Modified A.A.S.H.O." compaction method, a portion of the soil sample is compacted at a specific moisture content in five equal layers in a standard compaction cylinder having a volume of 1/30 cubic foot, using twenty-five 18-inch blows of a 10-pound rammer to compact each layer. In the "Proctor" method of compaction, a portion of the soil sample is compacted at a specific moisture content in three two-inch layers in a standard Proctor-type compaction cylinder having a volume of 1/20 cubic foot, using twenty-five 18-inch blows of a standard 5½-pound rammer to compact each layer.

For all methods, the wet density of the compacted sample is determined by weighing the known volume of soil; the moisture content, by measuring the loss of weight of a portion of the sample when oven dried; and the dry density, by computing it from the two determined quantities. A series of such compactions is performed at increasing moisture contents until a sufficient number of points defining the moisture-density relationship have been obtained to permit the plotting of the compaction curve. The maximum dry density and optimum moisture content for the particular compacting effort are determined from the compaction curve.

FRANK W. ATCHLEY
CONSULTING GEOLOGIST
821 Lois Avenue, Sunnyvale, California
REgent 6-8517

September 30, 1960

Dames & Moore
Soils Mechanics Engineers
340 Market Street
San Francisco 11, California

SUBJECT:
Geological Investigation of the
Sand Hill Linear Accelerator Site

Attention: Mr. Charles L. Nichols

Gentlemen:

Submitted herewith is my report on the Geological Investigation of the Sand Hill Linear Accelerator Site, Stanford University, in accordance with our verbal understanding and my letter proposal of July 24, 1960.

In brief summary, the investigation has revealed no geological conditions which would be prohibitive to the development of the Linear accelerator at the proposed site. There are differences in the topography, in complexity of geologic structure, and in soil and bedrock character in the alternate east or west end station areas. While either area can be developed for the proposed target installations, the exploration evidence indicates that the uniformity, physical character and general stability of the bedrock materials in the east end station area will provide substantially improved conditions for assured foundation design.

The completed explorations, in my opinion, are entirely adequate to undertake the construction design of the accelerator project, with recognition that the final foundation design will require additional borings at specific points of heavy loading.

Respectfully submitted,

Frank W. Atchley
FRANK W. ATCHLEY

FWA:ggs

Enclosures

SCOPE OF WORK

The present report covers the field explorations and general geology of the proposed accelerator alignment shown on the appended map. This alignment is basically the same line as previously investigated except that either end area is now being considered for the target installations. The location, access, climate, etc., of the site area are known to the client and are omitted from present discussion.

Field explorations included detailed geologic mapping, supplemented with photo-interpretation, and review and appraisal of trenching and drilling exploration data.

The drilling program was conducted by John A. Blume and Associates, with planning and supervisory assistance from Dames & Moore and the present writer. The trenching program was planned and directed by the writer, and consisted of 14 back-hoe excavations varying from 5-7 feet in depth and up to 250 feet long. Primary purpose of the trenching was to locate concealed rock contacts and establish bedding attitudes, while the drilling was designed to check subsurface foundation conditions and to provide samples for laboratory testing.

GENERAL GEOLOGY

The site area and regional geology have been described in previous reports*, hence will be discussed only briefly. It suffices to note that the Sand Hill site lies within the rolling foothill country southwest of Stanford University between Portola Valley and Alpine Road, and between San Francisquito Creek and Sand Hill Road. The terrain is fairly gentle, with smooth rounded slopes of 5-15 degrees and probably a maximum of 75-100 feet of relief between hills and valleys. Practically all of the area is mantled with residual soil. Natural outcrops are scarce and the delineation of rock units and geologic structure is often arbitrary.

Sedimentary rocks of Tertiary age underlie the entire site area. Three geologic rock units are present along the alignment and each has peculiar characteristics and differing geologic age. The western half of the alignment crosses a sequence of alternating sandstones and shales of Eocene age, while the eastern half extends through an area of massive sandstones and siltstones of Miocene age which are overlapped locally by a capping of sands and gravels of Pleistocene age. The latter rocks are known generally as the Santa Clara formation.

The above rock units are separated by hiatus or gaps in geologic time and have undergone repeated episodes of folding and faulting in the geologic past. The older

*Preliminary Geological Investigation of the Sand Hill and Felt Lake Linear Accelerator Sites, a report for John A. Blume & Associates, by Frank W. Atchley, January 1960.
*Geological Investigation of the Stanford Two-Mile Linear Accelerator Site: Part II, Geology of the Stanford Foothills; a report from Stanford University to the Atomic Energy Commission, by Frank W. Atchley and Robert O. Dobbs, January 1960.

Eocene rocks locally are crushed, intensely sheared, and highly faulted, while the younger Pleistocene rocks (in this area atleast) are relatively undeformed and are only gently folded. Practically all of the deformation in the area, as shown by fold axes, fault lines, etc., shows a general northwest trend either parallel or slightly oblique to the San Andreas rift zone, which cuts through Portola Valley about one mile west of the west end station. While both known and suspected fault lines cross the accelerator alignment, there is no evidence that they are or have been active in historical time.

ROCK UNITS

EOCENE SECTION

The Eocene rocks were mapped and differentiated into map units of sandstone and shale. However, the complexity of structure, scarcity of outcrops and varying resistance to weathering make accurate definition of individual strata quite difficult, hence the map units represent and delineate areas in which either sandstone or shale appears to be the predominate rock present.

Eocene sandstones are typically massive and occur in beds which range in thickness from 5-50 feet and average about 20. The rocks are white to tan in color, medium to coarse grained, and poorly sorted. Many of the sandstones are weakly cemented and friable but some are firmly cemented with silica and calcite and are quite hard.

Alternating with the Eocene sandstones are various strata of clay shales and siltstones which are thin bedded and often have a blocky fractured appearance. The shale is gray to greenish black when fresh and yellow-brown where weathered. Some of the shales contain considerable pyrite, which oxidizes and forms gypsum and other sulphates in the weathered zone. Much of the shale is intensely distorted and sheared, as in a fault zone, and shows plastic deformation and flowage around broken blocks of the more resistant sandstones. Some of the Eocene shales have swelling properties, and most of them exhibit moderate to severe air slaking on prolonged exposure. The shales form a distinctive black, expansive, "adobe-like" soil.

MIOCENE SECTION

The Miocene rock unit consists predominately of massive, poorly bedded, fine to very fine grained sandstone (almost a siltstone) which is typically weakly cemented. Almost all of the sandstone is a bluish-gray color where fresh and a buff color where weathered. It forms a distinctive light gray, powdery, non-expansive residual soil.

Also in the Miocene unit is a distinctive horizon marker of hard, thin-bedded, silty chert (or silicious siltstone) which is cocoa brown where fresh and forms white-weathered angular chips in outcrops.

PLEISTOCENE SECTION

The Pleistocene rocks consist predominately of a yellowish-brown, fine to coarse grained, poorly sorted, weakly cemented sandstones, which contain local layers and lenses of gravel. The gravel is mostly of small size (1/4 to 1 inch) but large sizes including cobbles and boulders are present locally. Red chert fragments in the gravel are diagnostic. Very little clay or shale are present in the site area, though are common elsewhere in the region.

The Pleistocene sandstones are difficult to distinguish from the Miocene sandstones and can be identified with certainty only by the presence of gravel and chert fragments. The Pleistocene sandstone tends to form a brownish sandy soil, but this can be deceptive.

ALLUVIUM

A local area of stream deposited alluvium consisting of interlensing unconsolidated sand silt clay and gravel underlies a short section of the alignment near the main bend in San Francisquito Creek. This alluvium was drilled out and is upward to 35 feet deep.

SITE GEOLOGY

The areal and subsurface geology along the proposed alignment is represented on the appended map and sections. The subsurface structure is inferred from scattered outcrops and interpretation of exploration data, consequently is diagramatic in places. Some of the rock discontinuities can be explained equally well by postulated unconformities, folding, or faulting, hence specific details are subject to question. However, regardless of details, the drilling and trenching program has given sufficient data to draw valid general conclusions concerning the engineering significance of the geologic conditions in question.

EAST END STATION AREA

The east end station area is underlain by massive fine grained Miocene sandstones, and by sandstones and gravel of the Pleistocene Santa Clara formation. The sandstones in these two units are quite similar in their physical and engineering properties, hence the bedrock of the area can be regarded essentially as a homogeneous unit. The gravel is minor in abundance and importance, and clay or shale strata seem to be absent. The overburden consists of 1-3 feet of sandy residual soil.

Geologic structure in the east end area is poorly defined because of gentle to flat-lying bedding attitudes. The few attitudes observed in the trenches suggest that the Miocene rocks dip northward into the hill, and that the capping of Santa Clara rocks wrap around the nose of a gentle fold and dip to the south and east at 5-15 degrees.

ACCELERATOR ALIGNMENT

Beginning at the east end station, the accelerator crosses a gentle sloping terrain underlain by sands and gravels of the Santa Clara formation; thence a central low ridge of Miocene sandstone. Here also the sandstones of the two units are similar and division of the two in some places is arbitrary. Since there are no outcrops in this area, the contacts shown are based largely on photo ground color and surface accumulation of chert pebbles and cobbles. Bedding attitudes are also indefinite though they apparently strike generally north to northeast and dip gently to the east.

The accelerator will cross a fill section placed on Santa Clara rocks near the east end station and be in a cut section farther to the west. In the cut area, the Santa Clara unit is quite thin and for the most part will lie above accelerator grade. Test Holes 19 and 20A show a thickness of the Santa Clara unit of only 15-20 feet.

Between the Santa Clara contact and Hole 13 (see appended map), the accelerator will cross a rolling hill area of Eocene and Miocene rocks in a major deep cut. This hill is masked by deep residual soil and exposes but few outcrops, hence the details of structure are largely speculative. In broad terms, however, the structure in this hill area comprises a faulted anticlinal complex where at least three fault lines and related shear zones cross the alignment. The evidence for the faults is stratigraphic repetition of Eocene shales and Miocene sandstone; the fault traces are nowhere exposed and have little or no topographic expression, hence are only approximately located. The cross fault between Trenches 5 and 6 is based on abrupt termination of resistant beds of silicious siltstone (and chert) exposed in Trench 5, but again the exact location and orientation of the fault is problematical. In short, the trend of bedding and structure is definitely to the northwest, more or less perpendicular to the alignment, but the local structure is largely concealed. The shale rock, as noted in Drill Holes 17, 17A, and 18, and Trenches 6, 7, 8 and 9, is generally sheared and deformed and the sandstone is broken and fractured. The latter condition is also suggested by excessive water loss in Holes 17 and 18 during drilling.

The preliminary mapping of the central hill area in January 1960 noted that the surface was locally blanketed by deep soil cover and might be underlain locally by Eocene shale, as is now confirmed.

In the vicinity of Hole 13, the accelerator will cross a broad gentle valley on fill foundation placed over typical Miocene sandstones and a hard, blocky, dark gray to black siltstone. This siltstone, or silty shale, resembles some of the Eocene shales, but the relative competence and apparent geologic structure both suggest that it must be a variation of material in the Miocene formation. The valley is floored largely by sandy soil wash alluvium of 3-4 foot thickness deposited over 6-8 feet of black, clayey residual soil, as shown by Drill Holes 13 and 14. Both holes encountered moist clay and overnight ground water seepage at 9-10 feet in depth. A fault line parallels the valley, but the trace is not well-defined.

The low ridge, marked by Drill Hole 12A is underlain predominately by massive Miocene sandstone, which strike northwest across the alignment and dip 40-50 degrees to the east. Drill Hole 12A revealed that the local capping of Santa Clara gravels does not extend across the alignment as previously shown.

Between Hole 12A and the west end station, the accelerator crosses a sequence of alternating Eocene sandstones and shales, and passes over a local terrace platform of unconsolidated alluvial sands, clays, and gravels (as shown in Drill Hole 10A). These alluvial materials probably would be compressible under heavy loadings. The Eocene rocks are typical of those described and strike west-northwest at acute angles across the accelerator and dip steeply to the northeast. A small, unimportant earth slide was noted in the steep cut bank just west of Drill Hole 10A.

Near Drill Hole 12 the accelerator will cross a deep, steep-walled gulley. Hole 12, on the east side of the gulley, was dry and showed approximately 20 feet of admixed soil and rock fragments at the surface. Hole 11, on the opposite side of the gulley, encountered ground water and severe caving conditions in sheared clay shale between 15 and 20 feet.

WEST END STATION

The geology of the west end area is considerably more complex than the east end area and there is corresponding greater uncertainty of the engineering significance of the structure and rock conditions. This factor warrants attention because the topography is higher and steeper and local 95-foot vertical cuts will be needed to reach design grade. The cuts will encounter sharp local differences in foundation character due to faulting, shear zones, and alternating interbedded sandstones and shales.

At least two fault lines cross through the west end station area, both striking northeast more or less at perpendicular angles to the rock bedding. Neither fault shows any evidence of recent activity. One of the faults cuts diagonally across the northwest corner of the area and the other the extreme southeast corner. The latter fault was disclosed in Drill Hole 10, where wet caving ground was experienced. The fault across the northwest corner has large displacement and shows a downdropped wedge of Miocene siltstone cutting across the strike of the Eocene strata. This fault is marked by topographic depressions and probably accounts for the sheared shale encountered in Drill Hole 4. Trenching disclosed two separate linear zones of intense shear deformation on the west side of the fault, as noted on the map. Where cut by Trench 1, the shear zone shows numerous disrupted and isolated blocks of sandstone embedded in plastically deformed shale. More than likely there are other faults and shear zones in the area, but they could not be identified with certainty.

The structure in the high hill marked by Drill Hole 5 is debatable. Surface outcrops and photographic evidence suggest that the bedding trends generally east-west and dips vertically, but attitudes in Drill Holes 5 and 7 suggest gentle dips and even flat-lying bedding.

The high hill marked by Trench 4 is underlain by typical alternating Eocene sandstones and shales striking northwestward and dipping about 30 degrees northward into the hill.

ENGINEERING GEOLOGY

The proposed floor elevation of the accelerator has been set at 276 feet. This elevation will necessitate maximum vertical cut depths of 55 feet in the east end area, 75 feet along the accelerator line, and 95 feet in the west end area. It is significant that the material at these cut depths will be truly fresh and unoxidized. There has been no construction experience with such material anywhere in the San Francisco Bay Area that I know of. Consequently, the physical behavior of the material with respect to possible rebound and slope instability warrants attention. For example, there is general rule that rock hardness, strength, and stability increase with increasing depth below the surface. This is the general case, but in the particular Miocene and Eocene rocks in question, this increase in hardness with depth will not hold true. Rather, the converse, and the rocks will decrease in hardness with depth. This is due to the phenomena of surface case hardening by oxidation and cementation of particles with iron oxides and other materials. In other words, the sandstones and shales will have a "dry" strength in the weathered zone that will not be present in the fresh material at grade depth.

Considering the above, it is pertinent that the Miocene and Eocene rocks along the proposed alignment are virtually identical to those found along the former tunnel alignment. Consequently, the observations and material testing made during the tunnel investigation are generally applicable to the present area. It would be advisable to compare and evaluate this previous data with the present work before design recommendations are made.

Following are summary remarks on the principal engineering geological features of the Sand Hill alignment.

EXCAVATION: All of the rock in the east end area can probably be excavated by ripping (new D-9 tractor with single hydraulic dog tooth) and carry-all scraping without resort to blasting. The same holds true for the cuts along the accelerator alignment, with the possible exception that local areas of Eocene sandstone near the bend in San Francisquito Creek may require some blasting. Probably 15% or more of the rock in the west end station will require blasting to be excavated, as some of the rock is a hard cemented sandstone.

FOUNDATION FILL: The sandstones in the east end area and along the central portion of the accelerator line will make excellent compactable stable fill, and engineered fill slopes of 2:1 should have ample safety. The same holds true for the Eocene sandstones in the west end area, except that a considerable portion of the fill would be rocky and might not break down into compactable material. The Eocene shales in the west end area, and along the central section of the alignment, have variable physical properties and some may have swelling properties, hence their suitability for foundation fill must be carefully appraised.

SETTLEMENT: Differential or gradual settlement from heavy or variable foundation loadings should be negligible in the east end area due to the homogeneous granular nature of the rock materials. This applies to fresh rock in the deep cut areas and to engineered fills placed on weathered rock materials at the surface. Since the surface is mantled by a thin veneer of sandy non-expansive soil, the fill preparation would involve only grubbing and perhaps a maximum of 2-3 feet of stripping.

The deep cuts in the central hill area should give no difficulty with settlement because of low unit loadings.

The broad valley area near Hole 13 will require 20 feet or so of foundation fill to obtain accelerator grade, then shielding fill to a total of 65-70 feet. This valley is floored by 1-3 feet of sandy soil wash deposited over 8-10 feet of black expansive clay, all of which should be excavated to insure against settlement. Drill Holes 13 and 14 both revealed competent foundation rock at 14 feet, which probably is the maximum stripping depth; the average stripping depth should be about 6-8 feet.

All of the unconsolidated alluvium beneath the accelerator should be excavated and replaced with engineered fill where it crosses the level terrace area near the main bend in San Francisquito Creek.

The question of settlement in the west end area is difficult to assess. As noted previously, the rock materials at grade depth will be truly fresh and unaltered. How these materials will behave on temporary and prolonged exposure is uncertain. For example, the resilient stability of the clay shales, and particularly the shear zone material, is totally unknown. They might well be in a preloaded stress condition and might rebound to some extent upon exposure. Regarding this possibility, it would be advisable to analyze carefully the conditions experienced in driving the Stanford Hetch Hetchy tunnel, where similar if not identical Eocene rocks were penetrated (see Stanford Report). In my opinion, the rock conditions at grade depth definitely possess a potential for rebound, but the occurrence, time factor, and magnitude would have to be assessed on the basis of physical test data. The same holds true generally for the occurrence and magnitude of foundation settlement. In this case, however, it is my opinion that local differential settlement will occur between isolated points of heavy loading. This condition is due to the variable nature of the foundation materials, as described previously. It is also possible that some of the Eocene shales will contain montmorillonite clay (known generally as bentonite) which conceivably could swell on exposure to water and cause heaving of foundations. Such material was encountered in the Eocene shales during the Stanford Accelerator tunnel investigation.

SLOPE STABILITY: Assessment of slope design of cuts as deep as those proposed must consider long term stability, possible consequences of failure, and level of desired safety. The problem is minimized along the accelerator itself, since shielding fill will buttress the toe of the cuts. In the end station areas the cuts would stand at full height. There is the additional problem of assessing the safe slope for temporary construction cuts, which factor depends somewhat on the time of year and on the duration of exposure.

The following estimates of required slope angles are the maximum steepness which would provide any reasonable long-term safety for the main cuts and give safe working conditions for temporary cuts along the accelerator channel.

In the east end area, and wherever in Miocene sandstone or Santa Clara formation, slopes of 1:1 (horizontal to vertical) with 30-foot bench height and 10-foot bench width, should give adequate long-term safety. Slopes of .5:1 should give ample safety for temporary construction cuts, if not over 10 feet in height. Practically all cut slope surfaces in the Miocene sandstones and Santa Clara formation will be subject to minor rain wash erosion, but none should require horizontal drainage to insure stability.

In the section of the deep cut through the central hill area, which crosses Eocene shales, slopes of 1-1/2:1 should be satisfactory, but 1-3/4:1 or even 2:1 might be dictated by local shear zone conditions, which can be determined only upon construction exposure. Slopes of 1:1, and possibly 1-1/2:1, will be needed for temporary construction. These shales dessicate and air slack on exposure, hence the cut slopes are likely to absorb water, soften, and be subject to extensive sloughing during the rainy season. It is quite possible that horizontal drainage will be needed locally to insure slope stability.

As with settlement, the assessment of stable slope design in the Eocene rocks in the west end area poses a troublesome problem. The interbedded nature of the sandstones and shales, the complex structure, and variable bedding attitudes, all bear on the problem. Moreover, the significance and extent of shear zones and distorted shales are practically unknown. Considering these factors and recognizing that the sheared shale beds revealed by trenching and drilling will constitute the "weak link", despite the stabilizing effect of interbedded sandstones, it is my opinion that the maximum permissible slope in the west end area should be set at 2:1, with maximum bench height of 20-25 feet with intervening 10-12 foot bench widths. In the sandstone horizons, slopes of 1/2:1 to 1:1 should afford ample safety for temporary cuts, whereas in shale horizons slopes of 1-1/2:1 will be necessary. With respect to temporary cuts, the severe caving conditions experienced in Drill Holes 10 and 11 should be noted. Both holes also encountered heavy ground water seepage. This evidence suggests that extensive horizontal drainage will be needed in the main cuts to achieve the necessary level of slope safety.

<u>GROUND WATER</u> : The deep cuts in the central hills and end areas will all be below the zone of pore saturation which is generally referred to as the water table. The Miocene sandstones have generally low permeability, and cuts therein should involve few if any serious seepage problems. This applies to the east end station area in particular. Some seepage might occur locally from gravel lenses in the Santa Clara formation, although Drill Holes 19 and 20A penetrated the full section and were perfectly dry.

Considerable seepage is expected in the central hill area in the vicinity of Holes 17 and 18, where heavy water losses occurred during drilling. Such losses show that the sandstones penetrated are naturally permeable or else are fractured and open. Elsewhere, the cuts in the central hills should be relatively dry.

Ground water will give little or no problem in the valley area marked by Drill Holes 13 and 14.

Continuous seepage can be expected in many places in the cuts through the Eocene sandstones and shales in the western part of the alignment and in the west end station area. Such seepage probably would be spotty but rather widespread. No large amounts are anticipated, but at the grade depth some of the seepages are likely to be perennial and require a permanent collection system.