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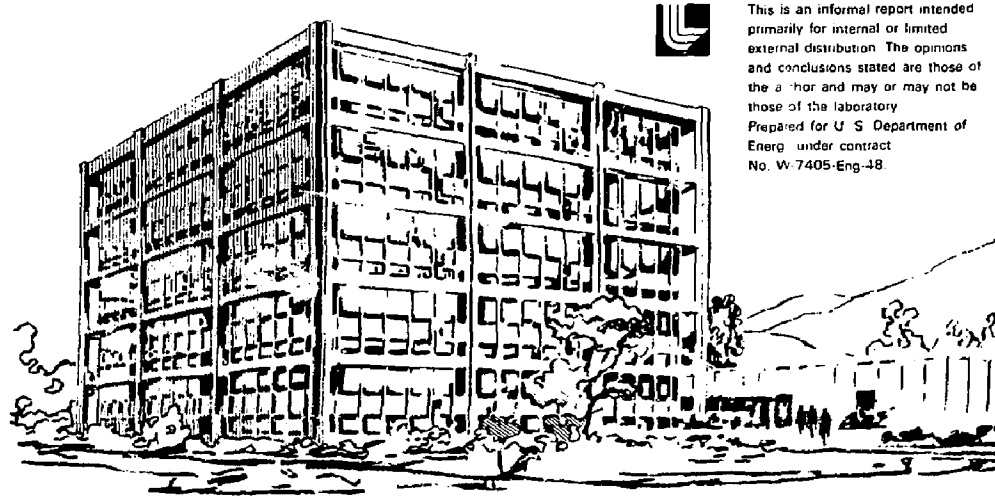
Lawrence Livermore Laboratory

PRELIMINARY REPORT: QATTARA PROJECT MATERIAL PROPERTIES

MARC COSTANTINO

JUNE 1979



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Interdepartmental letterhead

Mail Station L 350

Ext 26923 20 June 1979

M E M O R A N D U M

TO: John Toman

FROM: Marc Costantino

SUBJECT: PRELIMINARY REPORT: QATTARA PROJECT MATERIAL PROPERTIES

We have measured strength under triaxial loadin and compressibility under hydrostatic loading for four representative materi s along a proposed route of a canal from the Mediterranean Sea to the Qattar Depression. The results of these measurements are used in computer calcula.ions for cratering profiles using nuclear explosives. Considerations of the lithology along the route have led to a characterization of earth material types using four descriptors: 1) limestone, 2) sandstone, 3) high sand, and 4) clay/silt. This memo is a preliminary report of the work and data reduction. A more complete account will be published at a later date.

The organization of this memo is:

A. Introduction

B. General description of the as-received cores

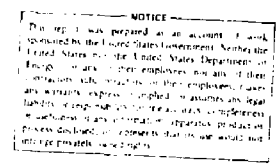
C. Apparatus

D. Results for limestone

E. Results for sandstone

F. Results for high sand

G. Results for clay/silt


NOTICE

A. Introduction

In August 1978, LLL agreed to undertake calculations of cratering profiles as part of a feasibility study for the Qattara Project. The concept is to use a series of underground nuclear explosions to create a canal between the Mediterranean Sea and the lip of the Qattara Depression in Egypt, a distance of about 80 km. The 60m drop to the Depression floor then provides a hydrostatic head for generating electricity.

In order to perform the cratering calculations, the lithography along the proposed canal route was characterized by dividing it into four broad

geologic types. The actual lithology of the region near an explosion is modeled using one or more of these types, and a computer code is used to predict the crater profile for a particular explosive configuration. Material density, water content, gas-filled porosity, compressibility and strength are required in performing the calculations. The Geophysics Section of the Earth Sciences Division was tasked to make laboratory measurements of compressibility and strength.

B. General Description of the As-Received Cores

On the basis of logs for drill holes C-2, N-1, N-2, N-3, and NN-4, the lithology was modeled as shown in Fig. 1. Samples of core totalling 20m in length (x's in Fig. 1) were requested in September 1978 to be sent to LLL. In December 1978 core samples ranging from 7.5 to 15 cm in diameter and totalling 18.5m in length were delivered (O's in Fig. 1).

In order to decrease the uncertainty of the measurements, the cores were to be preserved as nearly as possible in the in situ condition. Although the intact core samples were wrapped in cotton cloth and adequately waxed, all were quite dry with no evident moisture even for those from below the water table. The clay/silt cores showed through-going cracks, evidently owing to shrinkage, parallel to the bedding and radial cracks along the cylinder axis. The subsequent requirement to reconstitute samples results in increased uncertainty in relating laboratory data to in situ conditions.

C. Apparatus

Four major apparatus were used in this program. Failure curve (strength) measurements on the limestone and sandstone were done in the Washington press, in which σ_1 the axial (and major principal) stress and $\sigma_2 = \sigma_3$ (intermediate and minor principal stresses - - the confining pressure) could be controlled and measured independently and the axial strain measured. Compressibility tests for the limestone and sandstone were made with a purely hydrostatic pressure less than 20MPa using the SOB apparatus and for a quasi-hydrostatic pressure to 3500MPa using the Kennedy press. In the former, strain gauges attached to the copper jacketed samples are used to measure radial and longitudinal strains. In the latter, the volume of the sample inside a deformable tin cup is determined by comparison of axial displacements against a standard material (nickel).

Failure curves for the high sand and clay/silt were determined using for the first time a new apparatus, SASS. SASS permits independent measurements of axial stress (σ_1) confining pressure ($\sigma_2 = \sigma_3$), radial strain, and longitudinal strain for samples up to 11.5cm in diameter and 18cm long. This apparatus was assembled, tested, and calibrated during the course of the Qattara work. Additionally, sample preparation and jacketing techniques were developed.

D. Limestone

A limestone cap, decreasing in thickness from north to south, covers a portion of the route. Cores from hole C-2 (∿19m), termed "chalky" limestone and from N-1 (∿47m), termed "fossiliferous" limestone, were tested. Strength curves and hydrostats are shown in Figs. 2 - 5 and the results listed in Tables I and II. All measurements were made for 0% water saturation. At 0.1 MPa confining pressure failure is brittle. However, at 20 and 100 MPa confining pressure the material hardens after yielding at the end of an elastic region. Definitions of the terms used in Figures 3 and 5 are given in Figure 3A.

E. Sandstone

Sandstone samples taken from hole N-3 (∿133m) were competent, but friable, with widely scattered inclusions ranging from 1-10mm in diameter. Compressibility for the 100% and 0% saturated sandstone are shown in Fig. 6. Failure curves for 50% and 100% saturations are shown in Figs. 7 and 8. The data are in Tables III and IV. In the case of the partially saturated material, the matrix fails before the pore fluid fills the porosity. The pore fluid pressure then increases upon further compaction and the assemblage of unbonded sand grains has a strength similar to that of high sand. The pore pressure in the fully saturated sandstone increases sufficiently fast to prevent the early matrix collapse and the failure curve shows a normal behavior.

F. High Sand

Since the as-received cores showed significant water loss, the high sand samples were reconstituted by drying in vacuum at 105°C, adding an appropriate amount of water, and compacting to bring the density and water content near to that shown by the well log for hole NN-4 at 310m depth. A sample was made of a stack of five disks, each about 3cm thick and 7cm diameter, using material from the 27m depth of hole NN-4. Since the sample is fully saturated only at and above the overburden pressure, the 0.1 MPa failure point is for less than 100% saturation. The compressibility curve is shown in Fig. 9 and the failure curve in Fig. 10. Data are given in Table V.

G. Clay/Silt

The as-received samples of clay/silt were reconstituted as for the high-sand. Compressibility is shown in Fig. 11 and strength in Fig. 12. Data for the failure curve are in Table VI.

MC:jfc

Attachments
Tables I - VII
Figures 1 - 12

TABLE I

STRENGTH DATA FOR QATTARA CHALKY LIMESTONE

UNDER TRIAXIAL LOADING

0% SATURATION

	τ (MPa)	$\bar{\sigma}$ (MPa)
"Elastic" yield	9.5 ± 1.6	6.4 ± 1.1
	11.8 ± 3.7	27.9 ± 2.5
	2.5 ± 0.8	101.7 ± 0.6
3% Plastic strain	9.5 ± 1.6	6.4 ± 1.1
	18.7 ± 0.2	32.4 ± 0.1
	33.6 ±11.2	122.4 ± 7.5
5% Plastic strain	9.5 ± 1.6	6.4 ± 1.1
	20.2 ± 0.2	33.4 ± 0.1
	51.2 ±10.2	134.0 ± 7.0
10% Plastic strain	9.5 ± 1.6	6.4 ± 1.1
	23.2 ± 0.6	35.4 ± 0.4
	114.8 ±30.8	176.4 ±20.6

Grain density = 2.84 gm/cm^3

Bulk density = 1.42 gm/cm^3 (0% saturation)

Porosity = 0.50

TABLE II

STRENGTH DATA FOR QATTARA FOSSILIFEROUS LIMESTONE UNDER TRIAXIAL LOADING 0% SATURATION

	τ (MPa)	$\bar{\sigma}$ (MPa)
"Elastic" yield	6.0 ± 0.4	4.1 ± 0.2
	3.0 ± 1.4	22.0 ± 1.0
	3.0 ± 0.3	102.0 ± 0.2
3% Plastic strain	6.0 ± 0.4	4.1 ± 0.2
	11.7 ± 2.1	27.8 ± 1.4
	44.9 ± 11.9	129.9 ± 7.9
5% Plastic strain	6.0 ± 0.4	4.1 ± 0.2
	12.4 ± 3.2	29.6 ± 1.2
	66.0 ± 17.4	144.0 ±11.6
10% Plastic strain	6.0 ± 0.4	4.1 ± 0.2
	20.3 ± 1.4	33.5 ± 0.9

Grain density = 2.69 gm/cm^3

Bulk density = 1.80 gm/cm^3 (0% saturation)

Porosity = 0.33

TABLE III

FAILURE STRESS DATA FOR QATTARA SANDSTONE

UNDER TRIAXIAL LOADING CONDITIONS

~50% SATURATION

Sample	σ_c (MPa)	τ_f (MPa)	$\bar{\sigma}_f$ (MPa)
Q399	0.1	5.87	4.02
Q390A	0.1	3.24	2.26
Q391A	0.1	6.33	4.32
Q399A	0.1	9.52	6.45
Q393A	20.0	18.44	32.29
Q394A	20.0	7.17	24.78
Q395A	20.0	9.42	26.28
Q398A	20.0	9.52	26.69
Q395A	100.0	4.75	103.2
Q396A	100.0	3.69	102.5
Q397A	100.0	4.22	102.8

AVERAGE VALUES

τ_f (MPa)	$\bar{\sigma}_f$ (MPa)
6.2 ± 2.6	4.26 ± 1.7
11.3 ± 4.9	27.51 ± 3.3
4.22± 0.53	102.8 ± 0.4

Grain density = 2.77 gm/cm^3

Bulk density = 2.23 gm/cm^3 (0% saturation)

Porosity - 0.19

TABLE IV

FAILURE STRESS DATA FOR QATTARA SANDSTONE

UNDER TRIAXIAL LOADING CONDITIONS

100% SATURATION

Sample	σ_c (MPa)	τ_f (MPa)	$\bar{\sigma}_f$ (MPa)
Q390	0.1	6.03	4.12
Q391	0.1	4.05	2.80
Q392	0.1	9.52	6.45
Q393	20.0	13.86	29.24
Q394	20.0	13.86	29.24
Q395	20.0	5.85	23.90
Q396	100.0	19.62	113.1
Q397	100.0	17.72	111.8
Q398	100.0	15.61	110.4

AVERAGE VALUES

τ_f (MPa)	$\bar{\sigma}_f$ (MPa)
6.5 ± 2.8	4.5 ± 1.8
11.2 ± 4.6	27.5 ± 3.1
17.6 ± 2.0	111.8 ± 1.3

Grain density = 2.77 gm/cm^3

Bulk density = 2.23 gm/cm^3 (0% saturation)

Porosity = 0.19

TABLE V

FAILURE STRESS DATA FOR QATTARA HIGH SAND

UNDER TRIAXIAL LOADING CONDITIONS

100% SATURATION

Sample	σ_c(MPa)	τ_f(MPa)	$\bar{\sigma}_f$(MPa)
Q401	0.1	0.17	0.21
Q404	0.1	0.25	0.27
Q407	0.1	0.31	0.31
Q402	20.0	6.3	24.2
Q405	20.0	4.4	22.9
Q408	20.0	4.2	22.8
Q403	100.0	6.5	104.3
Q406	100.0	5.7	103.8
Q409	100.0	5.3	103.5

AVERAGE VALUES

τ_f(MPa)	$\bar{\sigma}_f$(MPa)
0.24 ± 0.07	0.26 ± .05
5.0 ± 1.2	23.3 ± 0.8
5.8 ± 0.6	103.9 ± 0.4

Grain density = 2.70 gm/cm^3

Bulk density = 2.23 gm/cm^3 (approximately 100% saturation)

Porosity = 0.26

TABLE VI

FAILURE STRESS DATA FOR QATTARA CLAY/SILT

UNDER TRIAXIAL LOADING CONDITIONS

100% SATURATION

Sample	σ_c (MPa)	τ_f (MPa)	$\bar{\sigma}_f$ (MPa)
Q175	0.1	0.28	0.29
Q176	0.1	0.40	0.37
Q179	0.1	0.40	0.37
Q171	20.0	0.71	20.47
Q174	20.0	0.42	20.28
Q177	20.0	0.49	20.33
Q180	20.0	0.55	20.37
Q172	100.0	0.70	100.47
Q178	100.0	0.69	100.46
Q181	100.0	0.68	100.45

AVERAGE VALUES

τ_f (MPa)	$\bar{\sigma}_f$ (MPa)
0.4 ± 0.1	0.3 ± 0.1
0.5 ± 0.1	20.4 ± 0.1
0.7 ± 0.01	100.5 ± 0.01

Grain density = 2.85 gm/cm^3

Bulk density = 2.06 gm/cm^3 (approximately 100% saturation)

TABLE VII

BRAZIL TEST RESULTS FOR QATTARA LIMESTONE

0% SATURATION

A. CHALKY LIMESTONE

Sample	τ_f(MPa)	
Q378	3.8	
Q379	2.0	
Q370A	3.3	τ_f (Avg.) = 3.5 ± 1.5
Q371A	3.0	
Q372A	6.3	
Q373A	2.4	

B. FOSSILIFEROUS LIMESTONE

Sample	τ_f(MPa)	
Q228	4.2	
Q229	2.7	
Q220	3.7	
Q221A	2.9	τ_f (Avg.) = 3.0 ± 0.7
Q222A	2.2	
Q223A	2.8	
Q224A	2.5	

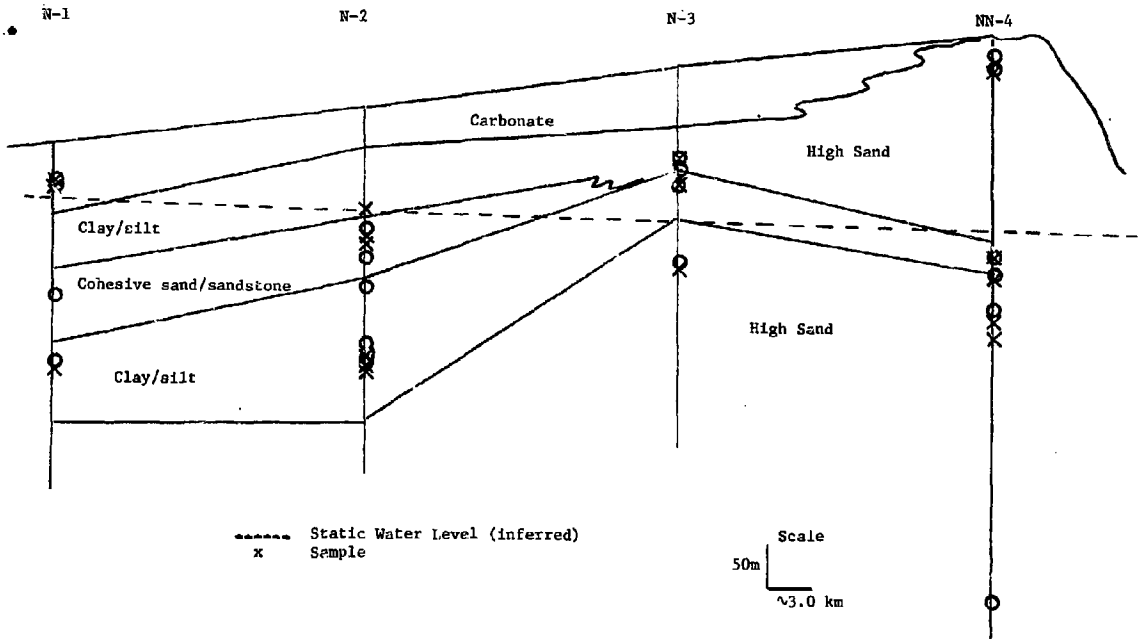


FIGURE 1
MODEL LITHOGRAPHY

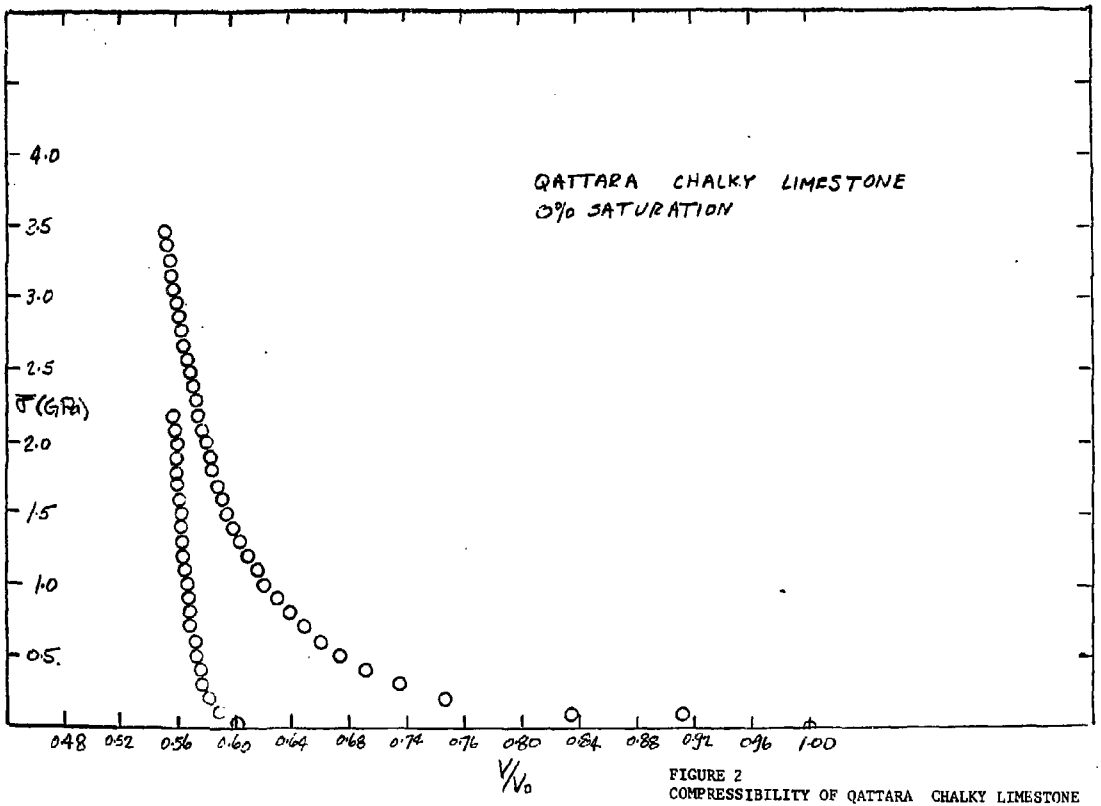


FIGURE 2
COMPRESSIBILITY OF QATTARA CHALKY LIMESTONE

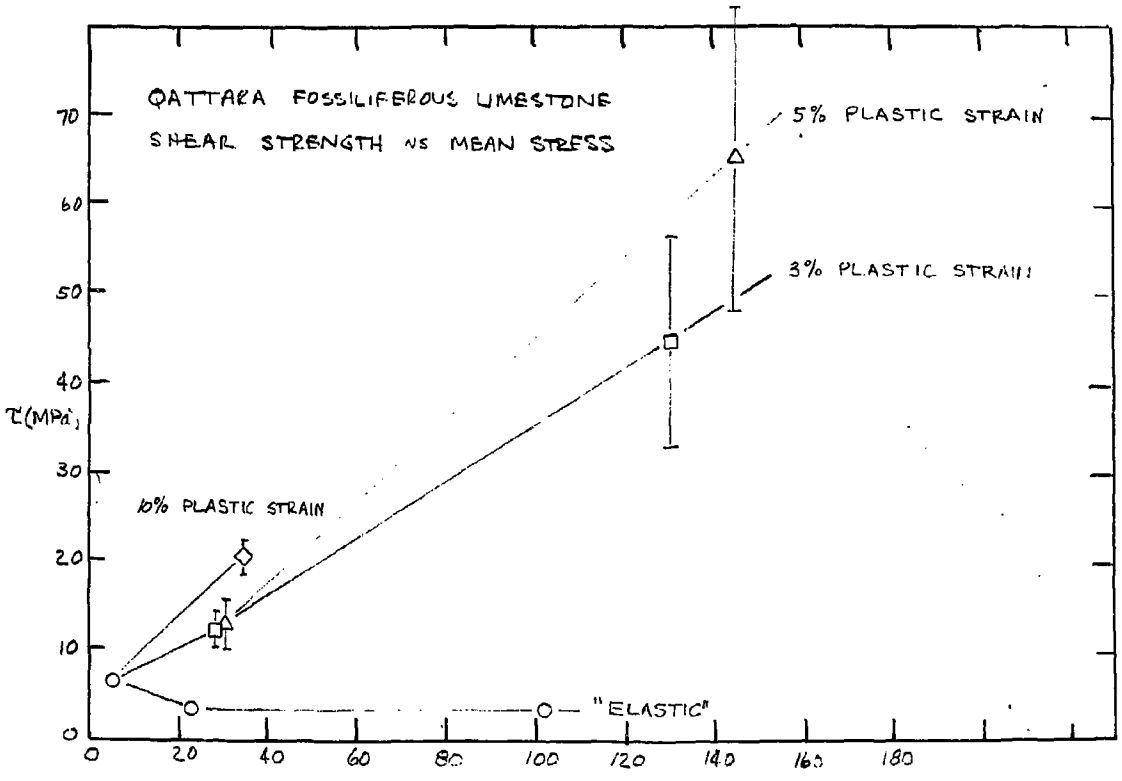


FIGURE 3
STRENGTH CURVE FOR QATTARA FOSSILIFEROUS LIMESTONE

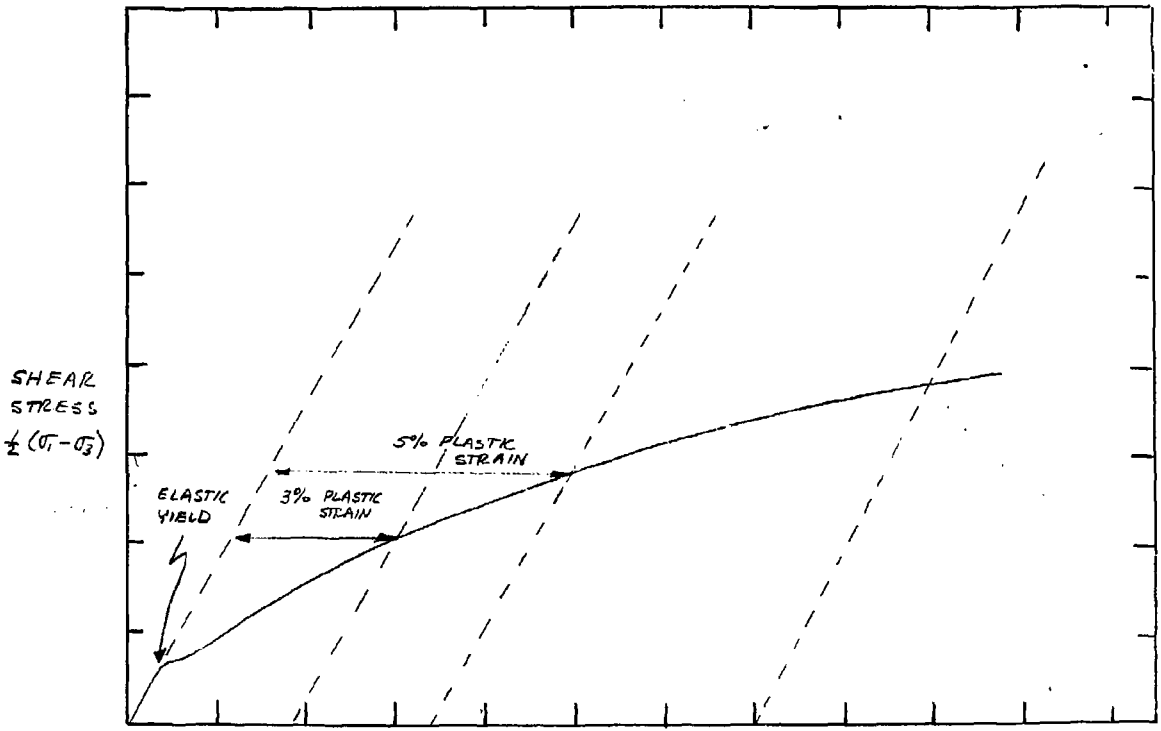


FIGURE 3A
SCHEMATIC OF LOADING CURVE FOR QATTARA LIMESTONE

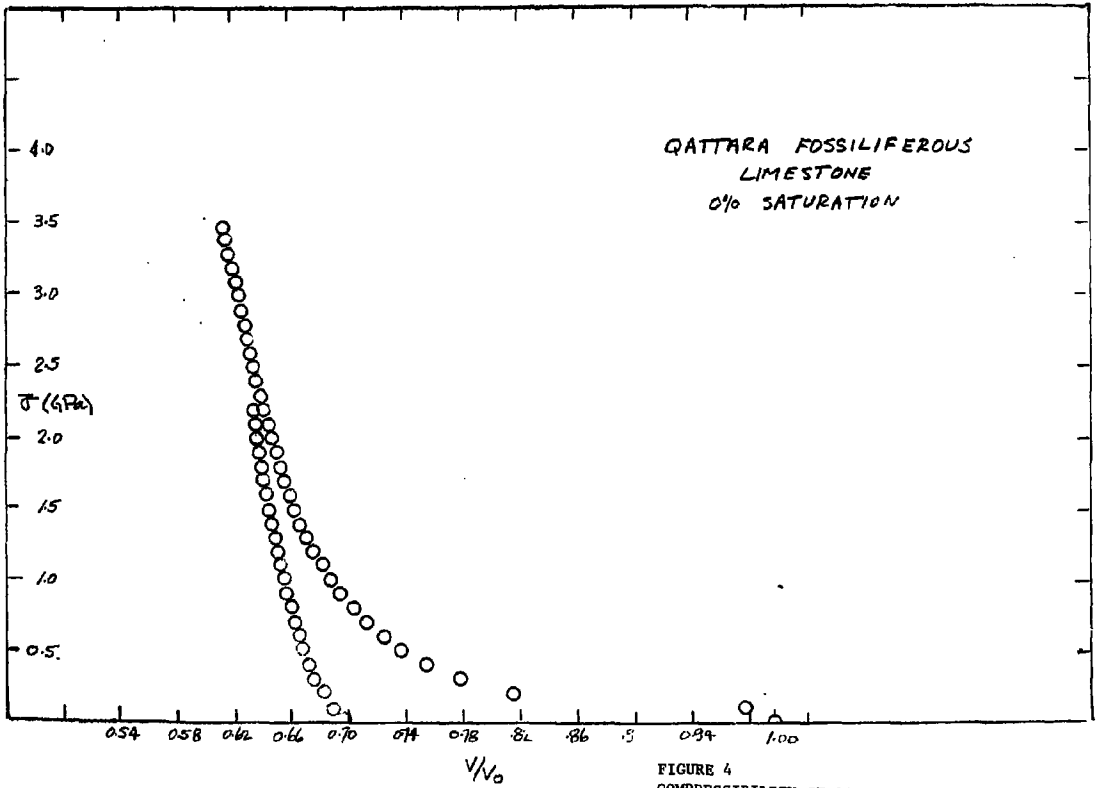


FIGURE 4
COMPRESSIBILITY OF QATTARA FOSSILIFEROUS LIMESTONE

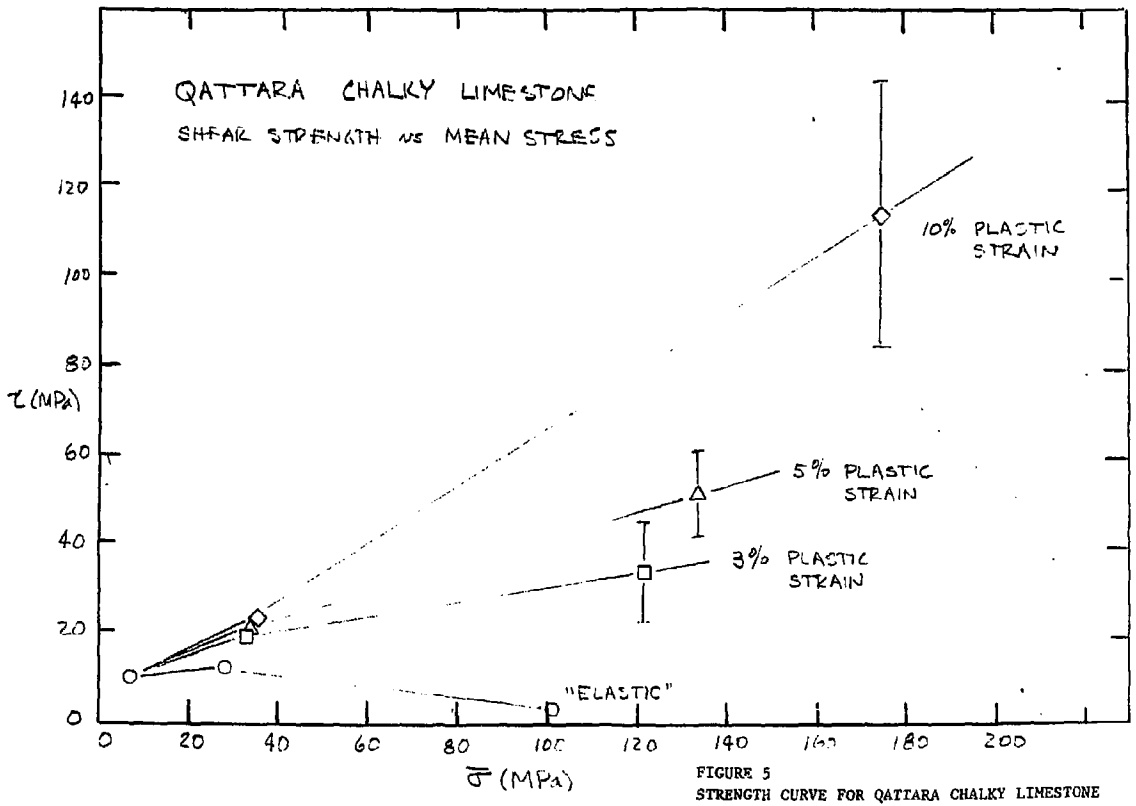


FIGURE 5
STRENGTH CURVE FOR QATTARA CHALKY LIMESTONE

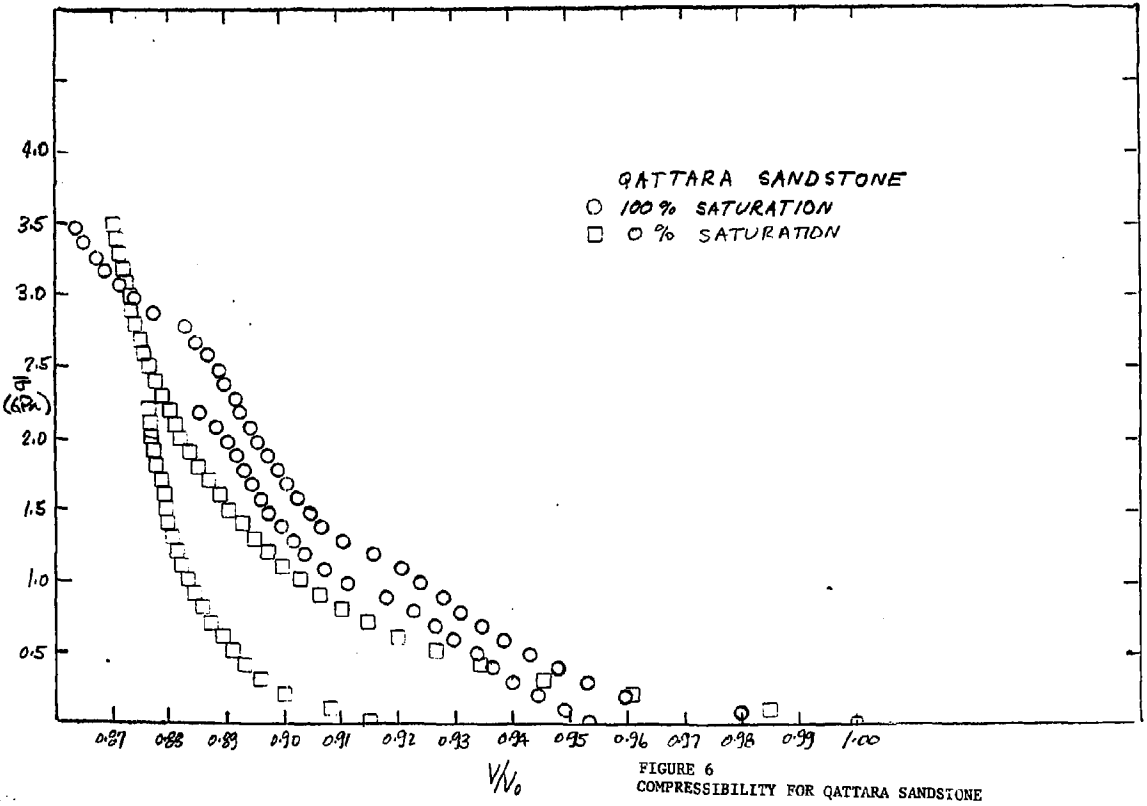


FIGURE 6
COMPRESSIBILITY FOR QATTARA SANDSTONE

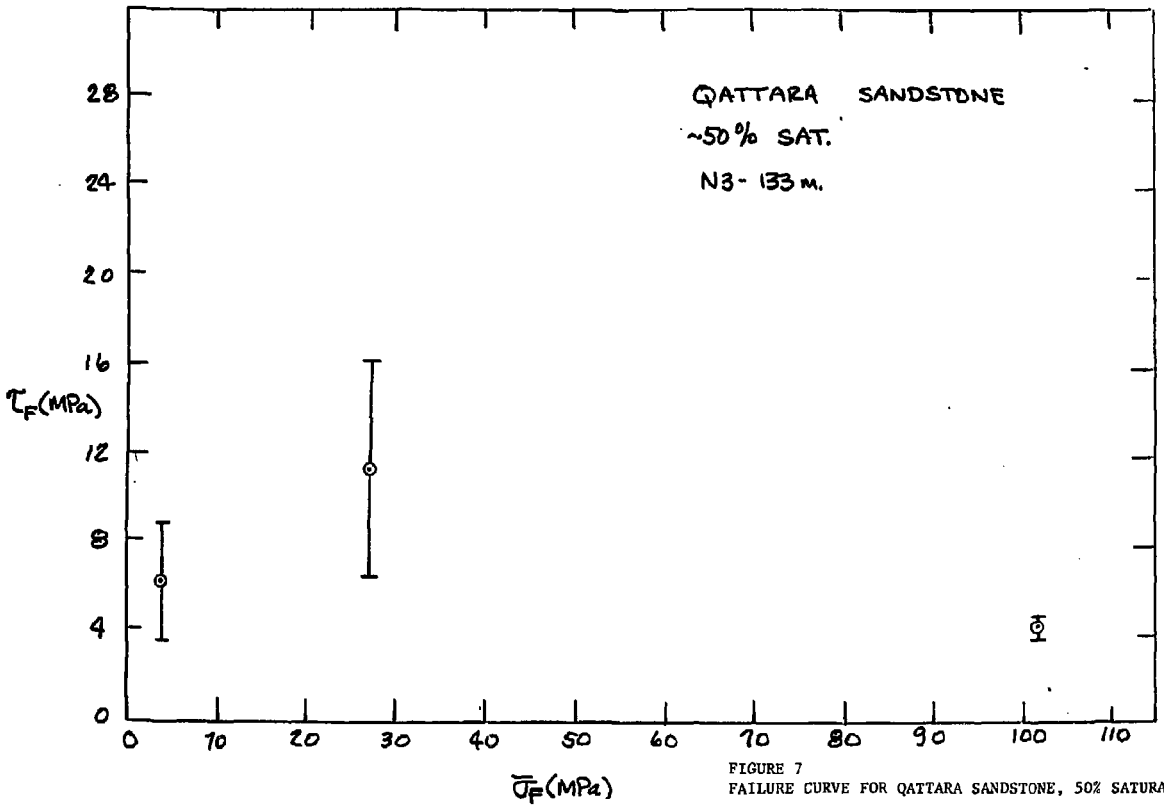


FIGURE 7
FAILURE CURVE FOR QATTARA SANDSTONE, 50% SATURAT.

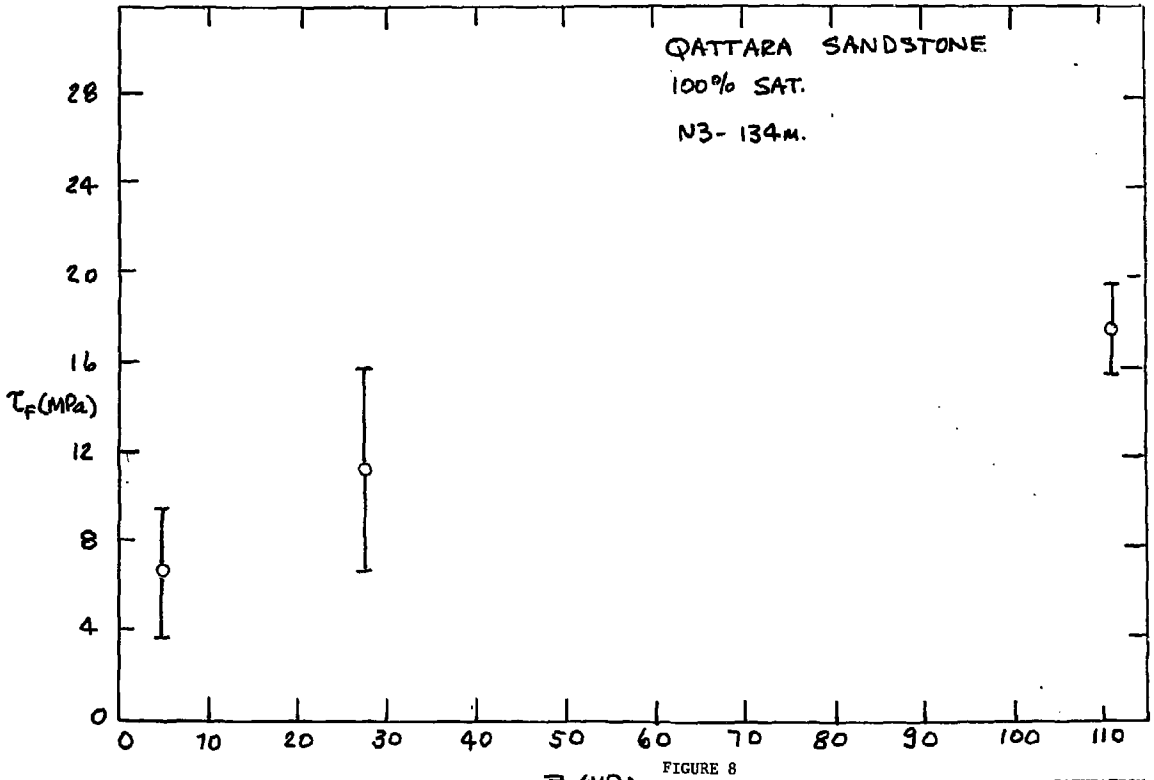


FIGURE 8
FAILURE CURVE FOR QATTARA SANDSTONE, 100% SATURATION

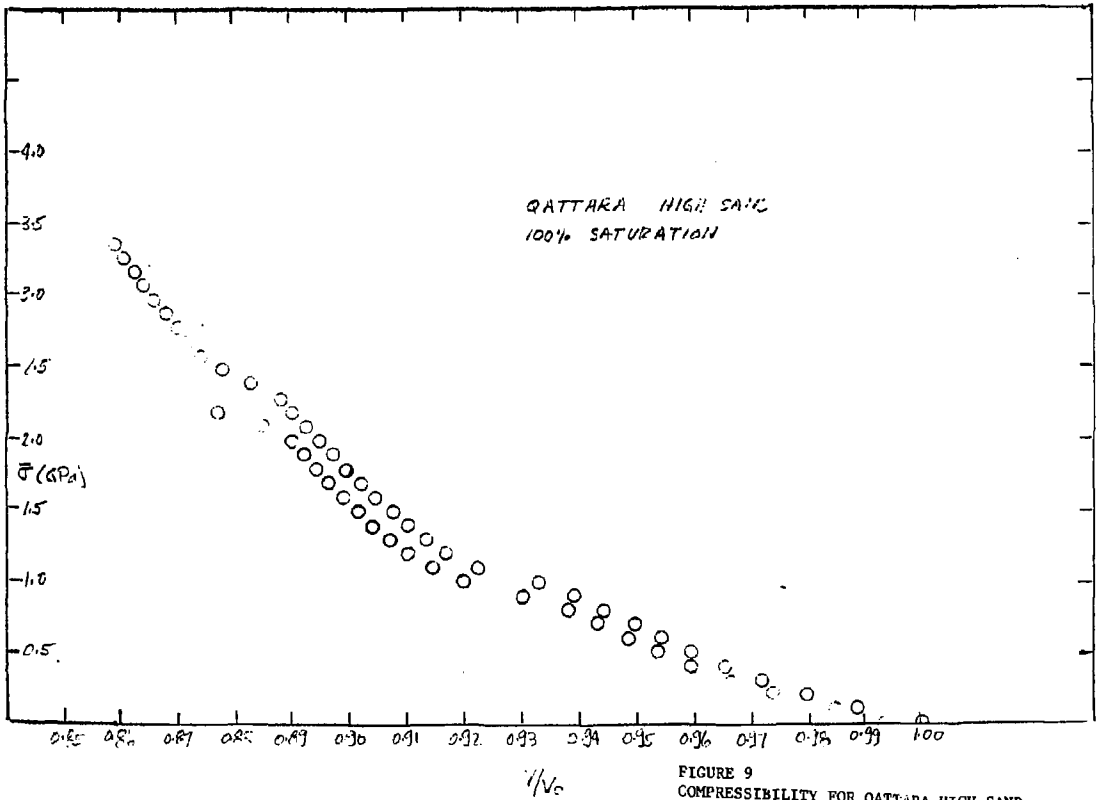


FIGURE 9
COMPRESSIBILITY FOR QATTARA HIGH SAND

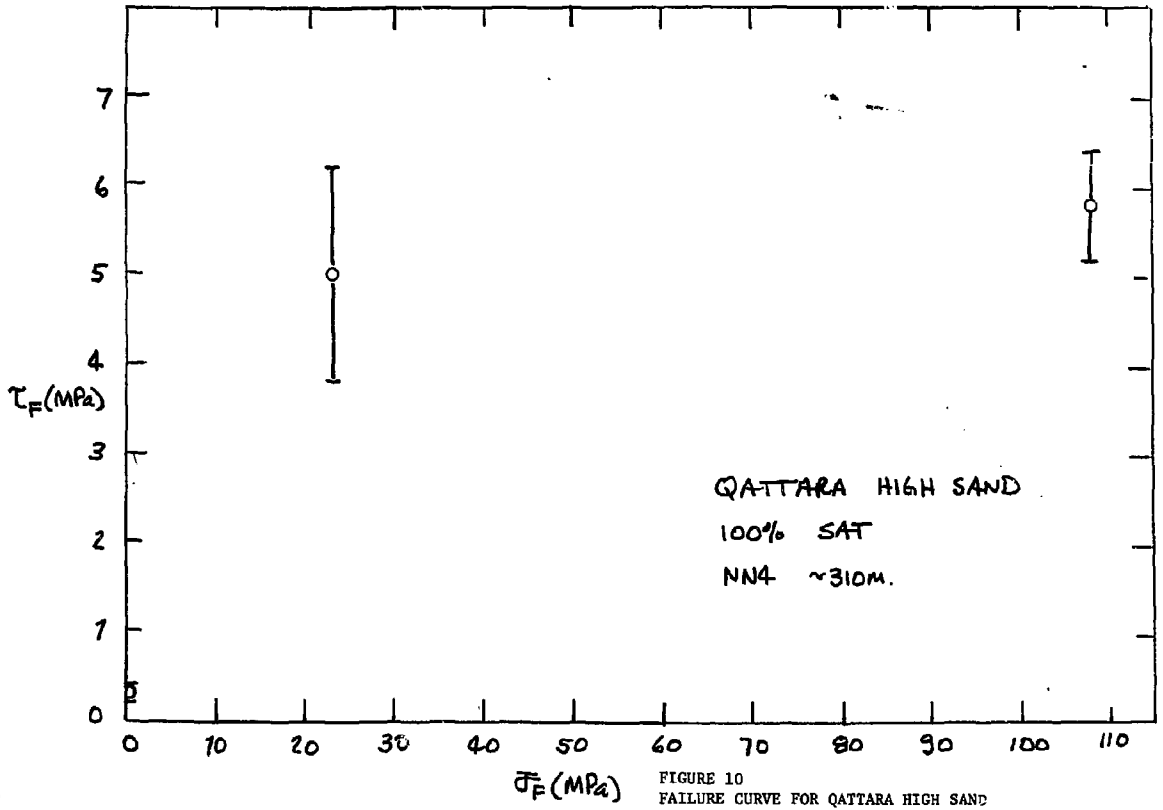


FIGURE 10
FAILURE CURVE FOR QATTARA HIGH SAND

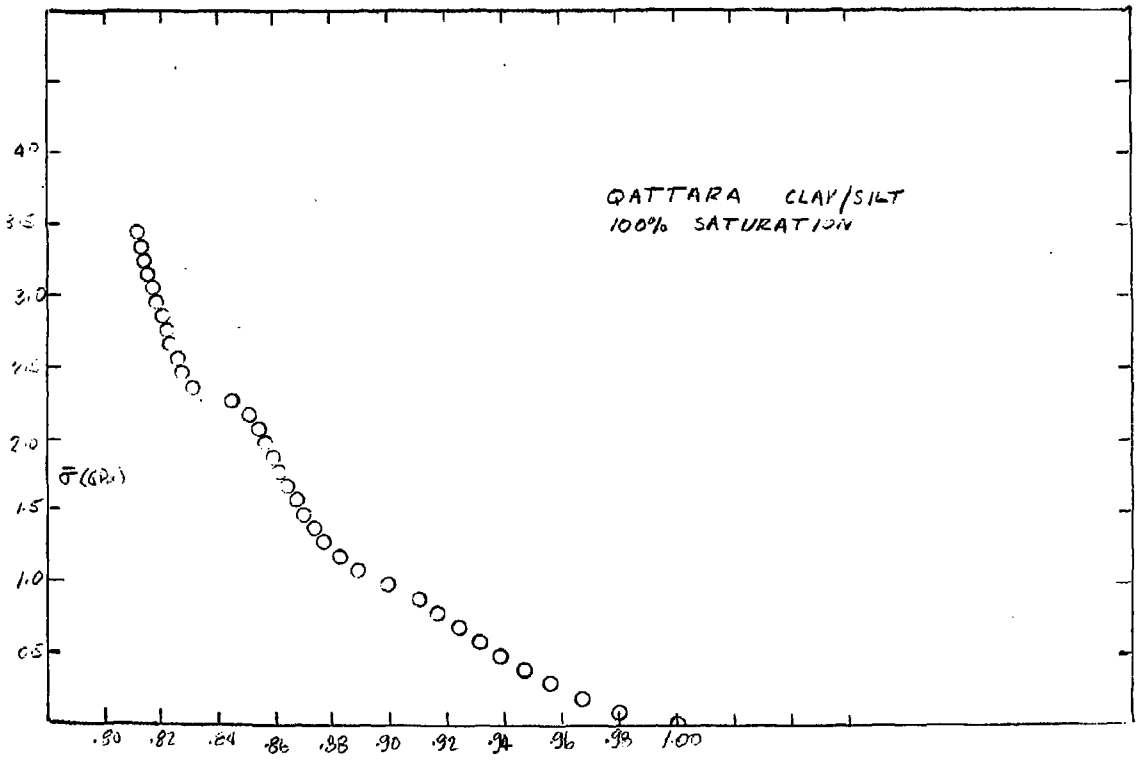


FIGURE 11
COMPRESSIBILITY FOR QATTARA CLAY/SILT

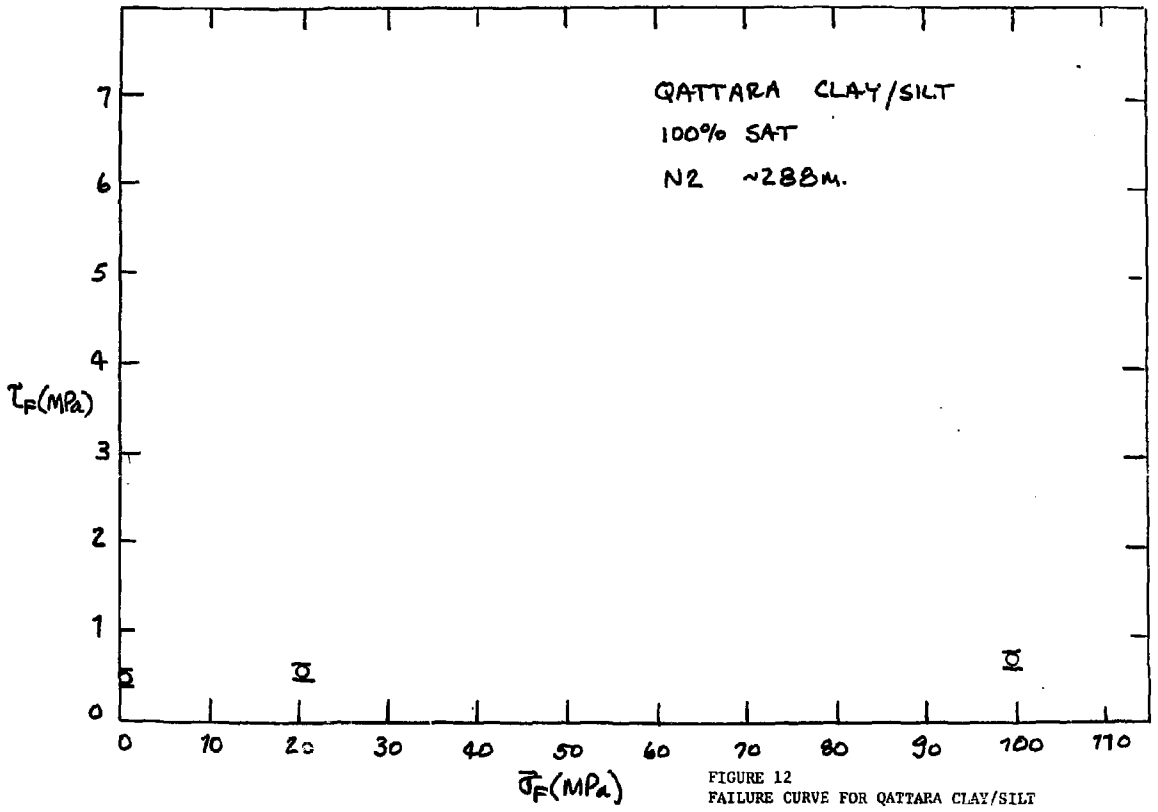


FIGURE 12
FAILURE CURVE FOR QATTARA CLAY/SILT