CYCLIC TRIAXIAL STRENGTH OF GYPSUM

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MARSHALL L. SILVER
CIVIL ENGINEER Ph.D P.E.

721 DOBSON AVENUE, EVANSTON, ILLINOIS 60202 TELEPHONE 312/491-9395

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CYCLIC STRENGTH OF GYPSUM MATERIALS FROM THE BEKER INDUSTRIES PLANT CONDA, IDAHO

by

Marshall L. Silver, Ph.D. P.E.
and
Linda G. Peck

Summary

Cyclic triaxial strength tests were performed on remolded specimens of waste gypsum remaining as a by-product from the manufacture of chemical fertilizer. Such test results may be used to evaluate the ability of the material to resist seismic shaking from earthquakes or the ability of the material to resist spontaneous liquefaction from ground born vibrations from activities such as construction.

It was found that for specimens compacted to 98% of maximum standard compaction density at the optimum water content, gypsum specimens are extremely resistant to the development of deformation in cyclic triaxial strength tests. For example, at a normalized cyclic stress ratio (peak shear stress divided by the effective confining pressure) of about 0.5, more than 60 load cycles were required to produce 5% peak to peak strain for specimens consolidated to 2.0 kg/cm^2 (4000 psf). It was further found that the laboratory cyclic strength of gypsum increases as the material is subjected to longer

periods of isotropic stress. It was found that primary consolidation was completed in less than 20 minutes for 63 mm (2.5 in) diameter specimens in the triaxial cell. However, secondary compression continued for longer periods of time and vertical deformations were measured even after days of isotropic loading in the triaxial cell. It was found that this secondary compression significantly increased the strength of the specimens. For example, specimens consolidated to 2.0 kg/cm^2 (4000 psf) for more than one day were significantly stronger than specimens consolidated for 20 minutes (the time for 100% consolidation).

Introduction

Gypsum is a waste by-product of the manufacture of phosphoric acid which is an important ingredient in the manufacture of chemical fertilizer. In one common chemical process used to manufacture phosphoric acid, apatite rock is reacted with sulphuric acid to produce a slurry of phosphoric acid and gypsum. The wet gypsum is left as a waste product after the phosphoric acid is filtered off. Large amounts of gypsum remain from the process and it requires transportation and storage. The disposal of gypsum is generally done in tailings dams similar to those used to retain other waste minings or manufacturing materials.

Only a few investigators have investigated the engineering properties of gypsum materials. Both Blight (1969) and Vick (1977) have investigated the index properties, strength and compressibility of gypsum materials. However, nowhere has the cyclic strength of gypsum been investigated to help evaluate its stability during ground shaking from earthquakes or from construction activities such as pile driving. Since a number of other waste materials have shown instability to these types of ground shaking, it is of interest to evaluate the dynamic behavior of gypsum to be able to compare its dynamic behavior and potential loss of strength during ground shaking with the behavior of other kinds of geotechnical materials. Therefore, a series of cyclic triaxial strength

tests were performed on remolded specimens of gypsum to evaluate their dynamic performance.

Materials Tested

The material tested in this study was a grey gypsum from the Beker Industries plant in Idaho. The material consists of needle like monoclinic cristals with a controlled grain size chosen to give required filtering rates in the manufacture of phosphoric acid. A wet sieve analysis and a hydrometer analysis of the material gave the following particle size distribution:

Sieve Opening or Particle Diameter	% Passing by Weight
0.297 mm (No. 50)	99%
0.149 mm (No. 100)	94%
0.074 mm (No. 200)	83%
0.037	55%
0.019	30%
0.009	15%

From the above data it may be seen that the material consists mainly of silt size particles. Atterburg limit tests shows that the gypsum is non-plastic.

Compaction Characteristics

The results of standard compaction tests on the material are shown in Appendix A and summarized in Table 1. It may be seen that the material had a maximum dry density of 1.39 g/cm^3

TABLE 1

SUMMARY OF STANDARD COMPACTION TEST RESULTS

Beker Industries Gypsum

	This Study Results	Northern Testing Results	Triaxial Specimen Characteristics
Maximum Dry Density (lb/ft^3)	87.1 86.7 Ave = 87.0	87.5 87.0 85.5 85.8	(1) 85.3
Optimum Water Content (2) (percent)	22.1 21.9 Ave = 22.0	21.8 22.2 22.5 22.8	22%

Notes

(1) 98% of Max Dry Density

(2) Oven Temperature 45°C for 48 hr.

(87.0 lb/ft^3) at an optimum water content of about 22%. Independent compaction test results obtained by another laboratory are also shown on Table 1 where it may be seen that the average maximum dry density was on the order of 1.38 g/cm^3 (86.3 lb/ft^3) at an optimum water content of about 22%. Based on the comparison of these two test results from two independent laboratories, it was felt that the compaction test results were reasonable.

Water Content Determination

In evaluating the engineering properties of gypsum, great care must be taken when making water content determinations since the temperature at which the gypsum specimen is dried has a great influence on the amount of water released. For example, a sample of gypsum might indicate a water content of 40% when dried in an oven at 105°C for 24 hours. The same sample of material will typically indicate a water content of approximately 20% when dried in an oven at 45°C for 48 hours.

In evaluating the engineering characteristics of gypsum it is felt that the lower water contents better represent engineering behavior. It appears that at hither temperatures, water of hydration may be released from the gypsum or possibly a chemical reaction may occur which breaks down the gypsum and releases water. Both water of hydration or chemically

bound water is probably held so tightly that it is not available to change the engineering behavior of the material under field conditions. Therefore, a oven temperature of 45°C and a drying time of 48 hours was selected for all water content determinations described in this report.

To further study the effect of method of drying on the water content of gypsum, specimens of the same sample of material were dried 1) in a microwave oven, 2) in a conventional oven for 24 hours at a temperature of 105°C and 3) in a conventional oven for 48 hours at a temperature of 25°C. Results of these tests are shown in Figure 1 where it may be seen that the time of drying in the microwave oven significantly changes the calculated water content. For example, for times between 1 and 6 minutes, the water content increased from a value of 4% to 21%. However, for times greater than 8 minutes the water content remained relatively constant at 22% and did not change with longer drying time.

It is interesting to note that approximately the same water content (21%) was obtained by drying the same specimen of material for 48 hours in a conventional oven at 45°C. On the other hand, a much higher water content of 42% was obtained by drying the same material in a conventional oven for 24 hours at 105°C.

These results suggest that microwave oven drying is a meaningful procedure that can be used for field control of

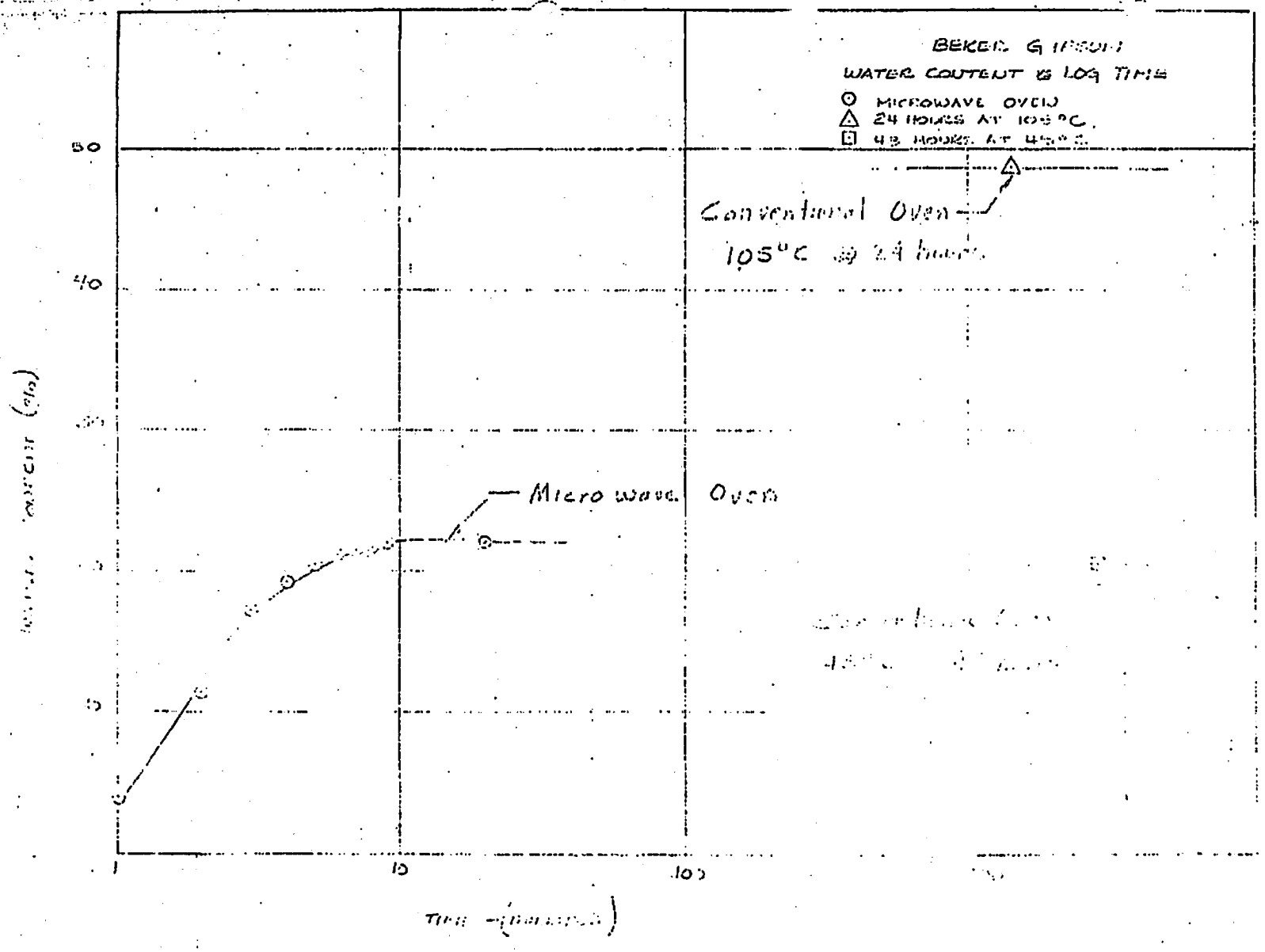

Fig. 1 Effect of Drying Time on the Measured Water Content of Gypsum Dried in a Microwave Oven (Note each point represents the water content of a fresh specimen from the sample).

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construction using gypsum. However, it is important that preliminary tests to evaluate the effect of time of drying on water content values be performed in the field. Further, it is important that care be exercised in standardizing the amount of material placed in the microwave oven for each water content determination since the larger the sample or the greater the number of samples dried, the less efficient the drying process and the longer it will take for the specimen to reach an equilibrium water content. For the tests shown in Figure 1, a single sample of approximately 80 g was put in the microwave oven for each test. Similar control on the weight of the material introduced into the microwave oven will have to be developed before using microwave oven drying techniques in the field for construction control.

Specimen Preparation, Saturation and Consolidation

A wet tamping compaction method was used to prepare all gypsum specimens. The procedure consists of tamping layers of soil into an external mold to a predetermined density. The procedure recognizes and makes corrections for the fact that when compacting material in layers, each preceding layer densifies the material in the layer below it. Therefore, specimens of uniform density throughout their height are prepared. The sample preparation technique is described in Silver (1977).

Gypsum specimens were compacted in an external mold to a density of 1.370 g/cm^3 (85.5 lb/ft^3) at a molding water content of 22%. The specimens were removed from the mold and dimensions were obtained using a circumference measuring tape and a scale. All initial dry unit weight calculations were based on measurements taken of the specimen after it was removed from the mold. Saturation was accomplished at a low effective confining pressure of 0.5 kg/cm^2. Specimens were allowed to saturate until B values of greater than 0.98 were achieved. For the first series of 3 specimens, consolidation was carried out by applying small isotropic stress increments of 0.5 kg/cm^2 while monitoring axial strain and volumetric change with time. A second series of 3 specimens were consolidated by applying one isotropic stress increment to the final effective confining pressure to evaluate the

effect of time of consolidation and method of consolidation on the cyclic strength of gypsum.

Following consolidation, specimens were transferred to a stress controlled loading frame for cyclic strength testing.

Precautions to be Taken in the Testing of Waste Gypsum

In laboratory testing of gypsum, Blight (1965) suggests that special precautions are required. This is because the pore fluid in a gypsum pile or dam, resulting from the manufacture of fertilizer, consists of a dilute solution of phosphoric, sulfuric and hydrochloric acids and various salts. In addition, the gypsum itself is slightly soluble in water with the result that any change in the pore fluid may alter the physical properties of the gypsum. Thus, Blight suggests that the fluid used to prepare samples of gypsum in the laboratory should be the same fluid that exists in the field as the pore fluid. In addition, he suggests that the cell fluid should not be water but the same pore fluid that exists in the gypsum pile in order to prevent osmotic pressure from developing and causing the transmission of pure water across the triaxial membrane into the specimen.

These precautions were considered in developing the laboratory testing program described in this report. However,

other tests on gypsum using both natural acidic pore fluid and pure water suggest that the strength of gypsum is not altered significantly by changing the nature of the cell or pore fluids. Therefore, distilled water was used in preparing gypsum specimens for testing. Similarly, pure water was used as the cell fluid. However, double membranes and heavy silicone oil was used to help reduce the infiltration of water across the membrane from the cell into the specimen. It was felt that these precautions were satisfactory based on the results obtained from the test program. However, further research may be necessary to better define the effects of 1) potential osmotic forces and 2) the migration of pure water into the sample on the geotechnical properties of gypsum.

Cyclic Triaxial Strength Test Procedure

Cyclic triaxial strength tests were performed to evaluate pore water pressure increase and induced cyclic strains caused by cyclic stresses such as those induced by strong ground shaking.

Triaxial testing was performed using the same specially designed dynamic triaxial cell as described in another section of this report.

The cell was mounted in a pneumatic loading frame capable of applying a periodic cyclic stress of constant amplitude.

Digital readout units and a stripchart recorder were used to monitor and record stress magnitude, induced vertical deformation and pore water pressure build-up with time.

Cyclic triaxial strength tests were performed under stress-controlled conditions on undrained specimens using the following testing procedure: The test was begun by programming the sine wave pneumatic actuator to a pre-determined peak cyclic stress magnitude. Then, the axial loading piston was connected to the load cell and the recording equipment was zeroed. Cyclic loading was started and continued until 1) double amplitude strains exceeded 10%; 2) axial compressive or extensive strains exceeded 20% or 3) the predetermined number of load cycles was achieved.

These cyclic triaxial strength test results were evaluated in terms of the magnitude of cyclic axial stress and the number of cycles required to produce 1) double amplitude, 2) compressive or 3) extension strains of 2.5, 5 % and, 10%. Also recorded was the first cycle at which the induced excess pore pressure first became

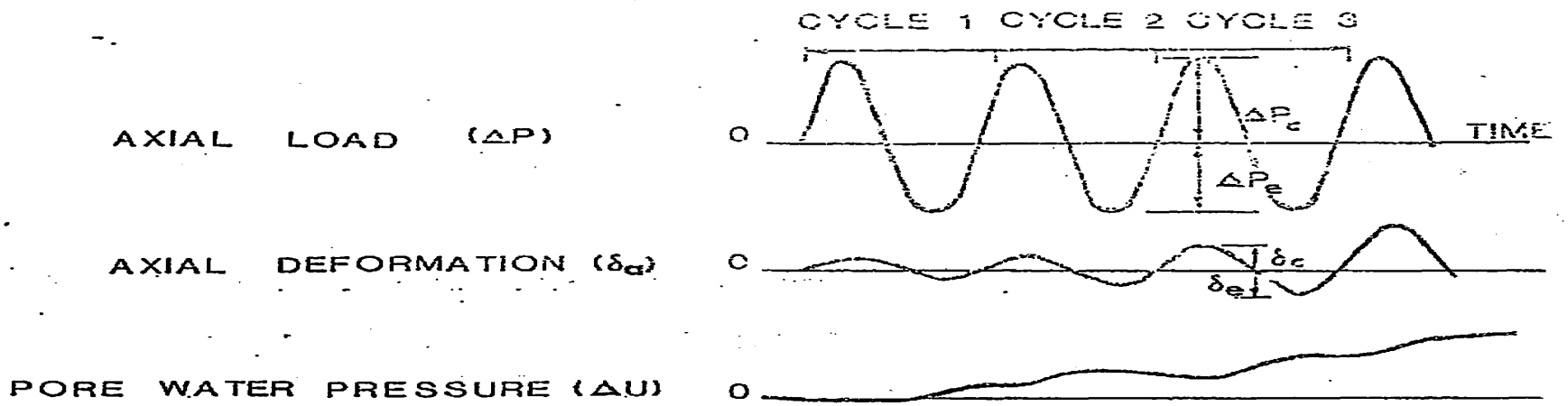
equal to the cell pressure which is often called inital liquefaction.

The effect of confining pressure on cyclic strength values was conveniently taken into account by plotting the number of cycles required to achieve a given strain amplitude by a dimensionless ratio called the stress ratio (SR)

$$SR = \frac{\Delta\sigma_a}{2\,\bar{\sigma}_{3c}}$$

where $\Delta\sigma_a$ is the single amplitude value of applied axial stress and $\bar{\sigma}_{3c}$ is the minor principal confining stress. For many purposes, the relationship between stress ratio (SR) and number of cycles to reach some failure criteria may be taken to be a unique relationship for a given soil at a given consolidation ratio (K_c).

The definitions of stress and strain used to evaluate these dynamic test results are summarized on Fig 2.



DEFINITION OF CALCULATED STRESS AND STRAIN VALUES

$$\Delta\sigma_a \text{ (SINGLE AMPLITUDE)} = \frac{\Delta P_c + \Delta P_e}{2A_c}$$

$$\epsilon_a \text{(DOUBLE AMPLITUDE)} = \frac{\delta_c + \delta_e}{L_c}$$

WHERE $\Delta P_c, \Delta P_e, \delta_c, \delta_e$ ARE DEFINED IN FIGURES ABOVE

A_c IS THE CONSOLIDATED SPECIMEN AREA

L_c IS THE CONSOLIDATED SPECIMEN LENGTH

Fig. 2 - Definition of Measured Load-Deformation Values and Calculated Stress Strain Values for Cyclic Triaxial Strength Tests

Cyclic Triaxial Testing Program

The cyclic strength testing program shown in Table 2 was designed to evaluate the effects of cyclic stress level, consolidation time and consolidation pressure on the cyclic strength of gypsum. An initial series of tests were performed on specimens consolidated to 2.0 kg/cm^2 at stress ratios estimated to give failure between 10 and 300 cycles. These specimens were consolidated very slowly in increments so as not to disturbe the fabric of the compacted gypsum. Further, the consolidation process was continued for a period of time to give the specimens time to reach an equilibrium void ratio.

A plot showing volume change values with time for a typical gypsum specimen consolidated in increments of 0.5 kg/cm^2 to an effective stress of 2.0 kg/cm^2 is shown in Figure 3. It may be seen that even after one week in the triaxial cell, volume changes were still occurring. Such movements occurred under zero excess pore water pressure. In fact, the permeability of the gypsum was found to be relatively high and primary consolidation seemed to be completed in less than 20 minutes. Vertical movements and volume changes that continued beyond 20 minutes seemed to be due to secondary compression. Additional time history plots of vertical settlement and volume change are shown in

TABLE 2

CYCLIC TRIAXIAL TEST PROGRAM

Beker Industries Gypsum

Moulding dry unit weight:	85.3 lb/ft^3
Moulding water content:	22%
Testing frequency:	1 hz
Effective Confining Pressures:	1.0, 2.0 and 4.0 kg/cm^2
Cyclic Stress Ratios:	0.3 to 0.7
Specimen Preparation:	Wet Tamping Compaction
Saturation:	Yes, with B Values greater than 0.98

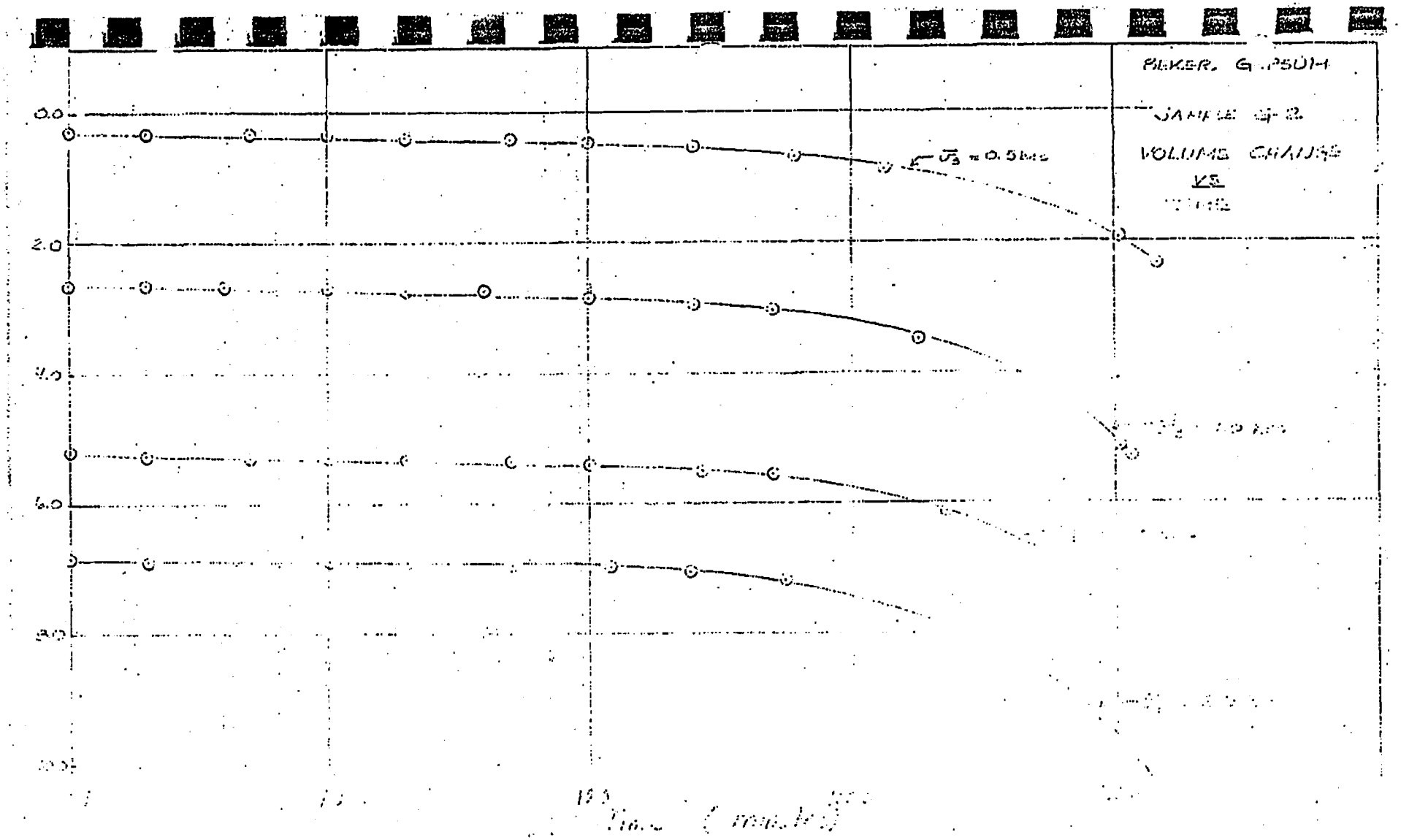


Fig. 3 Typical Volume Change Versus Time Relationship for one Gypsum Specimen Consolidated in Several Increments to an Effective Confining Pressure of 2.0 kg/cm^2. Specimen Tested after four Days of Loading.

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Appendix B.

For consistency, an initial three samples were consolidated under small stress increments of 0.5 kg/cm^2 until a confining pressure of 2.0 ksc was reached. The final stress increment was held constant for 24 hours prior prior to cyclic loading.

To investigate the effectiveness of time of consolidation and the secondary compression process on the cyclic strength of gypsum materials, a second series of tests was performed on three specimens which were cyclicly loaded at the end of primary consolidation (estimated to occur in 20 minutes). These specimens were saturated under an effective confining pressure of 0.5 ksc and then in one increment the consolidation pressure was raised to 1.0, 2.0 and 4.0 ksc respectively on the three individual specimens. Volume change versus time plots for these specimens is shown on Figure 4.

Using this consolidation procedure, it was possible to compare the cyclic strength of a specimen loaded at the end of primary consolidation (20 minutes) to the strength of a specimen loaded after secondary compression had taken place. Further, all three of the specimens from the second test series were subjected to a cyclic stress ratio of 0.5 making it possible to evaluate the effect of confining pressure on the cyclic strength of gypsum.

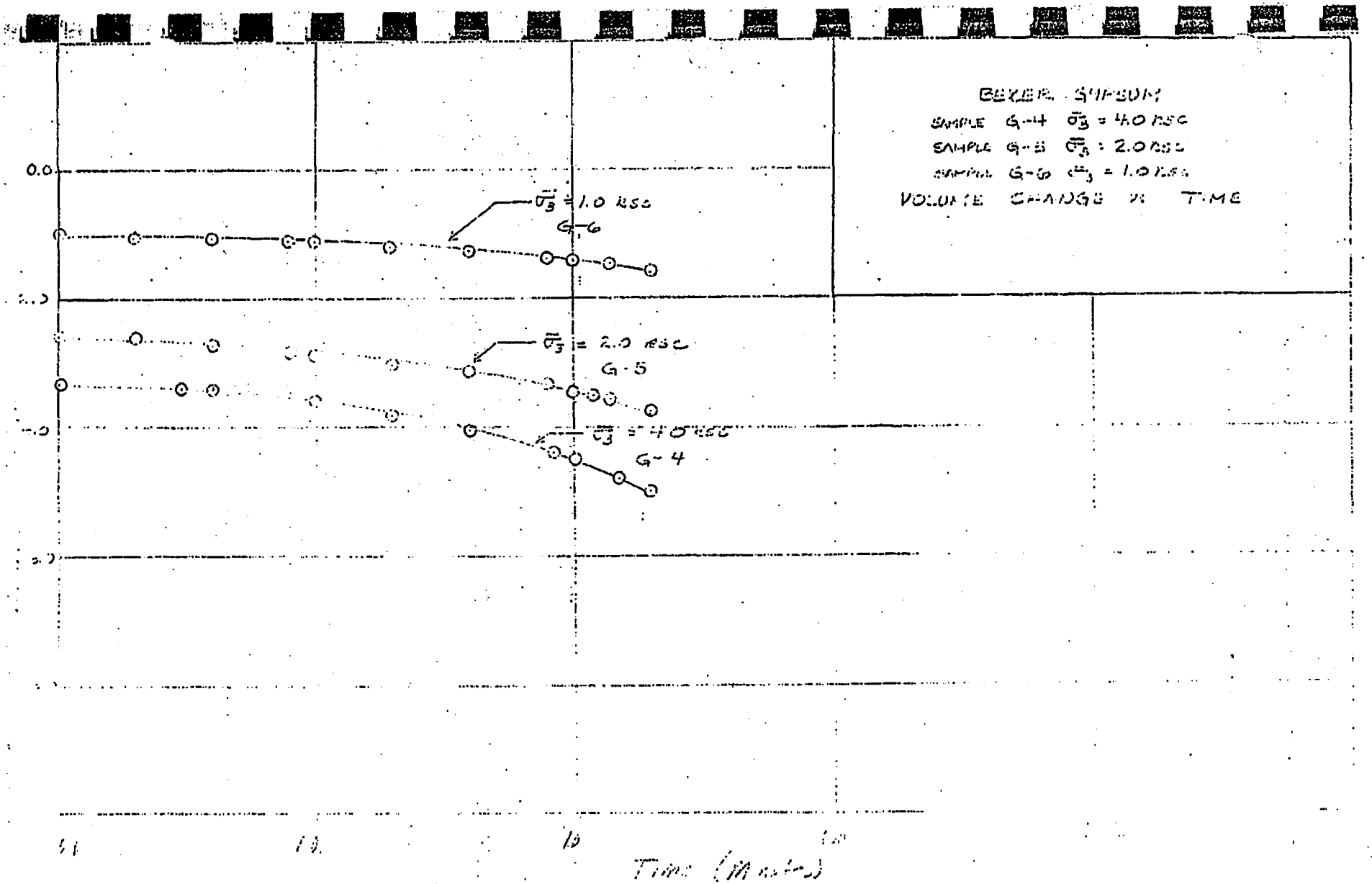

Fig. 4 Volume Change Versus Time Relationship for Three Gypsum Specimens Consolidated in One Increment to Effective Confining Pressures of 1.0, 2.0 and 4.0 kg/cm^2 Respectively. Specimens Tested after 20 Minutes of Loading.

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Cyclic Strength Test Results

Table 3 gives the physical characteristics of each gypsum specimen and Table 4 summarizes the cyclic strength results of each test.

Plots of single and double amplitude strain as a function of number of cycles for each specimen are shown in Figure 5. It may be seen that the specimens were able to withstand very high values of cyclic stress for a number of cycles without developing large strain amplitudes. In general, at low stress ratios, specimens failed by raveling throughout their height like loose sands. At high stress ratios, specimens failed by necking often near the base.

Figure 6 shows the number of cycles to initial liquefaction, 5% and 10% double amplitude strain versus the stress ratio for the first series of specimens tested after secondary compression occurred at an effective stress of 2.0 kg/cm^2. Figure 7 plots the number of cycles to initial liquefaction, 5% and 10% double amplitude strain for a second series of specimens tested at the end of primary consolidation (20 minutes) at effective stresses of 1.0, 2.0 and 4.0 kg/cm^2.

Both Figure 6 and Figure 7 show that the gypsum exhibits high cyclic strength. This high strength is probably due to the strong dilative nature of the silt size particles of

TABLE 3

SPECIMEN CHARACTERISTICS
CYCLIC TRIAXIAL STRENGTH TESTS

BEKER GYPSUM

Specimen No.	Molding or Initial Water Content	Dry weight of solids g	Initial Length mm	Initial Area cm^2	Consol. Length mm	Consol. Area cm^2	Initial Dry Unit Weight g/cm^3	Consol. Dry Unit Weight g/cm^3	Final Water Content %
G-1	22.0	600.560	150.4	29.116	147.9	28.981	1.371	1.401	28.32
G-2	22.0	600.560	150.0	29.039	147.8	28.741	1.379	1.414	28.55
G-3	22.0	600.560	149.6	28.973	147.7	28.647	1.386	1.419	27.87
G-4	22.0	594-090	150.9	29.075	149.2	29.082	1.354	1.369	28.15
G-5	22.0	592.672	150.1	28.887	149.1	28.834	1.367	1.379	29.02
G-2	22.0	593.393	150.4	28.928	149.6	28.961	1.364	1.370	28.54

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CYCLIC STREN TH TEST SUMMARY

BEKER GYPSUM

Specimen	Consolidated Dry Unit Weight g/cm^3	Effective Confining Pressure $\bar{\sigma}_{3c}$ Kg/cm^2	Kc = $\bar{\sigma}_{1c}/\bar{\sigma}_{3c}$	B Value	Stress Ratio $\frac{\Delta\sigma_a}{2\bar{\sigma}_{3c}}$	Number of Cycles: Initial Liquefact.	2.5% p-p Strain	5% p-p Strain	10% p-p Strain
G-1	1.401	2.0(2)	1.0	1.000	0.500	445	459	467	476
G-2	1.414	2.0(2)	1.0	1.000	0.360	See note 1			
G-3	1.419	2.0(2)	1.0	.984	0.640	63	80	86	93
G-4	1.369	4.0(3)	1.0	.986	0.480	13	12	16	19
G-5	1.379	2.0(3)	1.0	.994	0.510	40	45	53	61
G-6	1.370	1.0(3)	1.0	1.060	0.490	39	56	65	79

Notes:

1) 0.1% P-P Strain in 550 cycles

2) Consolidated for up to one week

3) Consolidated 20 minutes

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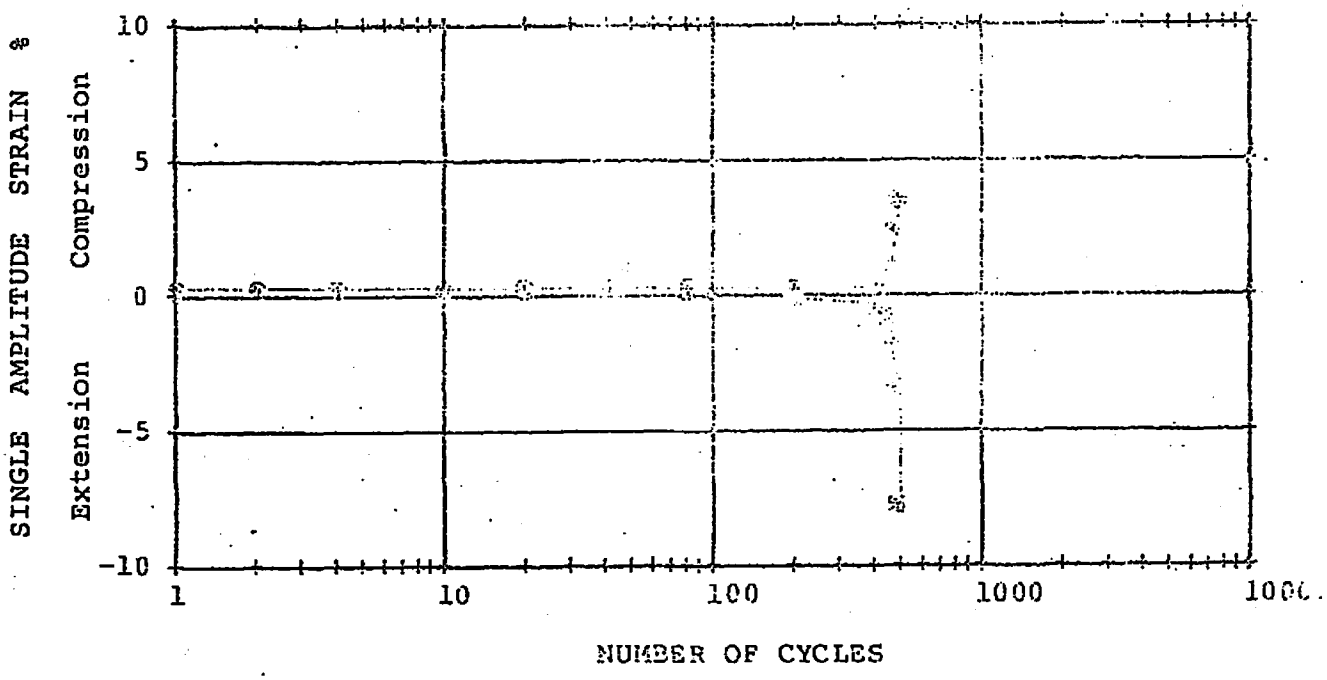


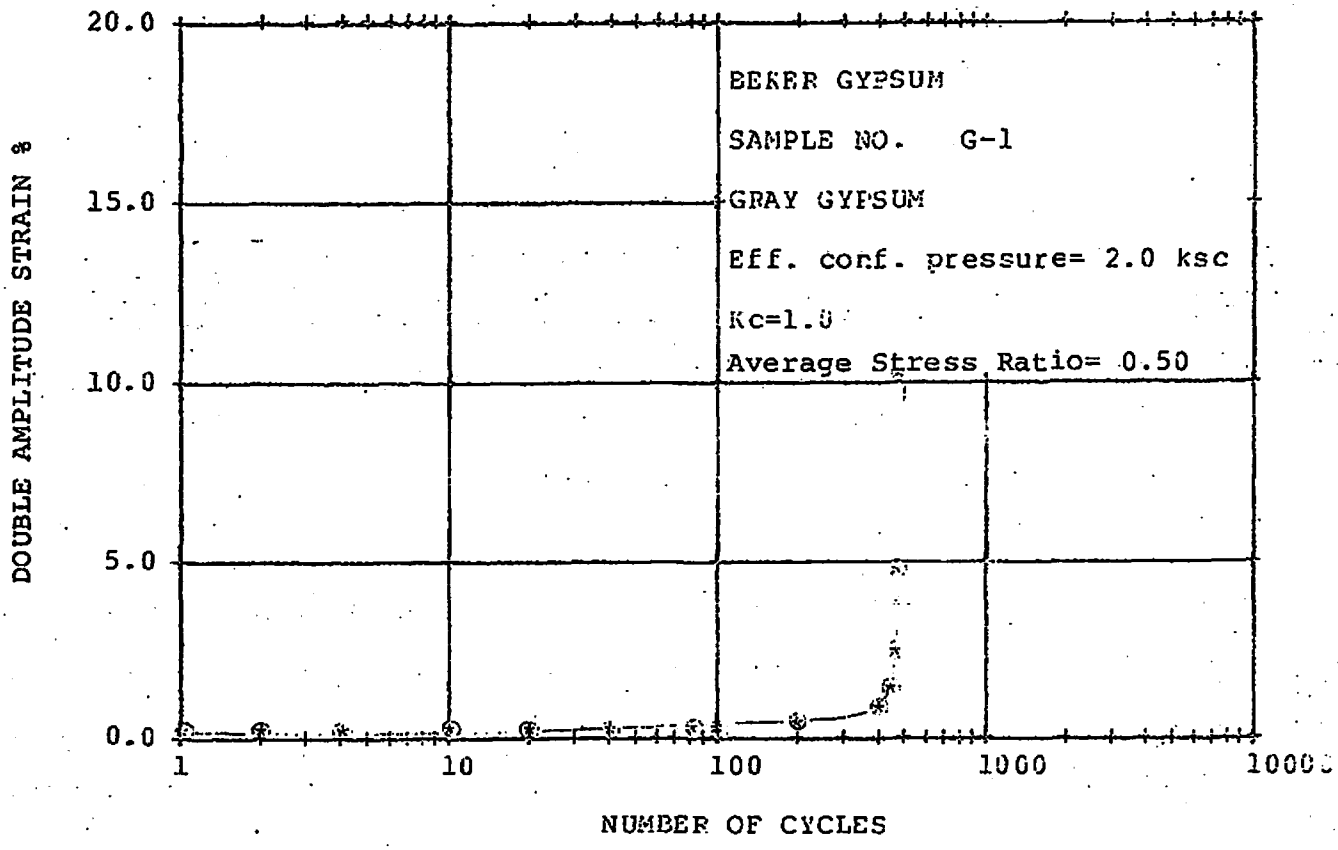
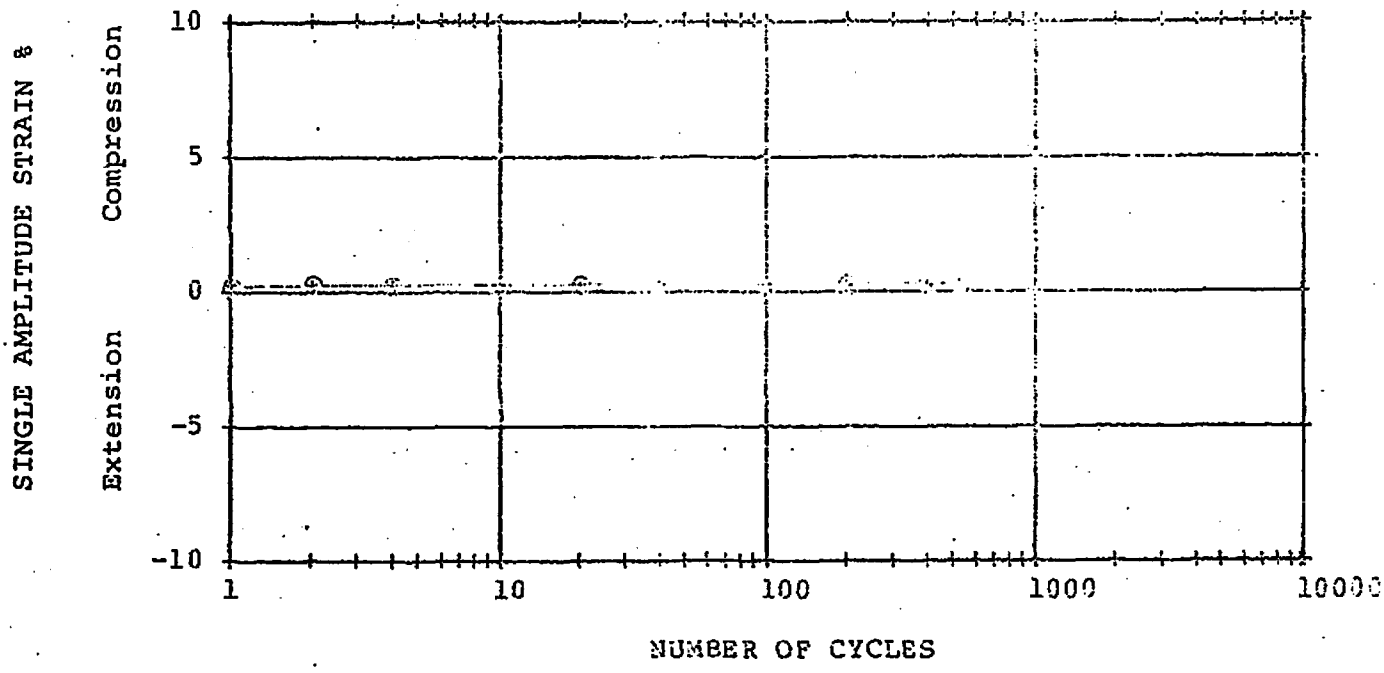


Fig. 5 Single Amplitude and Double Amplitude Strain Versus Number of Cycles for Cyclicly Loaded Gypsum Specimens.



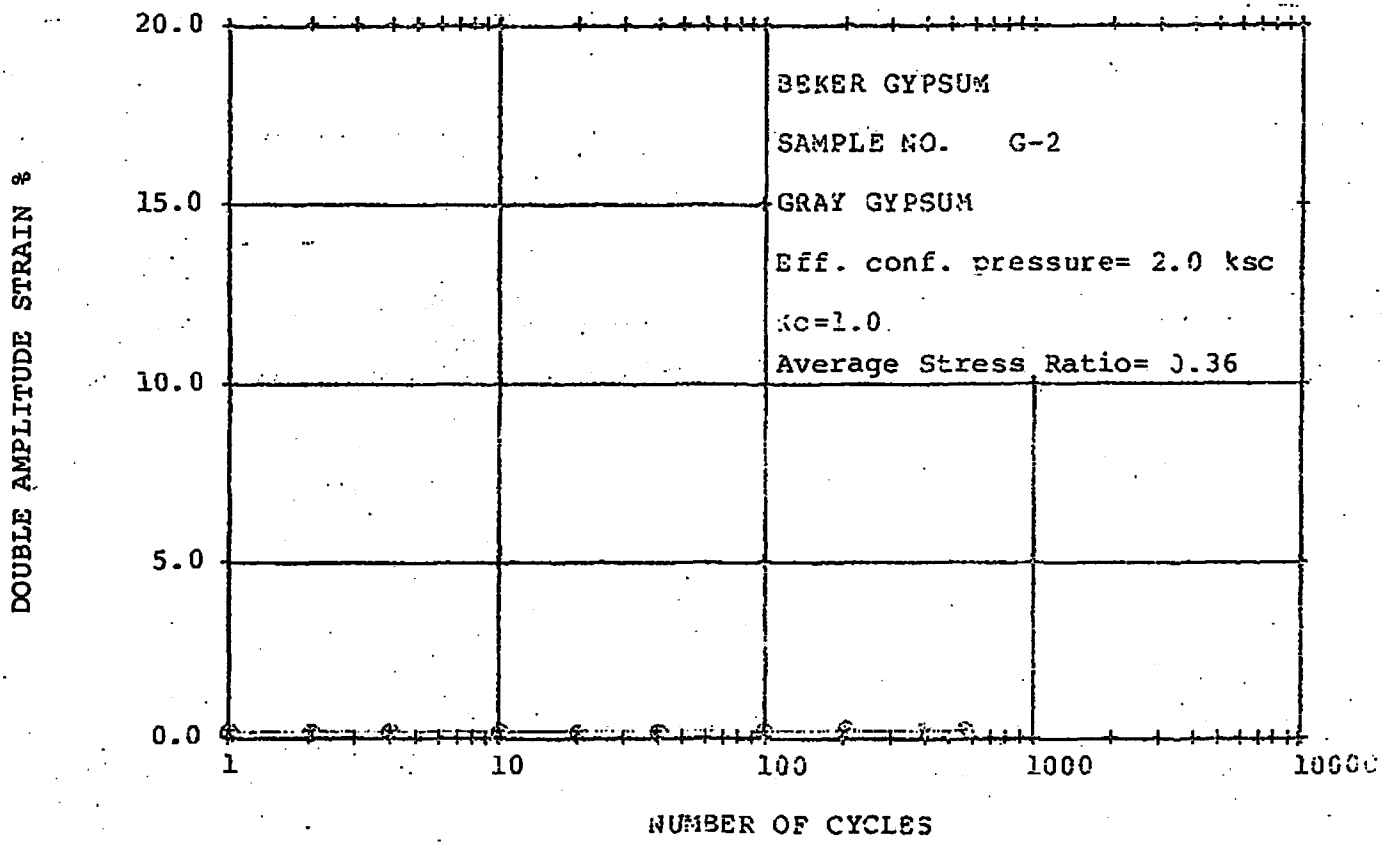
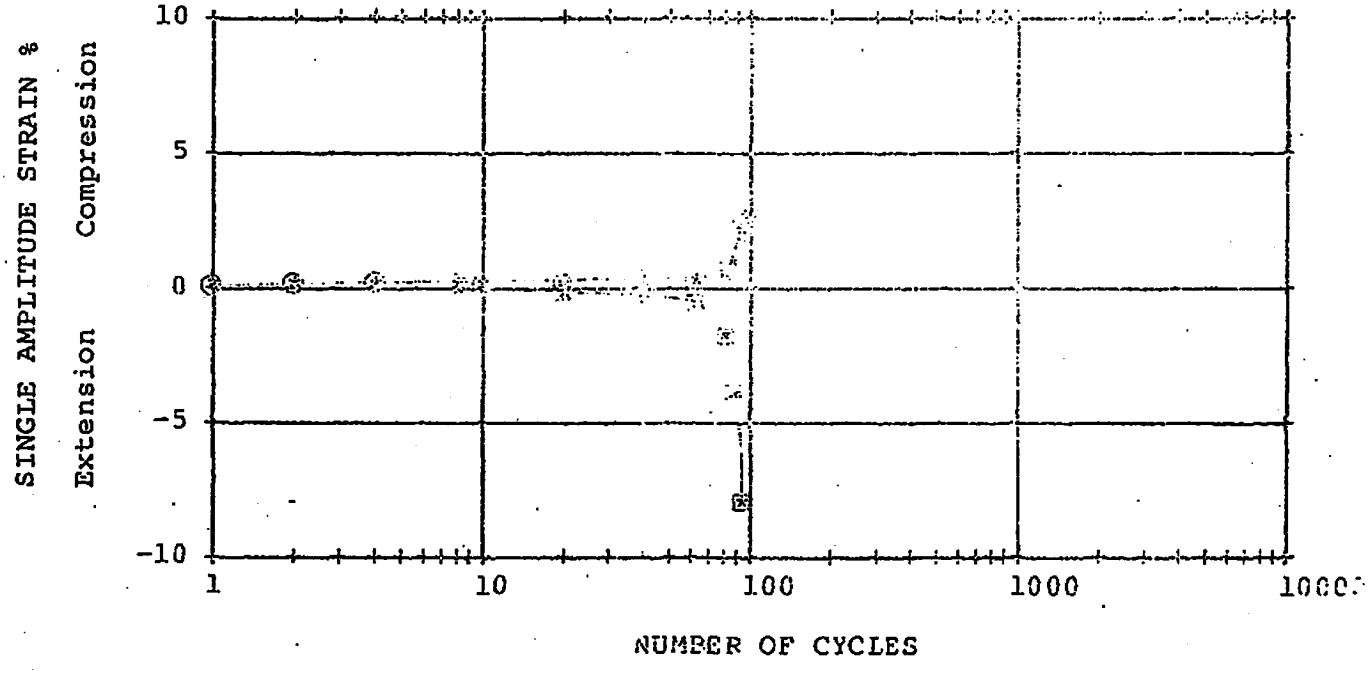
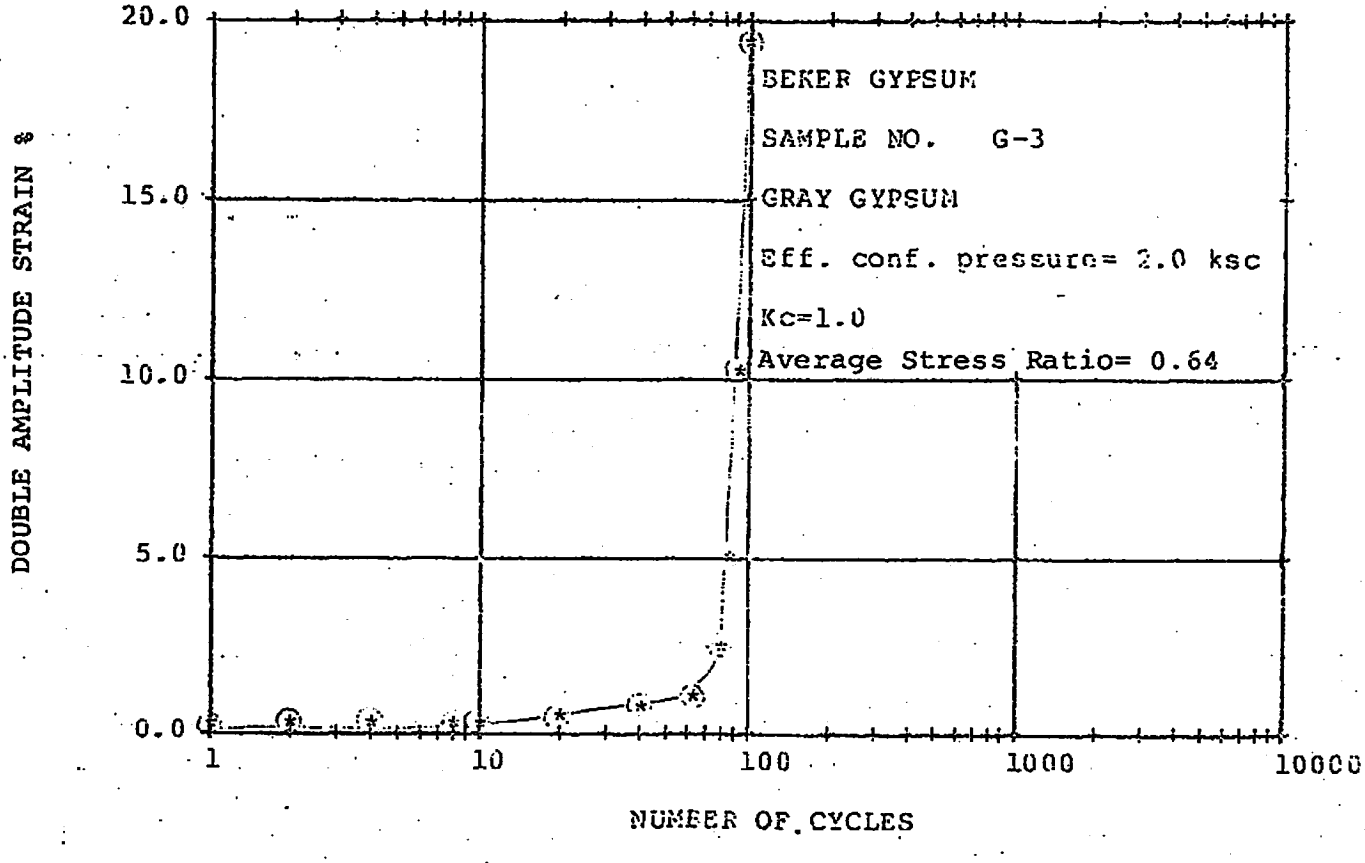


Fig. 5 (Continued)





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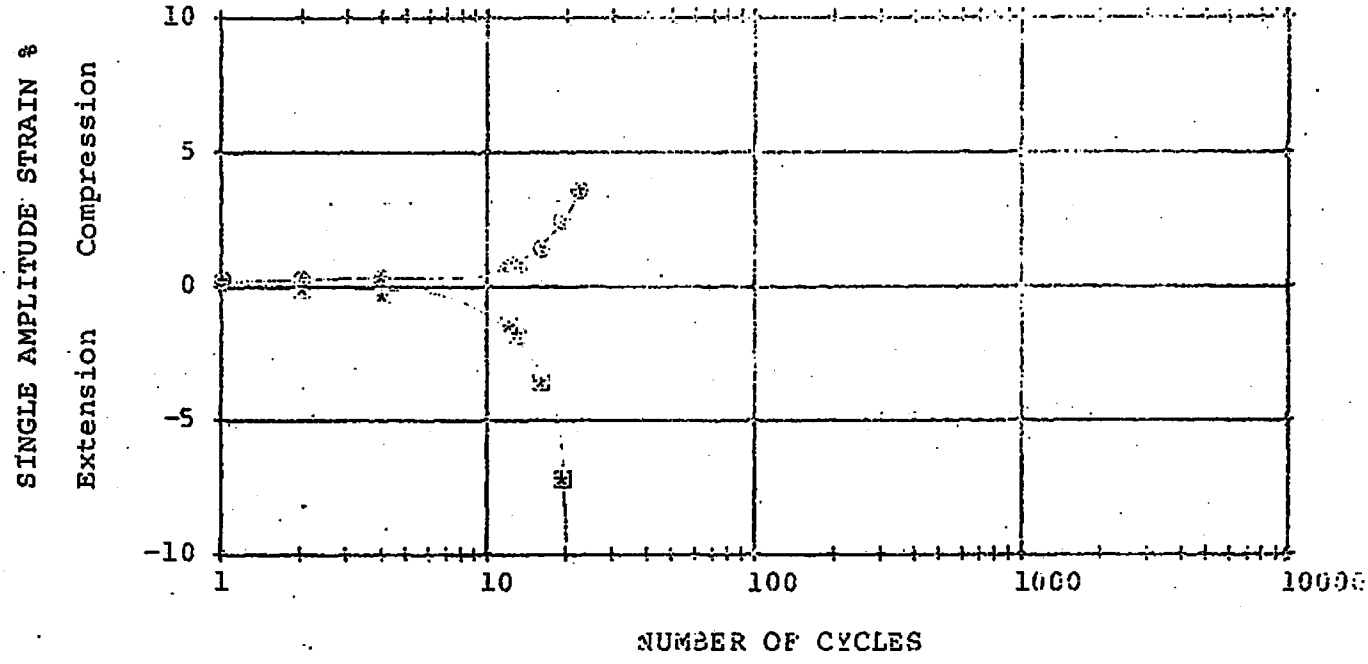

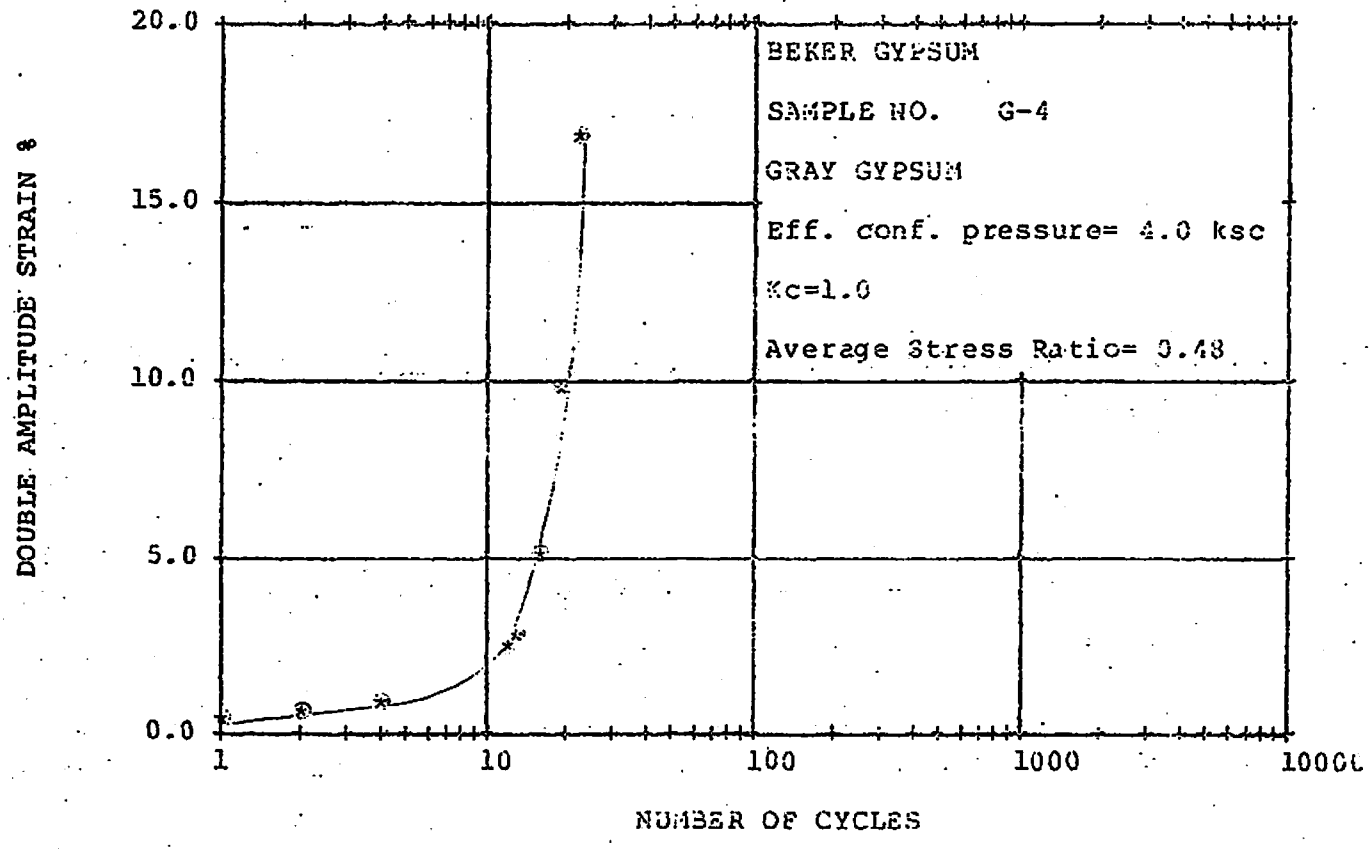

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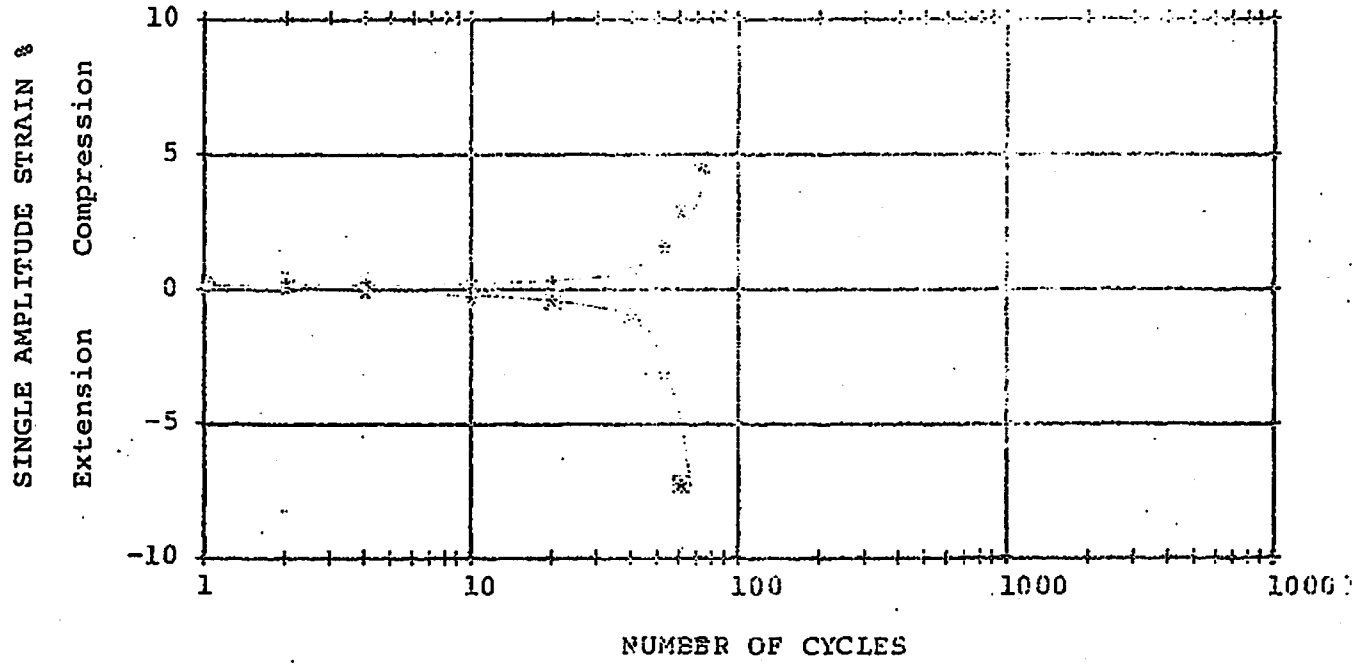

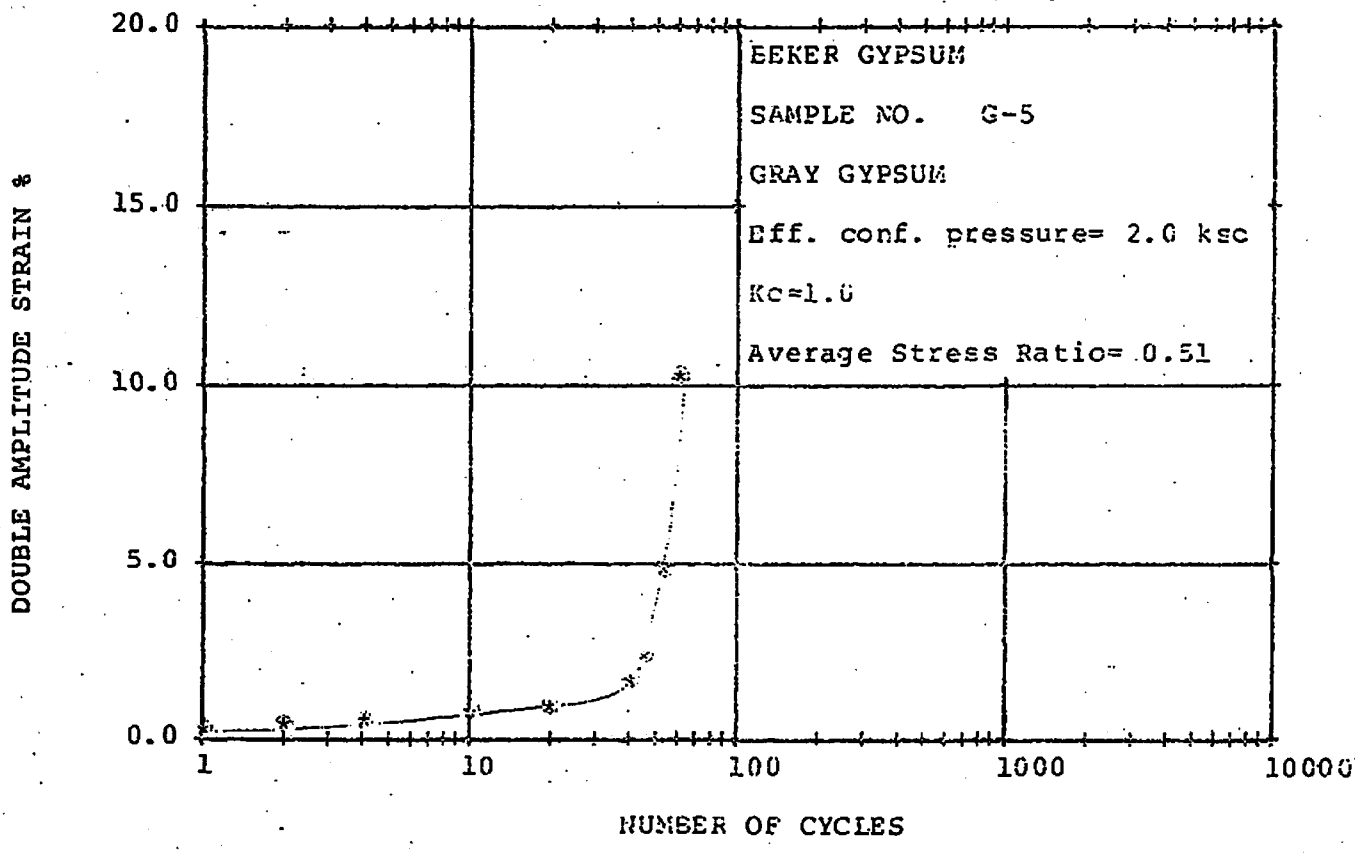

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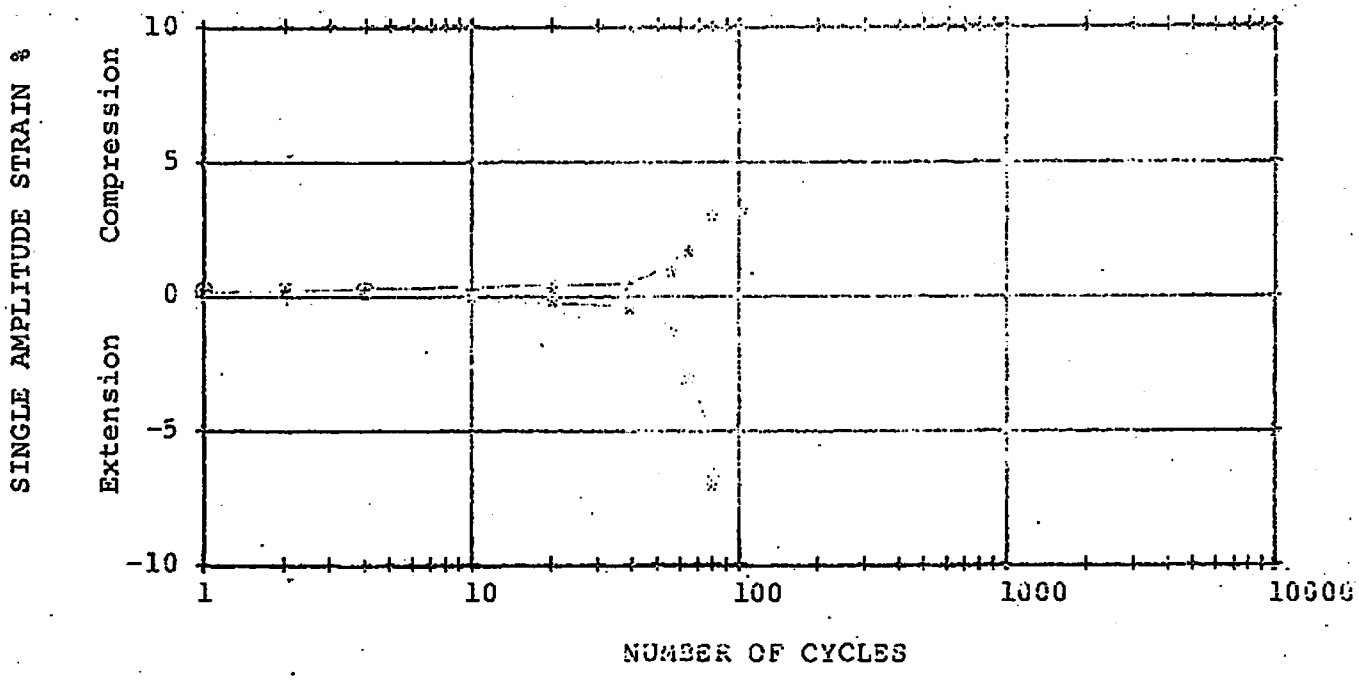

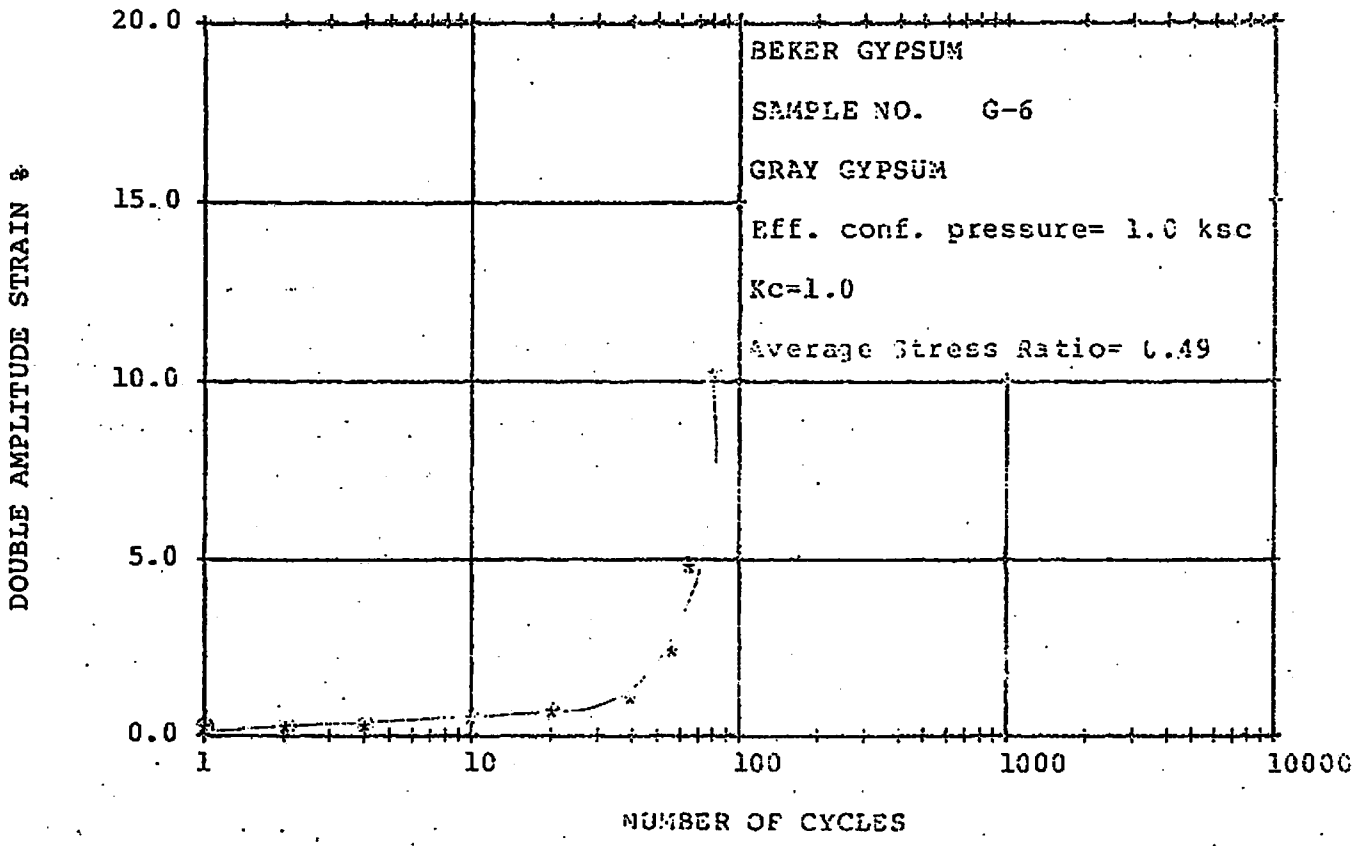

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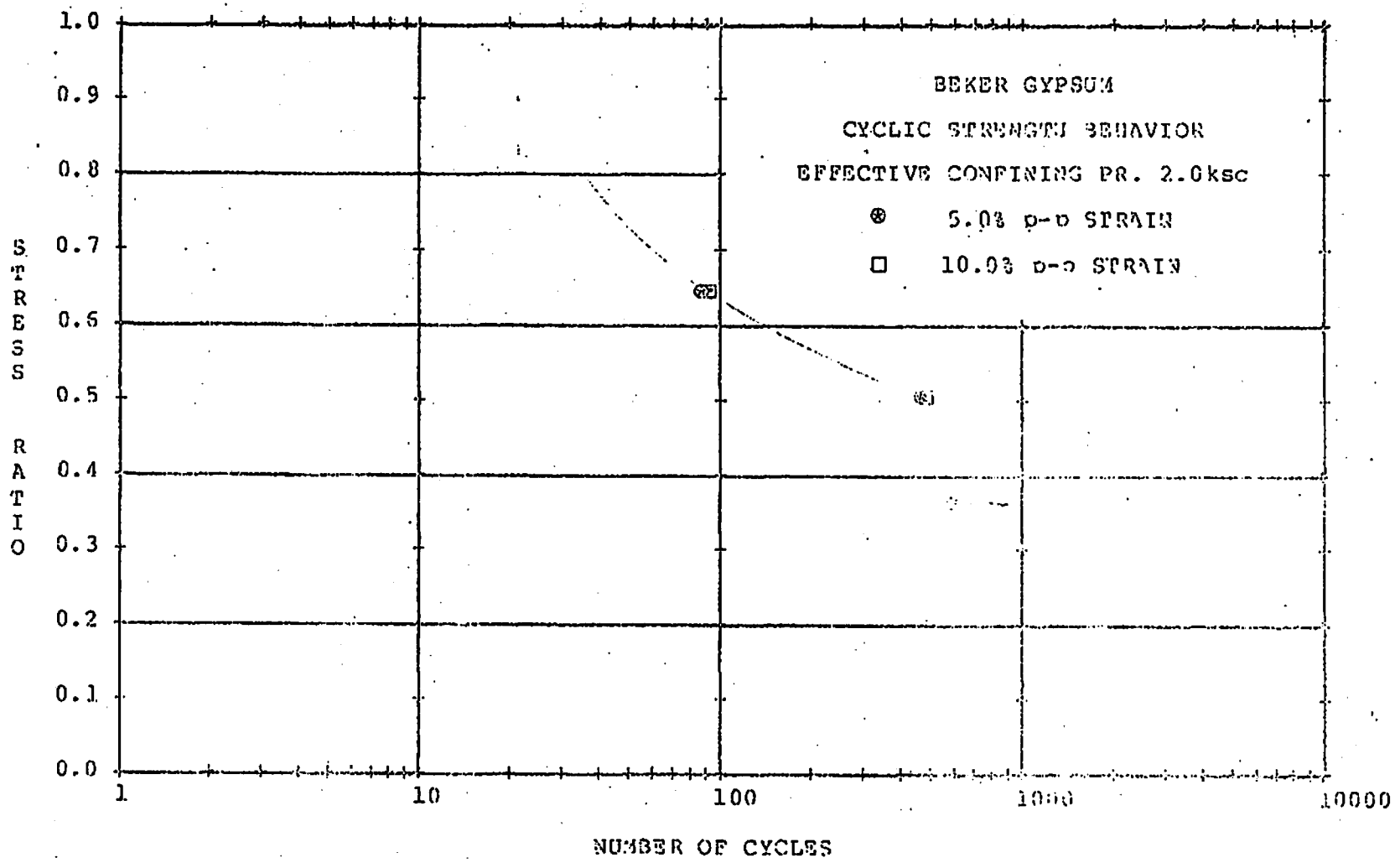

Fig. 6 Cyclic Strength of Gypsum Allowed to Consolidate into the Secondary Compression Range.

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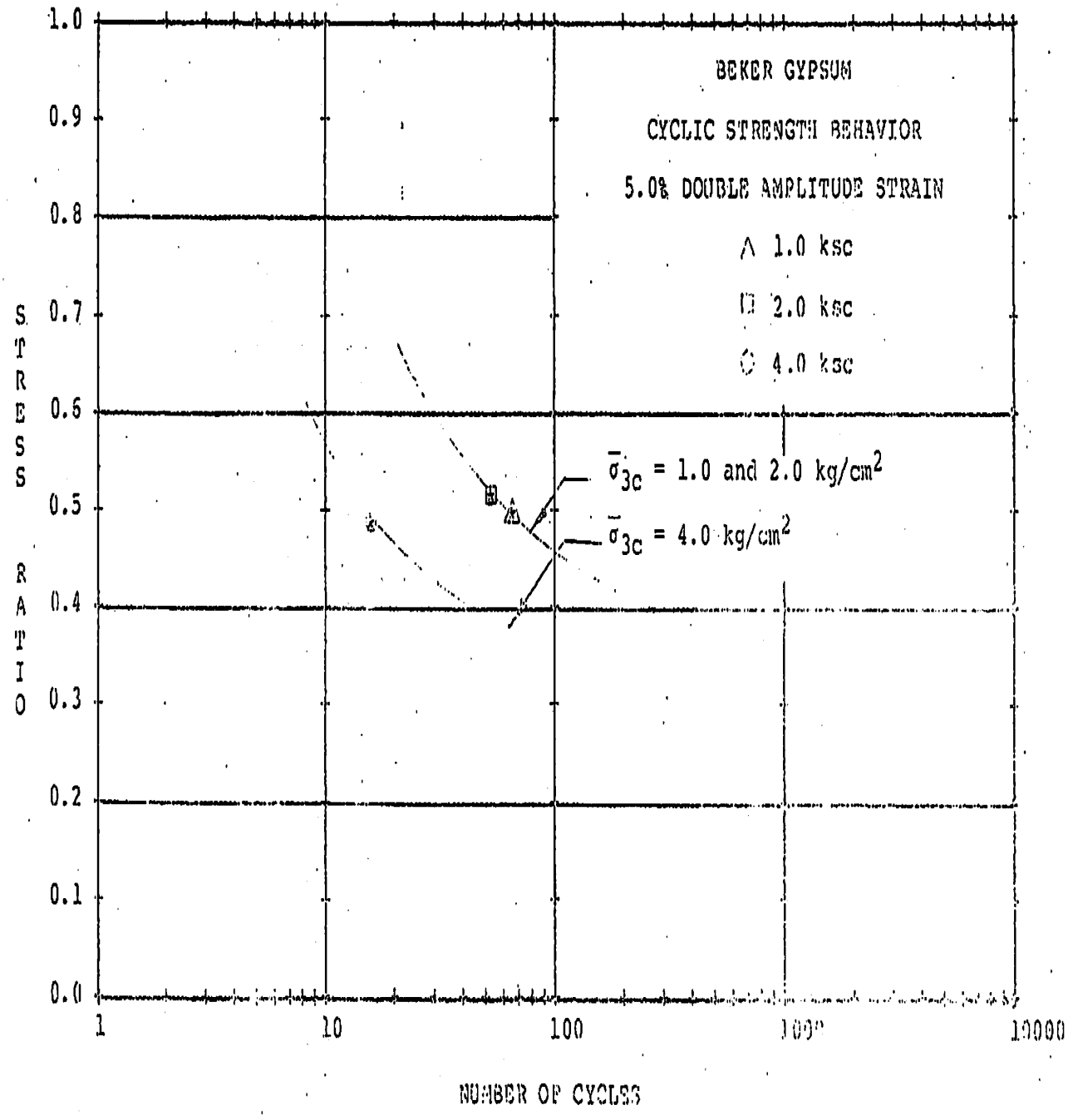

Fig. 7 Cyclic Strength of Gypsum Tested at the End of Primary Consolidation.

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gypsum. Low pore pressures and high effective stresses were generated in a portion of each loading cycle by dilation of the gypsum. This behavior made the specimens able to withstand high cyclic loads without developing significant deformations for a number of cycles.

Since Figure 7 shows the strength of specimens consolidated to different pressures but tested at a cyclic stress ratio of 0.5, any difference in the strength between these specimens shows the effect of confining pressure on cyclic strength. It may be seen that the strength of specimens consolidated to 1.0 ksc and 2.0 ksc is essentially the same with specimens reaching 5% double amplitude strain in about 50 cycles. However, it may be seen that the specimen subjected to a confining pressure of 4.0 kg/cm^2 had lower strength reaching 5% double amplitude strain in 16 cycles. This data implies that gypsum is somewhat weaker at higher confining pressures.

To evaluate the effect of time of consolidation on the strength of gypsum, the data from Figure 6 and Figure 7 for specimens consolidated to effective pressures of 2.0 kg/cm^2 but consolidated for different lengths of time are shown in Figure 8. The solid curve shows the cyclic strength of materials consolidated into the secondary compression range for four days. The dashed curve shows the cyclic strength of materials tested after the end of primary consolidation

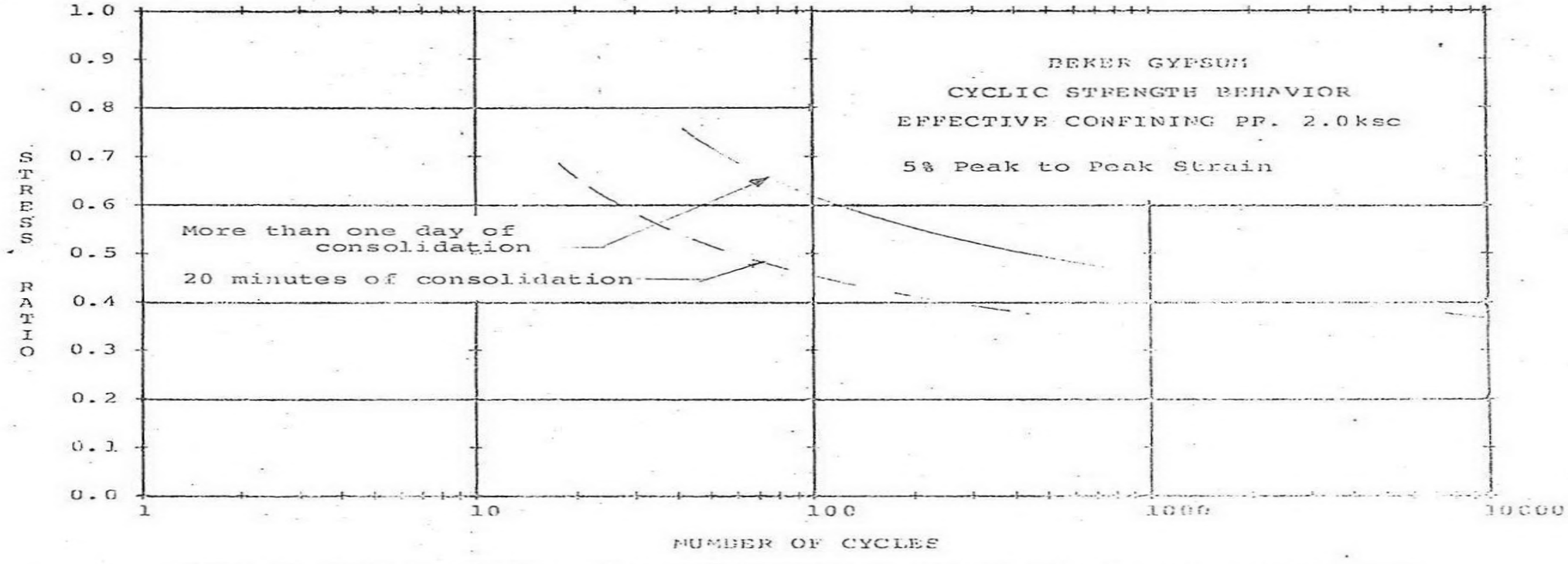

Fig. 8 Effect of Time of Consolidation on the Cyclic Strength of Gypsum.

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(20 minutes) based on results of the one test described previously performed at a confining pressure of 2.0 ksc. It would appear that longer consolidation times (especially in to the secondary compression range) significantly increased the strength of the gypsum. For example, the strength of specimens allowed to consolidate four days was on the order of 2 times the strength of the specimen tested after 20 minutes of consolidation. Such increase in strength with time has been noted for sands. However, the magnitude of the strength increase with time for gypsum is more than has been measured for other materials.

Summary and Conclusions

Based on cyclic triaxial strength tests performed on gypsum materials compacted to 98% of standard compaction, gypsum materials appear to be extremely strong and able to withstand significant levels of induced cyclic shear stress. Further, the strong dilative behavior of the material suggests that large deformations would not occur during small to moderate earthquakes in engineered embankments composed of gypsum materials. Further, the cyclic strength measured for specimens at the end of primary consolidation was high. Yet, tests indicate that cyclic strength of gypsum increases significantly after periods of sustained loading such as occur in the field.

This improved cyclic strength with time further enhances the potential stability of engineered embankments composed of gypsum materials.

It should be noted that field reports of spontaneous liquefaction of gypsum materials have been made. Such liquefaction possibly occurred in materials which were uncompacted and dumped at insitu densities on the order of 1.28 g/cm^3 (80 lb/ft^3) at water contents of from 20 to 40%. Based on this reported performance, it is suggested that additional tests be performed on gypsum materials at lower densities and higher water contents to evaluate the liquefaction behavior of materials that are placed without engineering improvement. This data may be useful in performing stability analyses to evaluate increased stresses on embankments if spontaneous liquefaction occurs in materials behind engineered gypsum embankments. Further, such tests will help to define if a critical void ratio exists for gypsum material above which spontaneous liquefaction is possible and below which spontaneous liquefaction is unlikely.

Additional tests to define the increase in both static and dynamic strength of Gypsum with time (greater than 30 days) might also provide results that could lead to the development of more economical embankment designs.

REFERENCES

1. Blight, G.E. (1969) "Waste Gypsum as an Embankment Material", Proceedings of the Seventh International Conference on Soil Mechanics and Foundation Engineering, Mexico City, Mexico, Vol 1, pp 39-43.

2. Turner, F.J. and Weiss, L.E. (1965) "Deformational Kinks in Brocite and Gypsum" Proceedings of the National Academy of Science, Vol 54, Washington, pp 359-364.

3. Vick, S.G. (1977) "Rehabilitation of a Gypsum Tailings Embankment" Proceedings, Geotechnical Practice for Disposal of solid waste materials, ASCE, Ann Arbor, Michigan pp 697-714.

4. Silver, M.L., "Laboratory Triaxial Testing Procedures to Determine the Cyclic Strength of Soils," Report NUREG-31, U.S. Nuclear Regulatory Commission, Washington, D.C., December 1976.

APPENDIX A

STANDARD COMPACTION TEST RESULTS

Beker Gypsum

COMPACTION TEST

Project [illegible] Job No. [illegible]

Location of Project [illegible] Boring No. [illegible] Sample No. [illegible]

Description of Soil [illegible]

Test Performed By [illegible] Date of Test [illegible]

Blows/Layer 25 No. of Layers [illegible] Wt. of Hammer [illegible] lb

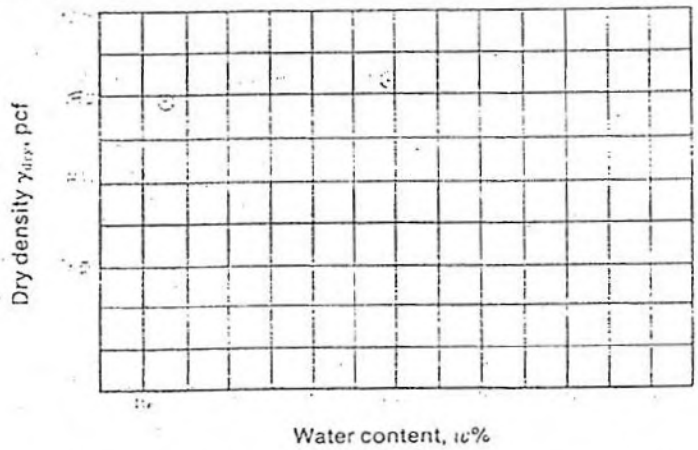
Mold dimensions: Diam. [illegible] ft Ht. [illegible] ft Vol. [illegible] cu ft

Water Content Determination

Sample no	1		2				4		5		6	
Moisture can no.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
Wt. of can + wet soil	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
Wt. of can + dry soil	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
Wt. of water	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
Wt. of can	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						
Wt. of dry soil	[illegible]	26.70	[illegible]	[illegible]	[illegible]	30.16						
Water content, w%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

Density Determination

Assumed water content	16	18	21 +			
Water content, w%	[illegible]	[illegible]	[illegible]			
Wt. of soil + mold	5460	5560	[illegible]			
Wt. of mold	3978	3978	3978			
Wt. of soil in mold	1482	1582	1679			
Wet density, ~~pcf~~ g/cm³	1.536/[illegible]	1.694/[illegible]	1.691/[illegible]			
Dry density γ_d, ~~pcf~~ g/cm³	1.362/[illegible]	[illegible]	1.310/[illegible]			



Optimum moisture = [illegible] % Maximum dry density = [illegible] pcf

COMPACTION TEST

Project [illegible] Job No. [illegible]

Location of Project [illegible] Boring No. [illegible] Sample No. [illegible]

Description of Soil [illegible]

Test Performed By [illegible] Date of Test [illegible]

Blows/Layer [illegible] No. of Layers [illegible] Wt. of Hammer [illegible] lb

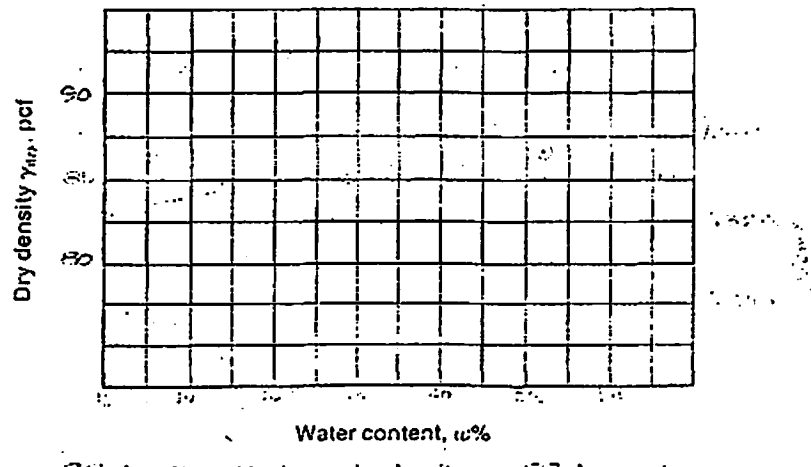
Mold dimensions: Diam. [illegible] ft Ht. [illegible] ft Vol. [illegible] cu ft

Water Content Determination

Sample no.	1		2		3		4		5		6	
Moisture can no.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Wt. of can + wet soil	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Wt. of can + dry soil	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Wt. of water	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Wt. of can	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Wt. of dry soil	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				
Water content, w%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				

Density Determination

Assumed water content	[illegible]	[illegible]	[illegible]	[illegible]		
Water content, w%	[illegible]	[illegible]	[illegible]	[illegible]		
Wt. of soil + mold	[illegible]	[illegible]	[illegible]	[illegible]		
Wt. of mold	[illegible]	[illegible]	[illegible]	[illegible]		
Wt. of soil in mold	[illegible]	[illegible]	[illegible]	[illegible]		
Wet density, pcf	[illegible] / [illegible]	[illegible] / [illegible]	[illegible] / [illegible]	[illegible] / [illegible]		
Dry density γ, pcf	[illegible] / [illegible]	[illegible] / [illegible]	[illegible] / [illegible]	[illegible] / [illegible]		



Optimum moisture = [illegible] % Maximum dry density = [illegible] pcf

APPENDIX B

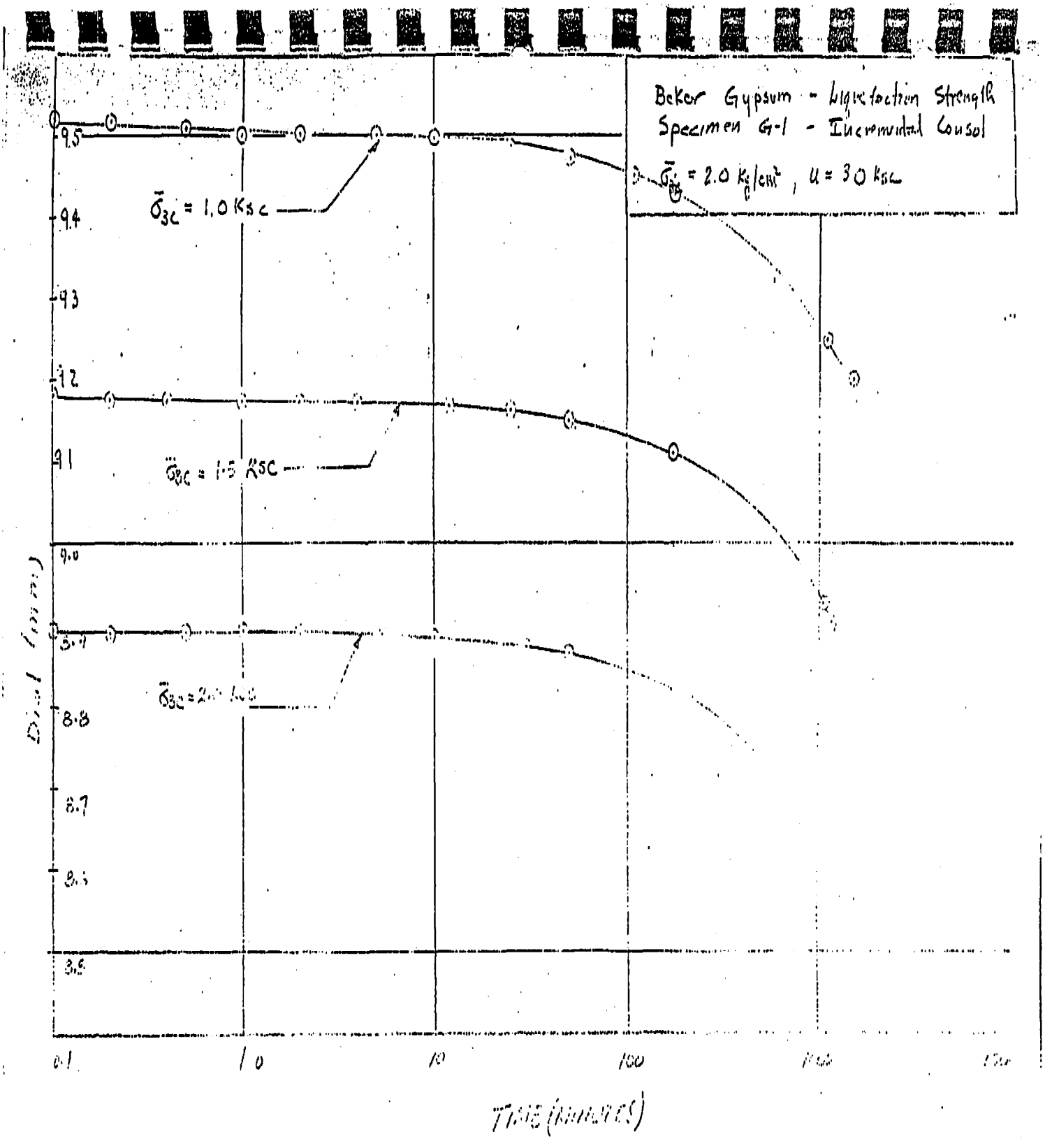
DIAL GAGE VERSUS TIME PLOTS

AND

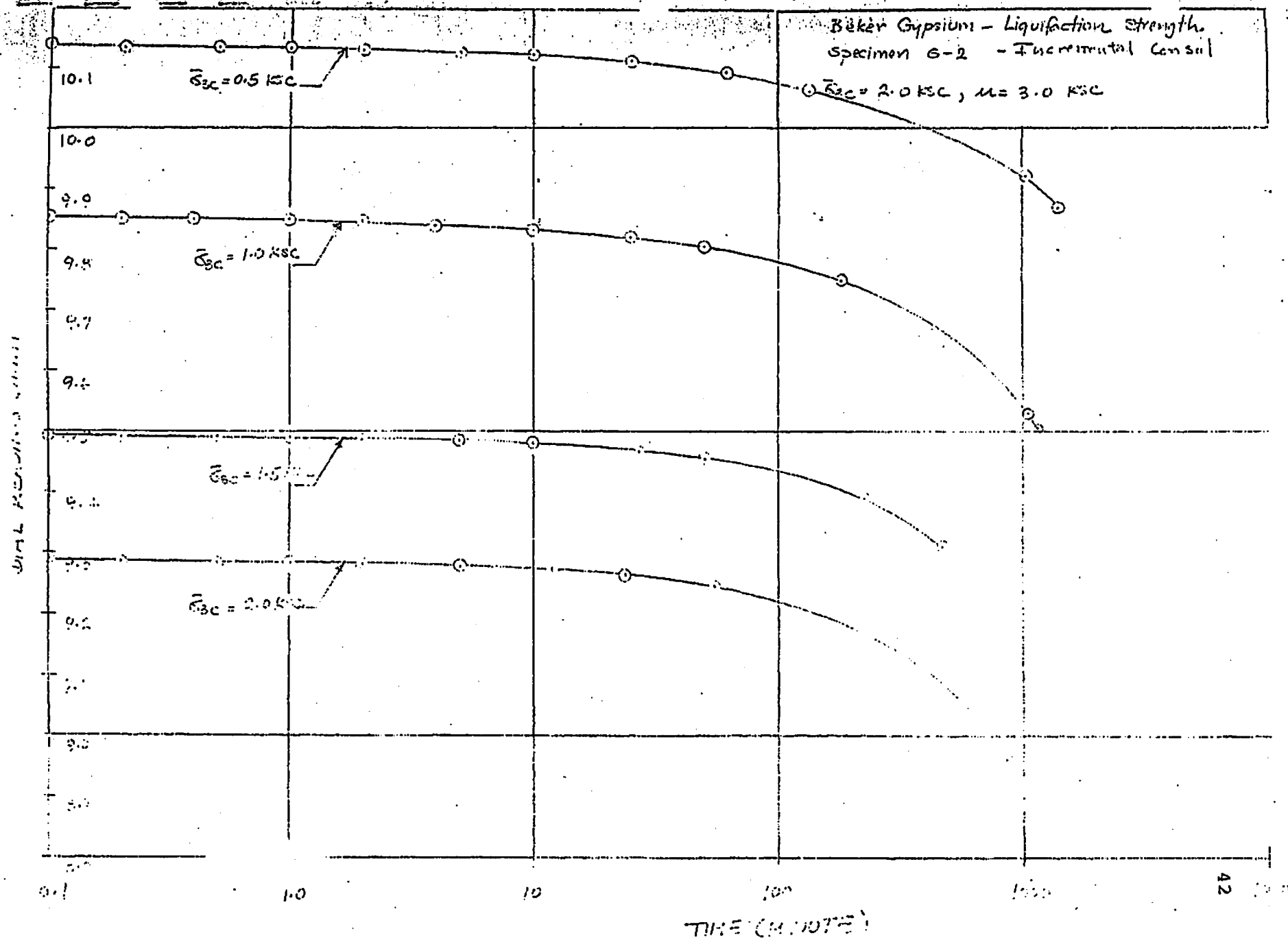
VOLUME CHANGE VERSUS TIME PLOTS

FOR

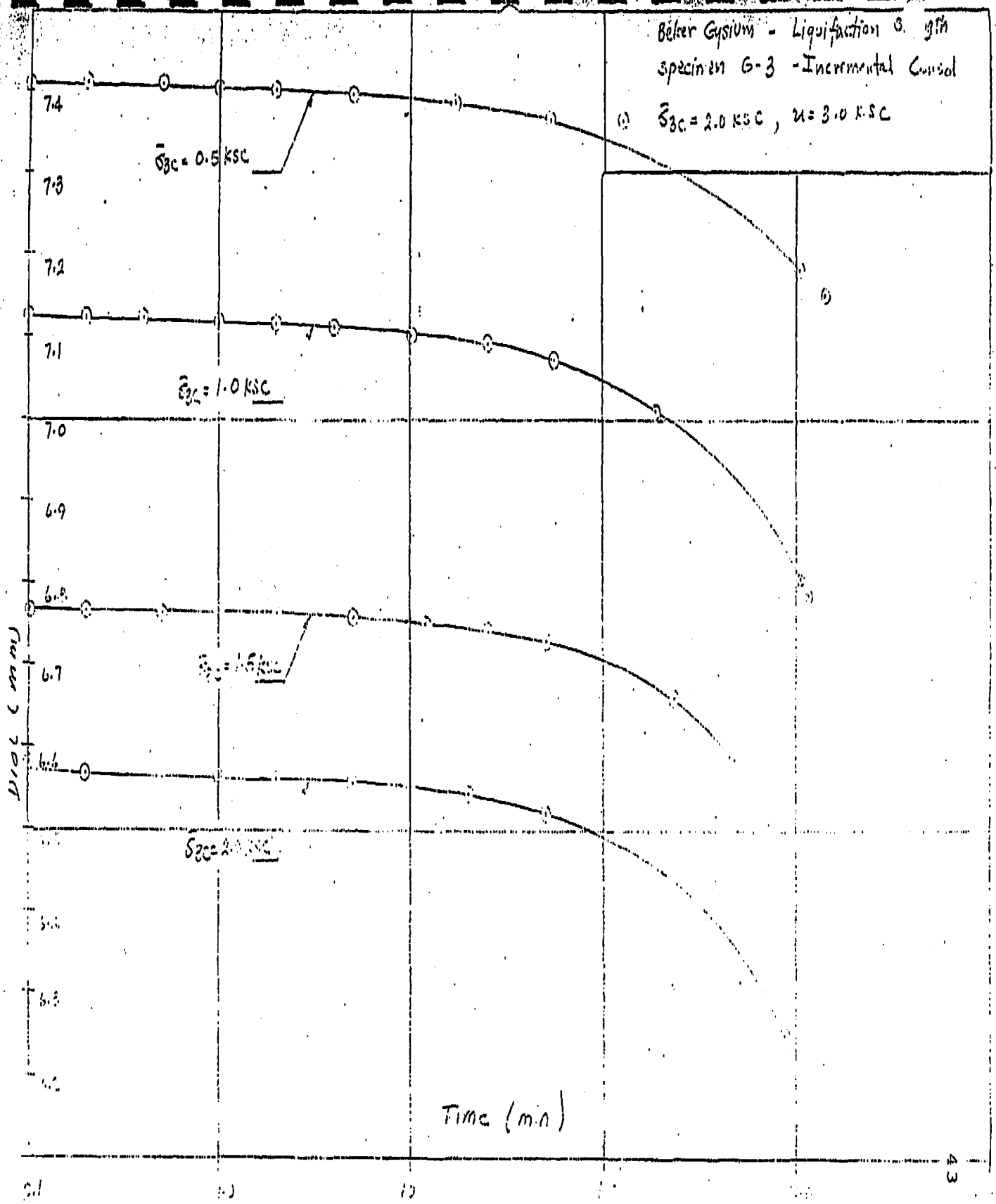
CONSOLIDATING GYPSUM SPECIMENS


Baker Gypsum - Liquefaction Strength
Specimen G-1 - Incremental Consol
$\bar{\sigma}_{3c}$ = 2.0 kg/cm², u = 30 ksc
$\bar{\sigma}_{3c}$ = 1.0 ksc
$\bar{\sigma}_{3c}$ = 1.5 ksc
9.5
9.4
9.3
9.2
9.1
9.0
8.8
8.7
0.1
1.0
10
100
TIME (MINUTES)

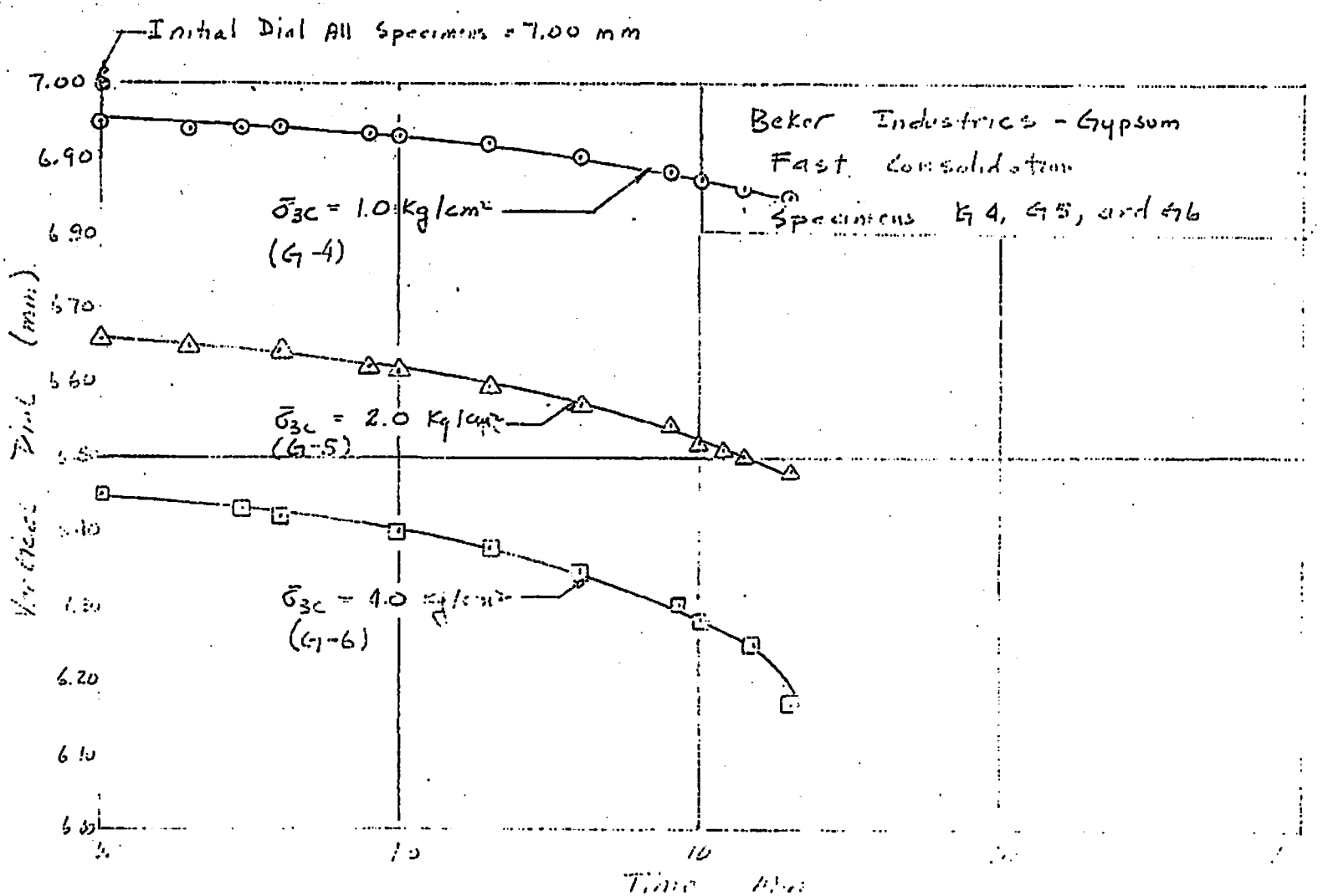
FH00029202


Baker Gypsum – Liquifaction Strength
Specimen 6-2 – Incremental Consol
$\bar{\sigma}_{3c}$ = 2.0 KSC, u = 3.0 KSC
$\bar{\sigma}_{3c}$ = 0.5 KSC
$\bar{\sigma}_{3c}$ = 1.0 KSC
10.1
10.0
9.9
9.8
9.7
1.0
10
TIME (MINUTES)

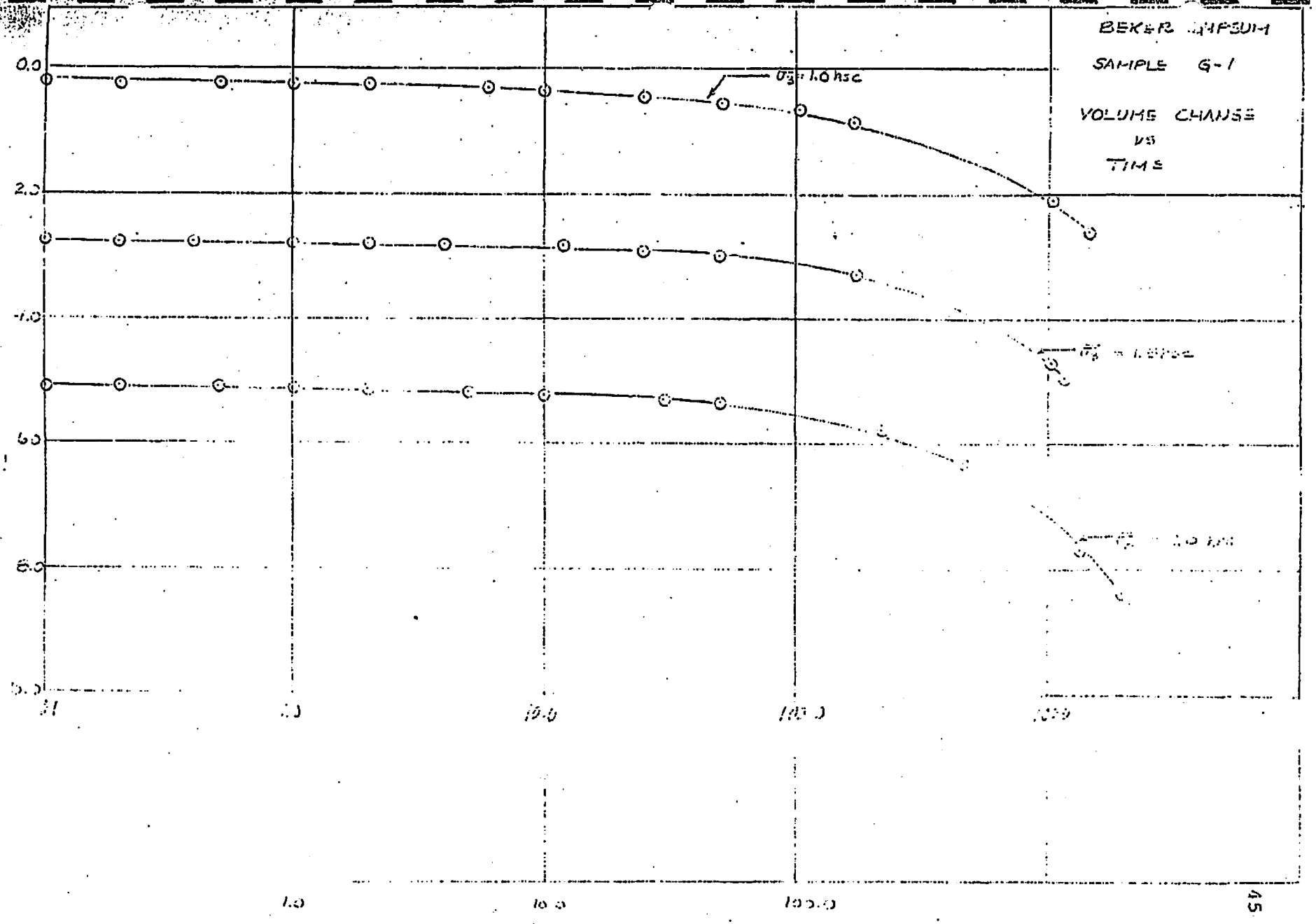
FH0029203


Beker Gysium - Liquifaction Strength
specimen G-3 - Incremental Consol
$\bar{\sigma}_{3c}$ = 2.0 KSC , u = 3.0 KSC
$\bar{\sigma}_{3c}$ = 0.5 KSC
$\bar{\sigma}_{3c}$ = 1.0 KSC
$\bar{\sigma}_{3c}$ = 1.5 KSC
$\bar{\sigma}_{3c}$ = 2.0 KSC
7.4
7.3
7.2
7.1
7.0
6.9
6.8
6.7
6.6
Dial (mm)
Time (min)
0.1
1.0
10
43

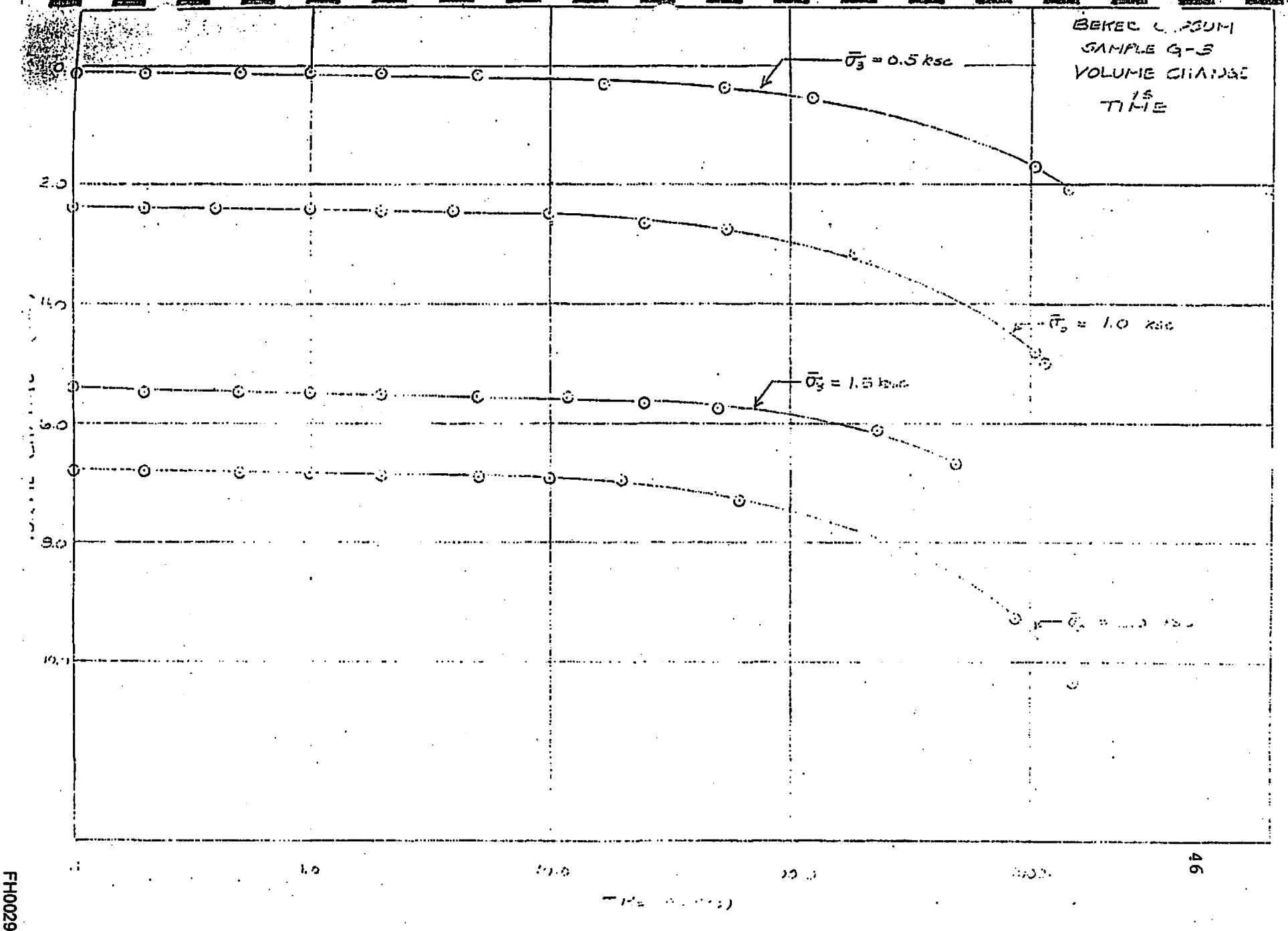
FH0029204


Initial Dial All Specimens = 7.00 mm
7.00
6.90
6.80
6.70
6.60
6.50
6.40
6.30
6.20
6.10
6.00
Dial (mm)
Beker Industries - Gypsum
Fast Consolidation
Specimens G4, G5, and G6
$\bar{\sigma}_{3c}$ = 1.0 Kg/cm²
(G-4)
$\bar{\sigma}_{3c}$ = 2.0 Kg/cm²
(G-5)
$\bar{\sigma}_{3c}$ = 4.0 Kg/cm²
(G-6)
5
10
Time

FH0029205


BEKER GYPSUM
SAMPLE G-1
VOLUME CHANGE
VS
TIME
0.0
2.0
4.0
6.0
8.0
10.0
1.0
10.0
100.0
1000.0

FH0029206


BEREA SANDSTONE
SAMPLE G-5
VOLUME CHANGE
VS
TIME
$\bar{\sigma}_3$ = 0.5 ksc
$\bar{\sigma}_3$ = 1.0 ksc
$\bar{\sigma}_3$ = 1.5 ksc
2.0
6.0
9.0

FH0029207

APPENDIX C

CYCLIC TRIAXIAL TEST RESULTS

GYPSUM SPECIMENS

GEOTECHNICAL ENGINEERING LABORATORY

MARSHALL L. SILVER P.E.

DATE 20 APRIL 78 JOB NO.

PROJECT BEKER GYPSUM

LOCATION

BORING NO. SAMPLE NO. G-1

DEPTH OF SAMPLE

SOIL DESCRIPTION GRAY GYPSUM

SAMPLE CHARACTERISTICS

	INITIAL	AFTER CONSOLIDATION
AVERAGE DIAMETER	60.9 mm	60.7 mm
AREA	2911.62 sq.mm	2898.07 sq.mm
HEIGHT	150.4 mm	147.9 mm
WEIGHT	732.64 gm	770.6 gm
WET UNIT WEIGHT	1.673 gm/cc	1.798 gm/cc
WATER CONTENT	22.0 %	28.32 %
DRY UNIT WEIGHT	1.371 gm/cc	1.401 gm/cc

MARSHALL L. SILVER P.E.

DATE	20 APRIL 78	LOCATION		
JOB NO.		SAMPLE NO.	G-1	$\bar{\sigma}_{3c}$ = 2.0 ksc
PROJECT	BEKER GYPSUM	SOIL TYPE	GRAY GYPSUM	σ_{3c} = 5.0 ksc
				u_o = 3.0 ksc

CYCLIC TRIAXIAL STRENGTH TEST SUMMARY

CYCLE NUMBER	AVERAGE CYCLIC SINGLE AMPLITUDE VERTICAL STRESS kg/sq cm	STRESS RATIO	MAXIMUM SHEAR STRESS kg/sq cm	DOUBLE AMPLITUDE STRAIN %	PORE PRESSURE RATIO $\Delta u/\bar{\sigma}_{3c}$
1	2.070	0.518	1.035	0.1	0.250
2	2.036	0.509	1.018	0.1	0.250
4	2.036	0.509	1.018	0.1	0.250
10	2.001	0.500	1.001	0.1	0.275
20	1.984	0.496	0.992	0.1	0.285
40	2.001	0.500	1.001	0.1	0.325
80	2.001	0.500	1.001	0.2	0.375
100	2.001	0.500	1.001	0.2	0.400
200	2.001	0.500	1.001	0.3	0.525
400	2.001	0.500	1.001	0.7	0.575
445	2.001	0.500	1.001	1.4	1.000
459	1.967	0.492	0.983	2.4	1.050
467	1.967	0.492	0.983	4.7	1.100
476	1.950	0.487	0.975	10.1	1.100
490	1.932	0.483	0.966	20.3	1.100

FH0029210

GEOTECHNICAL ENGINEERING LABORATORY

MARSHALL L. SILVER P.E.

DATE 20 APRIL 78 JOB NO.

PROJECT BEKER GYPSUM

LOCATION

BORING NO. SAMPLE NO. G-2

DEPTH OF SAMPLE

SOIL DESCRIPTION GRAY GYPSUM

SAMPLE CHARACTERISTICS

	INITIAL	AFTER CONSOLIDATION
AVERAGE DIAMETER	60.8 mm	60.5 mm
AREA	2903.97 sq.mm	2874.12 sq.mm
HEIGHT	150.0 mm	147.8 mm
WEIGHT	732.64 gm	772.0 gm
WET UNIT WEIGHT	1.682 gm/cc	1.817 gm/cc
WATER CONTENT	22.0 %	28.3 %
DRY UNIT WEIGHT	1.379 gm/cc	1.414 gm/cc

MARSHALL L. SILVER P.E.

DATE	20 APRIL 78	LOCATION		
JOB NO.		SAMPLE NO.	G-2	$\bar{\sigma}_{3c}$ = 2.0 ksc
PROJECT	BEKER GYPSUM	SOIL TYPE	GRAY GYPSUM	σ_{3c} = 5.0 ksc
				u_o = 3.0 ksc

CYCLIC TRIAXIAL STRENGTH TEST SUMMARY

CYCLE NUMBER	AVERAGE CYCLIC SINGLE AMPLITUDE VERTICAL STRESS kg/sq cm	STRESS RATIO	MAXIMUM SHEAR STRESS kg/sq cm	DOUBLE AMPLITUDE STRAIN %	PORE PRESSURE RATIO $\Delta u/\bar{\sigma}_{3c}$
1	1.409	0.352	0.705	0.0	0.200
2	1.409	0.352	0.705	0.0	0.210
4	1.427	0.357	0.713	0.0	0.225
10	1.427	0.357	0.713	0.0	0.225
20	1.427	0.357	0.713	0.0	0.250
40	1.427	0.357	0.713	0.0	0.275
100	1.479	0.370	0.739	0.0	0.325
200	1.479	0.370	0.739	0.1	0.400
400	1.479	0.370	0.739	0.1	0.500
550	1.479	0.370	0.739	0.1	0.600

FH0029212

GEOTECHNICAL ENGINEERING LABORATORY

MARSHALL L. SILVER P.E.

DATE 20 APRIL 78 JOB NO.

PROJECT BEKER GYPSUM

LOCATION

BORING NO. SAMPLE NO. G-3

DEPTH OF SAMPLE

SOIL DESCRIPTION GRAY GYPSUM

SAMPLE CHARACTERISTICS

	INITIAL	AFTER CONSOLIDATION
AVERAGE DIAMETER	60.7 mm	60.4 mm
AREA	2897.29 sq.mm	2864.73 sq.mm
HEIGHT	149.6 mm	147.7 mm
WEIGHT	732.64 gm	767.9 gm
WET UNIT WEIGHT	1.690 gm/cc	1.815 gm/cc
WATER CONTENT	22.0 %	27.8 %
DRY UNIT WEIGHT	1.386 gm/cc	1.419 gm/cc

MARSHALL L. SILVER P.E.

DATE	20 APRIL 78	LOCATION		
JOB NO.		SAMPLE NO.	G-3	$\bar{\sigma}_{3c}$ = 2.0 ksc
PROJECT	BEKER GYPSUM	SOIL TYPE	GRAY GYPSUM	σ_{3c} = 5.0 ksc
				u_o = 3.0 ksc

CYCLIC TRIAXIAL STRENGTH TEST SUMMARY

CYCLE NUMBER	AVERAGE CYCLIC SINGLE AMPLITUDE VERTICAL STRESS kg/sq cm	STRESS RATIO	MAXIMUM SHEAR STRESS kg/sq cm	DOUBLE AMPLITUDE STRAIN %	PORE PRESSURE RATIO $\Delta u/\bar{\sigma}_{3c}$
1	2.583	0.646	1.292	0.1	0.300
2	2.583	0.646	1.292	0.2	0.350
4	2.566	0.641	1.283	0.2	0.375
8	2.566	0.641	1.283	0.2	0.425
10	2.566	0.641	1.283	0.2	0.450
20	2.548	0.637	1.274	0.4	0.550
40	2.548	0.637	1.274	0.7	0.750
63	2.548	0.637	1.274	0.9	1.000
80	2.548	0.637	1.274	2.4	1.050
86	2.548	0.637	1.274	4.9	1.100
93	2.496	0.624	1.248	10.2	1.150
101	2.496	0.624	1.248	19.3	1.150

FH0029214

GEOTECHNICAL ENGINEERING LABORATORY

MARSHALL L. SILVER P.E.

DATE 24 APRIL 78 JOB NO.

PROJECT BEKER GYPSUM

LOCATION

BORING NO. SAMPLE NO. G-4

DEPTH OF SAMPLE

SOIL DESCRIPTION GRAY GYPSUM

SAMPLE CHARACTERISTICS

	INITIAL	AFTER CONSOLIDATION
AVERAGE DIAMETER	60.8 mm	60.9 mm
AREA	2907.47 sq.mm	2908.20 sq.mm
HEIGHT	150.9 mm	149.2 mm
WEIGHT	724.79 gm	761.3 gm
WET UNIT WEIGHT	1.652 gm/cc	1.755 gm/cc
WATER CONTENT	22.0 %	28.2 %
DRY UNIT WEIGHT	1.354 gm/cc	1.369 gm/cc

MARSHALL L. SILVER P.E.

DATE	24 APRIL 78	LOCATION	
JOB NO.		SAMPLE NO.	G-4
PROJECT	BEKER GYPSUM	SOIL TYPE	GRAY GYPSUM

$\bar{\sigma}_{3c}$ = 4.0 ksc

σ_{3c} = 6.0 ksc

u_o = 2.0 ksc

CYCLIC TRIAXIAL STRENGTH TEST SUMMARY

CYCLE NUMBER	AVERAGE CYCLIC SINGLE AMPLITUDE VERTICAL STRESS kg/sq cm	STRESS RATIO	MAXIMUM SHEAR STRESS kg/sq cm	DOUBLE AMPLITUDE STRAIN %	PORE PRESSURE RATIO $\Delta u/\bar{\sigma}_{3c}$
1	3.954	0.494	1.977	0.3	0.400
2	3.954	0.494	1.977	0.5	0.500
4	3.903	0.488	1.951	0.7	0.650
12	3.868	0.484	1.934	2.3	0.975
13	3.868	0.484	1.934	2.7	1.000
16	3.834	0.479	1.917	5.0	1.050
19	3.834	0.479	1.917	9.7	1.050
22	3.834	0.479	1.917	16.8	1.050

FH0029216

GEOTECHNICAL ENGINEERING LABORATORY

MARSHALL L. SILVER P.E.

DATE 25 APRIL 78 JOB NO.

PROJECT BEKER GYPSUM

LOCATION

BORING NO. SAMPLE NO. G-5

DEPTH OF SAMPLE

SOIL DESCRIPTION GRAY GYPSUM

SAMPLE CHARACTERISTICS

	INITIAL	AFTER CONSOLIDATION
AVERAGE DIAMETER	60.6 mm	60.6 mm
AREA	2888.71 sq.mm	2883.44 sq.mm
HEIGHT	150.1 mm	149.1 mm
WEIGHT	723.06 gm	764.7 gm
WET UNIT WEIGHT	1.668 gm/cc	1.779 gm/cc
WATER CONTENT	22.0 %	29.0 %
DRY UNIT WEIGHT	1.367 gm/cc	1.379 gm/cc

MARSHALL L. SILVER P.E.

DATE	25 APRIL 78	LOCATION		$\bar{\sigma}_{3c}$ = 2.0 ksc
JOB NO.		SAMPLE NO.	G-5	σ_{3c} = 5.0 ksc
PROJECT	BEKER GYPSUM	SOIL TYPE	GRAY GYPSUM	u_o = 3.0 ksc

CYCLIC TRIAXIAL STRENGTH TEST SUMMARY

CYCLE NUMBER	AVERAGE CYCLIC SINGLE AMPLITUDE VERTICAL STRESS kg/sq cm	STRESS RATIO	MAXIMUM SHEAR STRESS kg/sq cm	DOUBLE AMPLITUDE STRAIN %	PORE PRESSURE RATIO $\Delta u/\bar{\sigma}_{3c}$
1	2.116	0.529	1.058	0.1	0.350
2	2.116	0.529	1.058	0.3	0.425
4	2.116	0.529	1.058	0.4	0.525
10	2.116	0.529	1.058	0.7	0.675
20	2.081	0.520	1.040	0.8	0.825
40	2.046	0.512	1.023	1.5	1.000
45	2.046	0.512	1.023	2.3	1.000
53	2.046	0.512	1.023	4.7	1.050
61	2.046	0.512	1.023	10.1	1.050
73	2.029	0.507	1.014	21.1	1.050

FH0029218

GEOTECHNICAL ENGINEERING LABORATORY

MARSHALL L. SILVER P.E.

DATE 25 APRIL 78 JOB NO.

PROJECT BEKER GYPSUM

LOCATION

BORING NO. SAMPLE NO. G-6

DEPTH OF SAMPLE

SOIL DESCRIPTION GRAY GYPSUM

SAMPLE CHARACTERISTICS

	INITIAL	AFTER CONSOLIDATION
AVERAGE DIAMETER	60.7 mm	60.7 mm
AREA	2892.84 sq.mm	2896.08 sq.mm
HEIGHT	150.4 mm	149.6 mm
WEIGHT	723.94 gm	762.8 gm
WET UNIT WEIGHT	1.664 gm/cc	1.760 gm/cc
WATER CONTENT	22.0 %	28.5 %
DRY UNIT WEIGHT	1.364 gm/cc	1.370 gm/cc

MARSHALL L. SILVER P.E.

DATE	25 APRIL 78	LOCATION		$\bar{\sigma}_{3c}$ = 1.0 ksc
JOB NO.		SAMPLE NO.	G-6	σ_{3c} = 4.0 ksc
PROJECT	BEKER GYPSUM	SOIL TYPE	GRAY GYPSUM	u_o = 3.0 ksc

CYCLIC TRIAXIAL STRENGTH TEST SUMMARY

CYCLE NUMBER	AVERAGE CYCLIC SINGLE AMPLITUDE VERTICAL STRESS kg/sq cm	STRESS RATIO	MAXIMUM SHEAR STRESS kg/sq cm	DOUBLE AMPLITUDE STRAIN %	PORE PRESSURE RATIO $\Delta u/\bar{\sigma}_{3c}$
1	1.036	0.518	0.518	0.1	0.600
2	1.001	0.501	0.501	0.1	0.620
4	1.001	0.501	0.501	0.1	0.670
10	1.001	0.501	0.501	0.3	0.800
20	0.984	0.492	0.492	0.5	0.900
39	0.984	0.492	0.492	0.9	1.000
56	0.984	0.492	0.492	2.3	1.000
65	0.967	0.483	0.483	4.7	1.100
79	0.932	0.466	0.466	10.1	1.100
103	0.984	0.492	0.492	20.4	1.100

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