CREEP PROPERTIES OF GYPSUM ROCK UNDER TRIAXTAL LOADING

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خاصية الزحف لحجز الجبس المعرض للقوى من الانجاهات الثلاث

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خلاصة المقالة

في اعمال اسس المنشآت الهندسية والمناجم وانفاق الطرق والمياه تكون الصخور في الطبيعة تحت ضغوط وقوى مسلطة عليها من جميع الانجاهات . لذلك عند دراسة خواصها الميكانيكية لاغراض تصميمية او تنفيذية يجب محاولة جعل ظروف فحص النماذج منها مشابهة للظروف الطبيعية التي تتعرض لها تلك الصخور.

على ضوء ماورد تم اجراء بحث لدراسة تصرف وزحف نماذج من حجر الجبس تحت تأثير قوى مختلفة سلطت عليها من جميع الانجاهات وقد استعمل في البحث جهاز خاص سبق وان اعطيت تفاصيله في بحث سابق للمؤلفين(٤) .

لقد سلطت قوى مختلفة ولمدد متفاوتة على عدة نماذج من الحجر المذكور وتم ايجاد معادلات تعكس تصرف هذا النوع من الصخور تحت هذه الظروف .

هذا وقد تم اختيار حجر الجبس للبحث لكثرة وجوده في المنطقتين الغربية والشمالية الغربية من القطر العراقي ولانه نموذج جيد للصخور الرسوبية . .

ان هذا البحث هو بداية لدراسة طويلة ستجرى لتحديد ومعرفة الخواص الميكانيكية للصخور العراقية للحاجة الضرورية لهذه المعرفة لاي تصمم انشائي يتعلق بهذه الصخور باي شكل من الاشكال .

1. Introduction

In many circumstances in the mining and civil Engineering industries, knowledge of the conditions under which rock failure and deformation occurs is of vital importance for safe working. Much rock testing has been done on a short term basis, in which simple, bending of rock beams, uniaxial and traixial compressive loading etc. has been used. Generally, studies of the time dependent or "creep" behaviour of rock have been somewhat limited because of the difficulties associated with carrying out such long term tests. Also, most investigators, studying creep phenomena in rocks have used simple stress systems, e.g. beam bending, (5) uniaxial compression etc. Since in practical circumstances the bulk of the rock material inside mine pillars, in the surrounding regions of an excavation, or beneath a foundation is in fact triaxially loaded over long time periods, it was felt that studying the creep phenomena of some evaporite rocks under a triaxial system of loading could add valuable information to the limited knowledge available on rock behaviour in such conditions. Gypsum was chosen initially as a suitable evaporite rock which is found all over the world (for example, it is found in west and north of Iraq; Yorkshire, U.K; etc) for carrying out this work, cylindrical core specimens drilled perpendicular to rock bedding being used in this investigation.

2. Apparatus

The apparatus used is described in detail elsewhere. (Williams and Elizzi (4). The following is thus a brief description of the equipment. It consists, mainly, of three parts, Figs (1) and (2):

1) Pressure source and control system.
2) The pressure cell.
3) Load and displacement measurement system.

1) Compressed nitrogen was used as a suitable source for both axial and confining pressures. Each

section of this system consists of automatic pressure control valves (c and f) Figs. (1) and (2), pressure gauges (a, h and j) and a blow-off valve (e), an automatic relief valve (g) being provided in the confining pressure section of the system. Suitable intensifiers were used to obtain the required pressures in both the axial (l and m) and the confining (k) systems from the controlled nitrogen pressure. The high pressure sides of these intensifiers are connected to the confining pressure cell and are thus filled with hydraulic oil.

2) The pressure cell is a 341 mm long by 100mm diameter stainless steel cylinder (n) the head of which is the second axial intensifier (m) while its base is fitted with some twenty insulated sockets and leads which are carried through the base via an epoxy resin sealed hole enabling external connections to be made to strain gauges and LVDT's within the cell.

3) The axial load applied to the specimen can be otained from the measured gas pressure and the ratio of the axial intensifiers, which is 9:1, and then allowing for some less easily defined frictional losses at the oil seals in the pistons. However, a more accurate method was used for determining this by measuring the output of the system of strain gauges mounted on a calibrated load cell within the pressure cell. This load cell also forms the specimen seat. The confining pressure can be read directly on the pressure gauge (j).

The strain was measured in the middle third of the rock specimen by means of three linear variable differential transformers (LVDT's) mounted around the specimen at 120° intervals. The LVDT's are connected together via a balancing circuit, the output being obtained externally via the sockets in the cell base.

The displacement readings are then obtained by the use of a transducer multimeter. The LVDT system is not temperature sensitive and the devices can be allowed to operate unprotected in hydraulic oil at high confining pressure. The system has very high stability and freedom from drift.

3. Experimental Procedure

A series of 75mm long by 25mm diameter nominal size cores of gypsum were drilled from manageable sized pieces of rock obtained from site. The drilling was perpendicular to rock bedding. After the end faces were finished on a lapping machine to give smooth surfaces accurately perpendicular to the sample axis, the specimens were left to be air dried. Oven drying was avoided to ensure that no water of crystallisation was lost from the specimens. Each specimen then was jacketed in a P.V.C. tube, the ends of which extended over two steel platens of the same diamter as the specimen to prevent any direct contact between the sample and the surrounding oil. The LVDT's were then accurately positioned and clamped around the sample, a special jig being used in this operation. Leads from the LVDT's and balancing circuit were plugged into the base sockets, and finally the sample was placed on the specimen seat (load cell) in the pressure cell.

Following insertion of the specimen into the cell the system was filled with hydraulic oil and zero readings were checked for both load and displacement systems.

By operating the gas pressure control valves (f) and (c) the confining pressure and the axial load were increased to the required values. The reading of the displacement at the end of the loading operation was considered as the instantaneous deformation of the specimen. Afterwards many readings were recorded at known intervals of time to reveal the creep behaviour of the rock.

4. Experimental results

Several short term triaxial tests were first carried out on gypsum speciments under different confining pressures. The data obtained from these tests are given in table (1).

It can be seen that the ultimate strength of gypsum increases as the confining pressure increases.

This relationship is non—linear as shown in Fig.3.

Three confining pressure levels, namely, 10, 20 and 30 MPa were used in carrying out the creep tests and at each pressure tests were carried out at axial loads equal to 30 %, 50 %, 65 % and 80 % of the short term failure load at that confining pressure.

The creep curves obtained at different confining pressures are shown in Figs. 4, 5 and 6.

Plotting the data obtained on semi—long and log—log graphs in order to determine the equations of these curves, gave the following results:

1) At 10 MPa confining pressure and axial stress 30 % of the short term strength the creep curve followed two laws:

(a) Up to 24 hours following commencement of loading the creep curve followed a relationship of the form suggested by Griggs[1] $\varepsilon = A + n \log t$, in which

ε = creep strain

A = creep strain at t = 1

n = slope of the straight line on the semi—log plot

t = time in hours.

In this case, A = 38.2 and n = 22.7

(b) At times greater than 24 hours the creep curve followed a power relationship of the form $\varepsilon = Bt^m$. In which

ε = creep strain

B = creep strain at t = 1

m = slope of straight line on the log—log plot

t = time in hours

This is in agreement with Comte[2] in his work on artificial rock salt.

2) At higher confining pressures the creep curves followed the power relationship $\varepsilon = Bt^m$ at all levels of axial stress throughout the tests.

3) A summary of the values of the constants obtained for the creep strain relationships is given in Table 2. The values of creep rate at various times is provided in Table 3.

5. Discussion and Conclusion

From these results it can be observed that:

1) At any confining pressure the constants (B and m) of the power equation increase as axial stress increases.

2) At axial stresses corresponding to constant percentages of the short term atrength, both B and m increase as the confining pressure increases.

3) At a constant axial stress the values of B, m and creep rate at any time decrease with increase in confining pressure. Fig. 7 shows the effect of confining pressure on creep rate of gypsum at constant axial stress.

4) With a constant differential stress ($\sigma_1 - \sigma_3$), it can be seen that as the confining pressure increases, the values of B, m and the creep rate at any time incerease by variable ratios. For example, Fig. 8 shows that at a differential stress of 37 MPa, as the confining pressure increases from 10 MPa to 30 MPa, the value of B increases by about 30 % and the value of m increases by about 9 % while the rate of creep at t = 240 hr increases by almost 60 %.

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Table (1)

Ultimate compressive strength (σ_u) of gypsum in short term triaxial tests.

No. of Specimens Tested	Conf. Press. MPa	Mean Ultimate Strength, (σ_u) MPa
8	0	57.46
3	5	73.97
5	10	92.07
3	15	102.51
5	20	114.58
3	25	128.37
6	30	136.44
3	35	147.80

TABLE (2)

Values of Constants in Creep Strain Equations for Gypsum Rock

Axial Stress as % of Short Term Failure Stress.	Confining Pressure MPa					
	10		20		30	
	B	m	B	m	B	m
30	44.9*	0.134*	62.1	0.199	69.4	0.214
50	74.2	0.250	83.3	0.267	94.6	0.273
65	107	0.285	118.4	0.288	131.7	0.307
80	140.1	0.307	148.3	0.313	164.2	0.344

$$\varepsilon = Bt^m \times 10^{-6}\ \mu S$$

*After 24 hrs., up to 24 hrs., $\varepsilon = (38.2 + 22.7 \log t) X 10^{-6} \mu S$

TABLE (3)

Rate of creep strain at different values of t, $\varepsilon = Bt^m$

Conf. Press. MPa	$\frac{\sigma_1}{\sigma_u} \times 100$ percent	Equation constants B $\times 10^{-6}$	m	Creep rate after t hours from loading, microstrain per hour 1 hr	12 hr	24 hr	120 hr	240 hr	360 hr	480 hr	600 hr
10	30	34.9	0.134	5.58 *	1.89 *	0.95 *	0.08	0.05	0.03	0.03	0.02
	50	74.2	0.250	18.55	2.87	1.71	0.51	0.30	0.22	0.18	0.15
	65	107.2	0.285	30.58	5.16	3.15	1.00	0.61	0.55	0.37	0.32
	80	140.1	0.307	43.10	7.68	4.76	1.56	0.97	0.73	0.60	0.51
20	30	62.1	0.199	12.52	1.69	0.97	0.27	0.15	0.11	0.09	0.07
	50	83.3	0.267	22.40	3.61	2.18	0.67	0.40	0.30	0.24	0.21
	65	118.4	0.288	34.10	5.81	3.54	1.13	0.69	0.52	0.42	0.36
	80	148.3	0.313	46.40	8.41	5.23	1.73	1.08	0.82	0.67	0.57
30	30	69.4	0.214	14.85	2.15	1.22	0.34	0.20	0.15	0.12	0.10
	50	96.4	0.273	26.28	4.32	2.61	0.81	0.49	0.37	0.30	0.25
	65	131.7	0.307	46.20	8.25	5.12	1.67	1.04	0.78	0.64	0.55
	80	164.2	0.344	56.50	11.08	7.03	2.44	1.55	1.19	0.98	0.85

* The creep curve in these periods follow the logarithmic equation $\varepsilon = A + n \text{ Log } t$

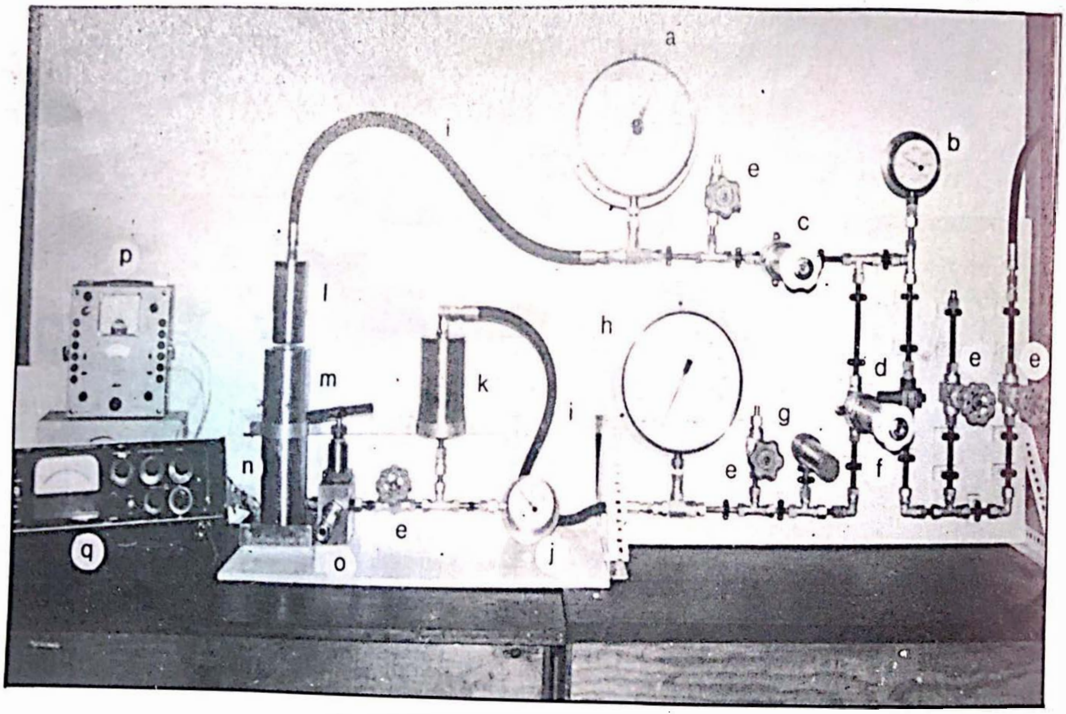


Fig. 1. Triaxial Creep Apparatus

a. Axial pressure gauge (N_2)
b. Nitrogen bottle gauge pressure
c. Axial pressure control valve
d. Filter
e. Shut off valve
f. Confining pressure control valve
g. Automatic relief valve
h. Confining pressure gauge (N_2)
i. High pressure hose
j. Confining pressure gauge (oil)
k. Confining pressure internsifier
l. Axial load intensifier
m. Pressure cell head
n. Triaxial cell
o. Oil inlet valve
p. Strain gauge indicator
q. Transducer multimeter

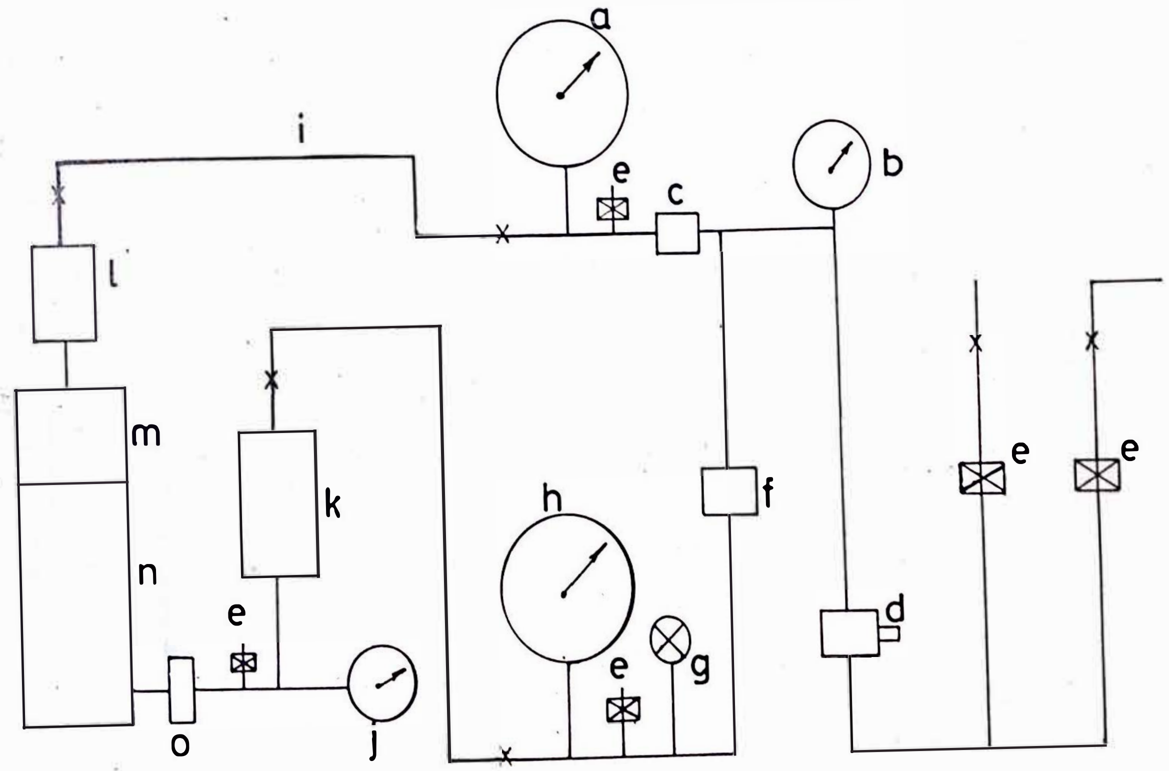


FIG 2 Schematic diagram of creep apparatus (for symbols see Fig1)

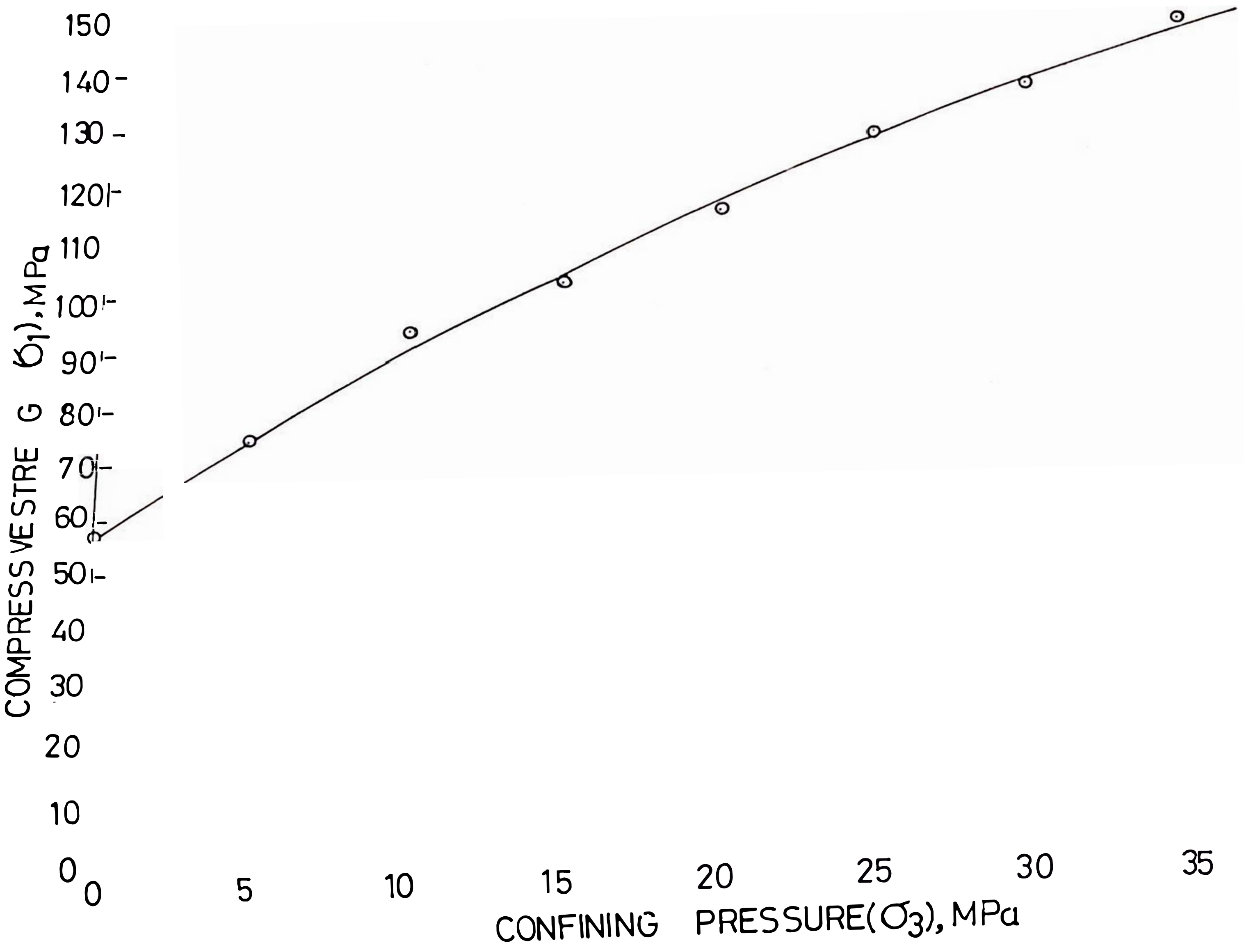


FIG.3. COMPRESSIVE STRENGTH OF GYPSUM AT DIFFERENT CONFINING PRESSURES

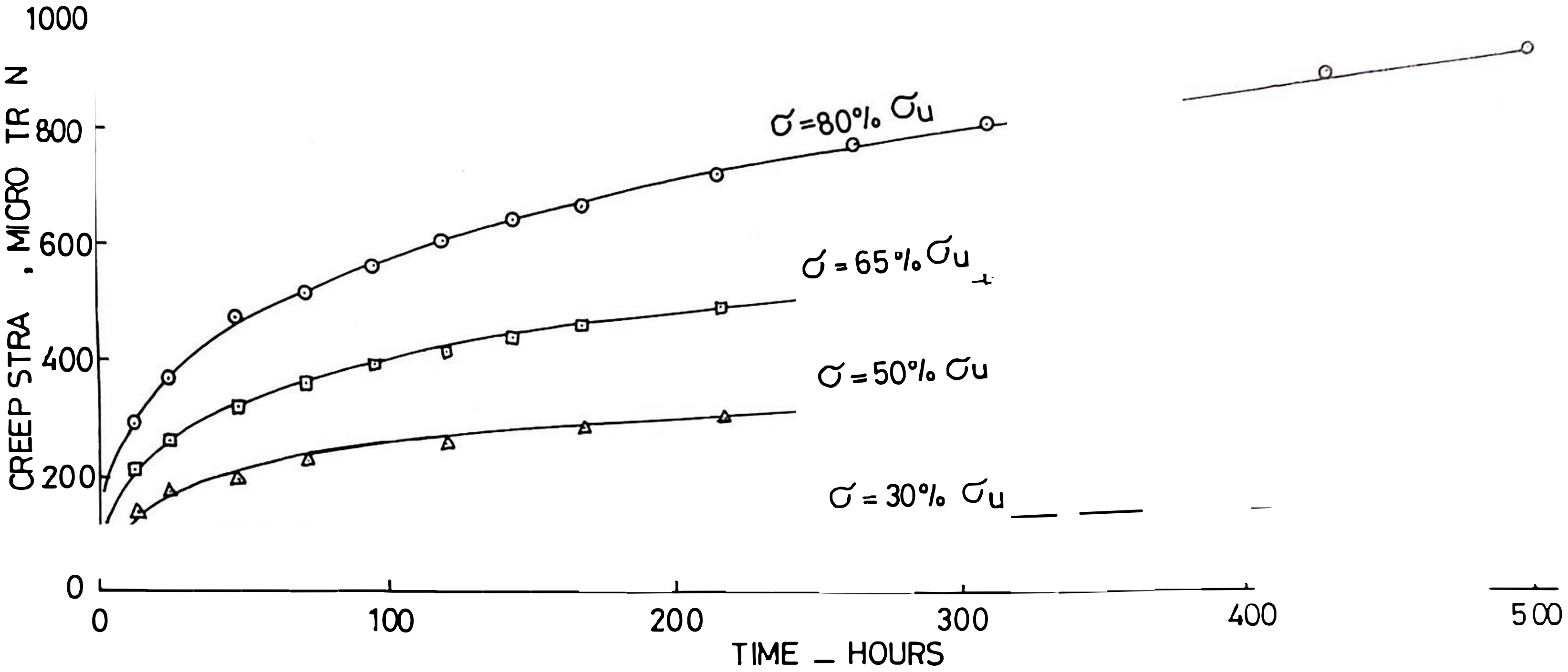


FIG. 4. CREEP OF GYPSUM IN TRIAXIAL COMPRESSION AT 10 MPa CONFINING PRESSURE

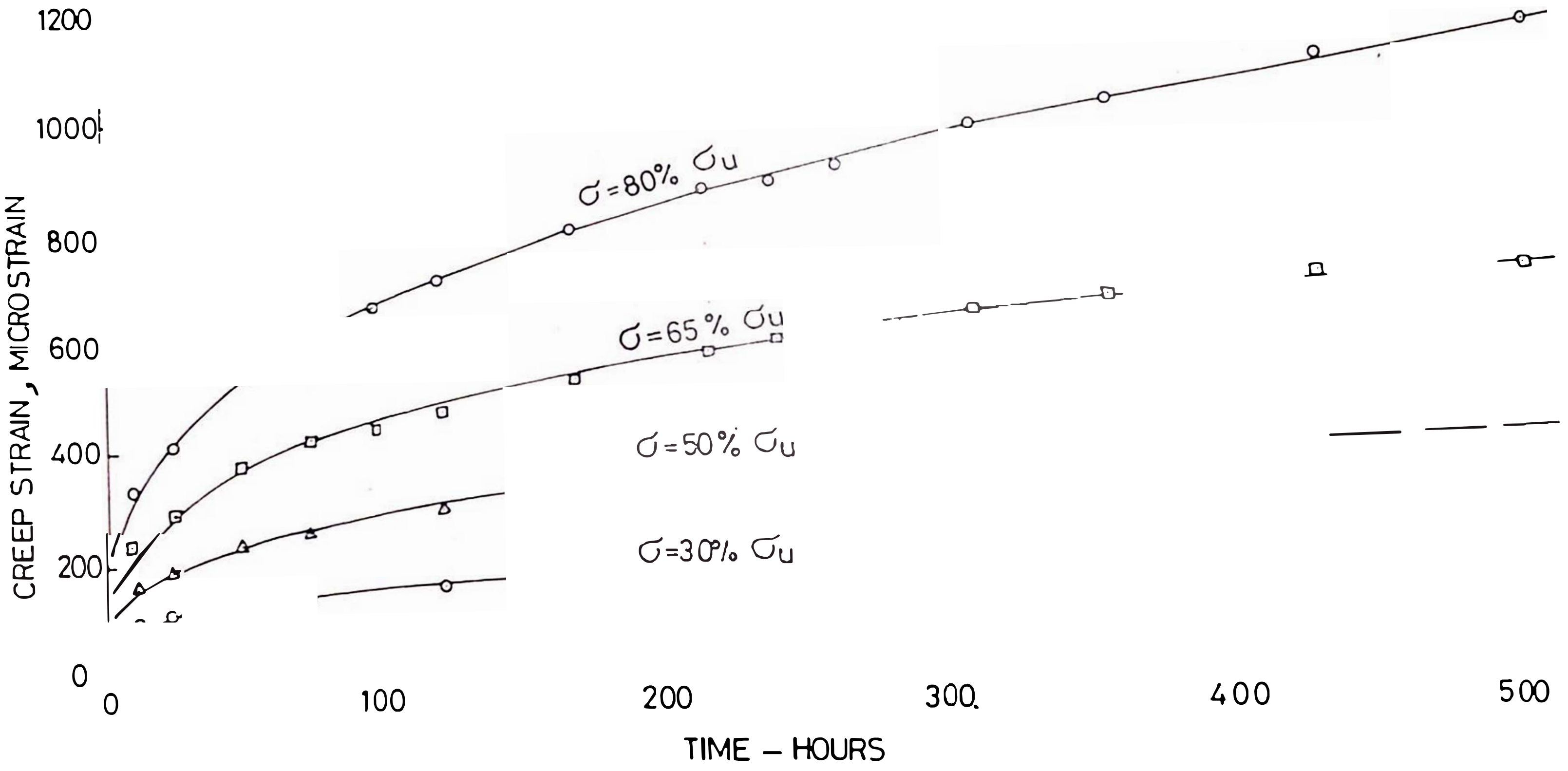
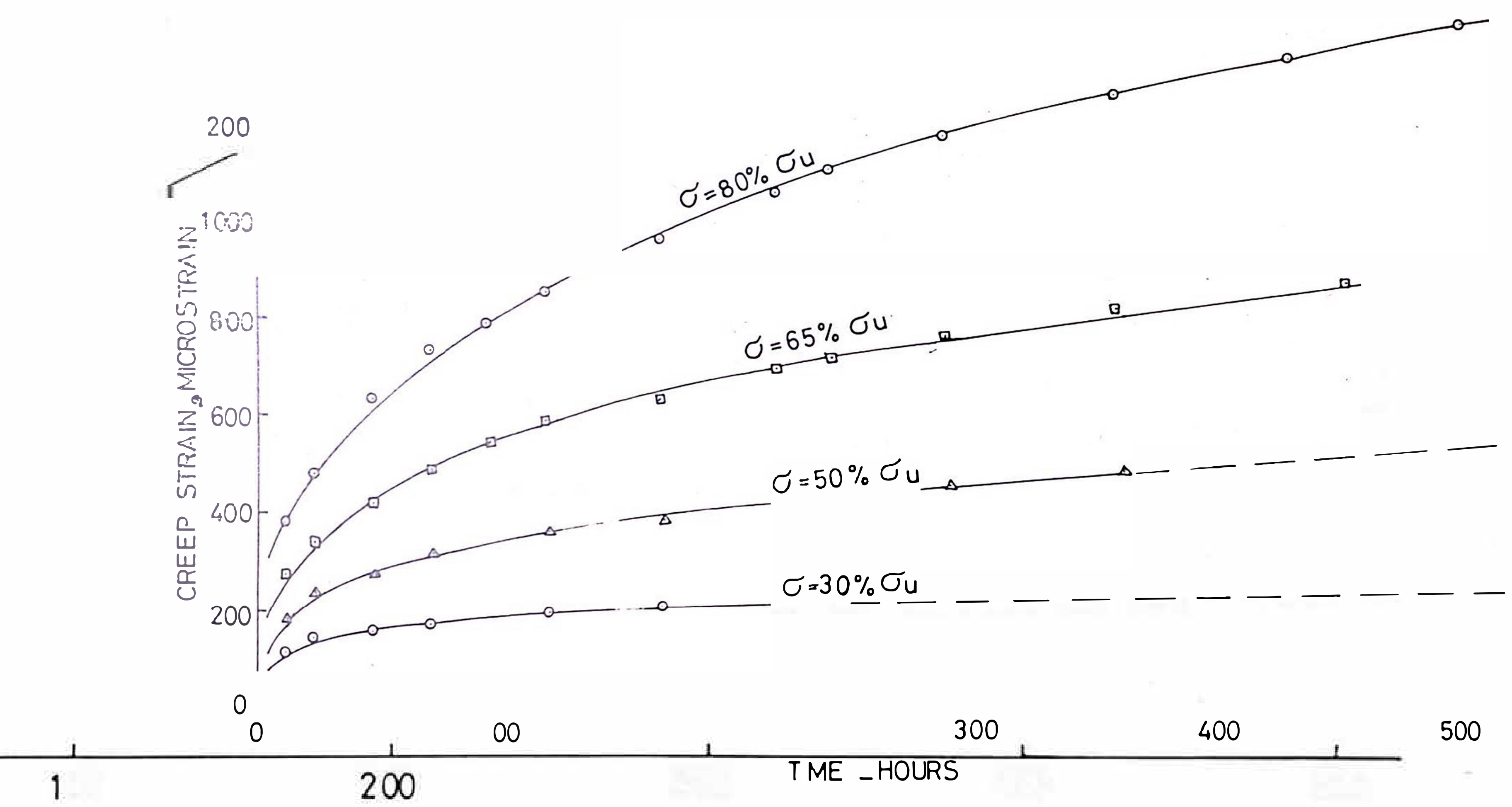


FIG 5 CREEP OF GYPSUM IN TRIAXIAL COMPRESSION AT . 20 MPa CONFINING PRESSURE



F G 6 CR EP O G PS M N AX PRESS ON AT 30 MPa CON NI G PRE URE

Y U I TRI IAL COM I FI N SS

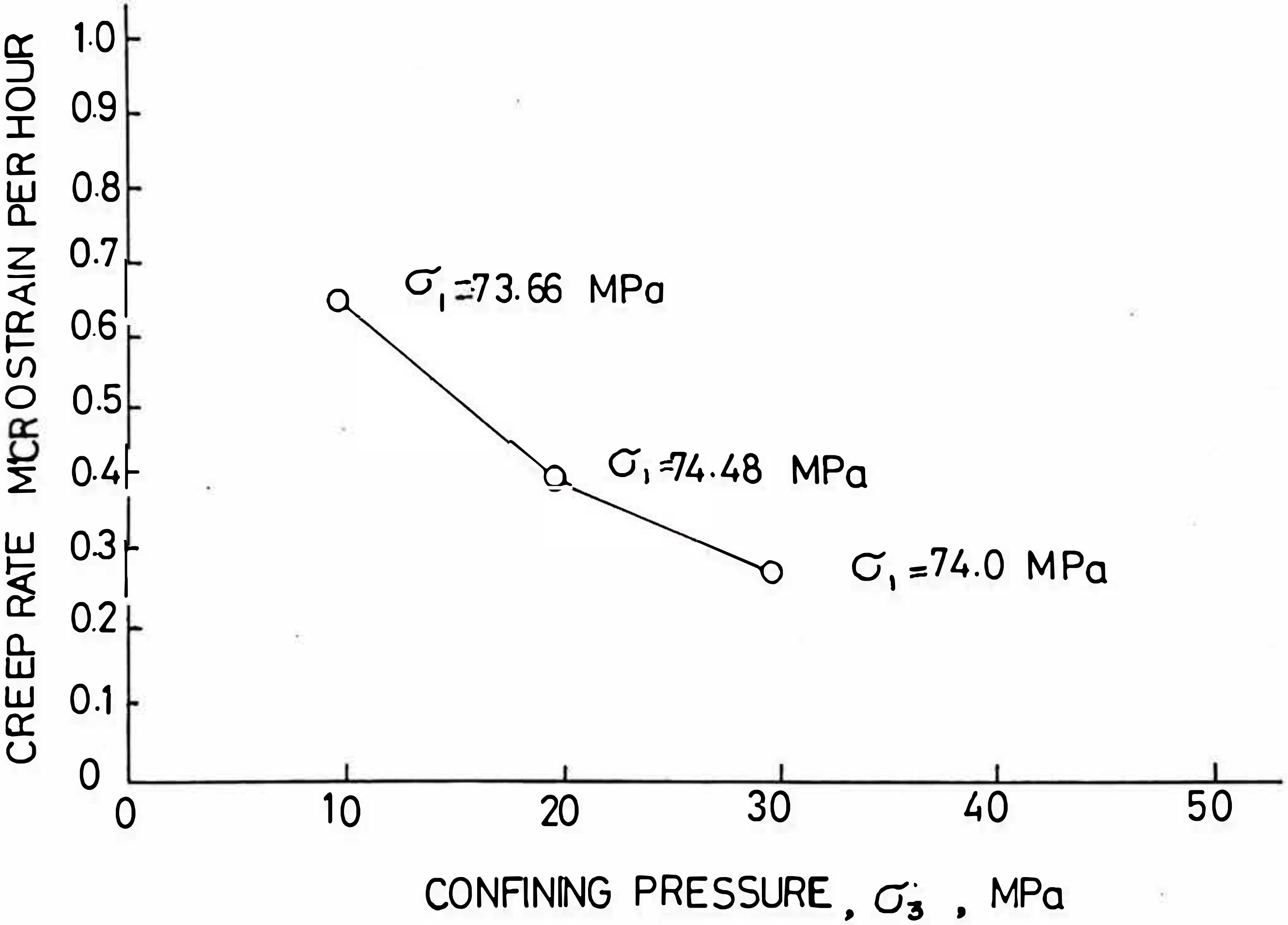


FIG.7. EFFECT OF CONFINING PRESSURE ON CREEP RATE FOR THE PERIOD 480 → 600hr AFTER LOADING

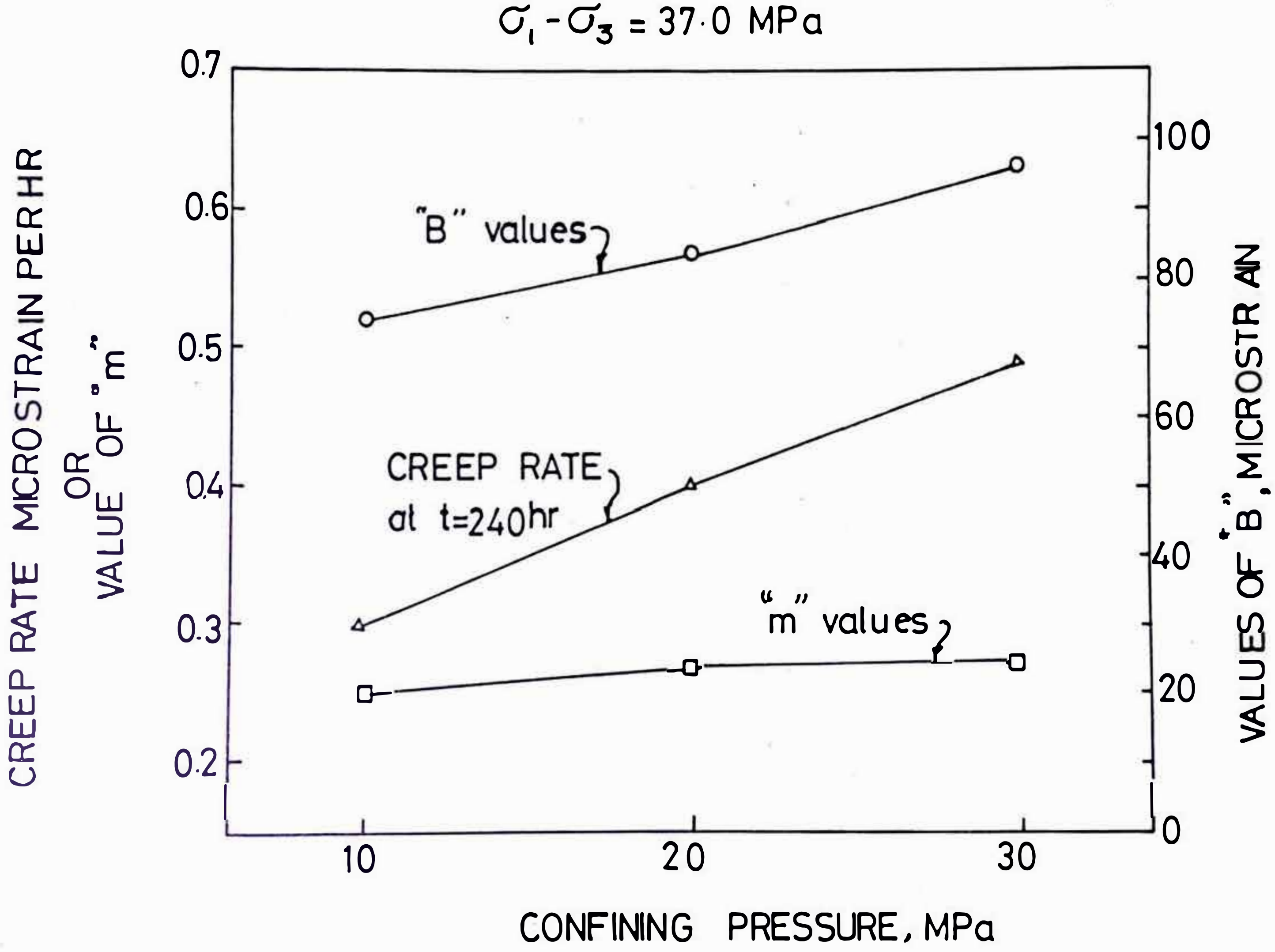


FIG 8 EFFECT OF CONFINING PRESSURE ON "B", "m" AND CREEP RATE AT CONSTANT $(\sigma_1 - \sigma_3)$