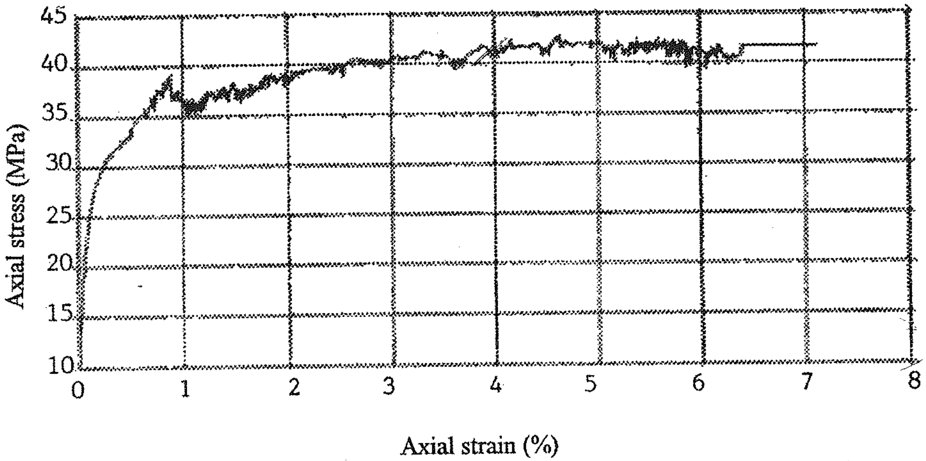
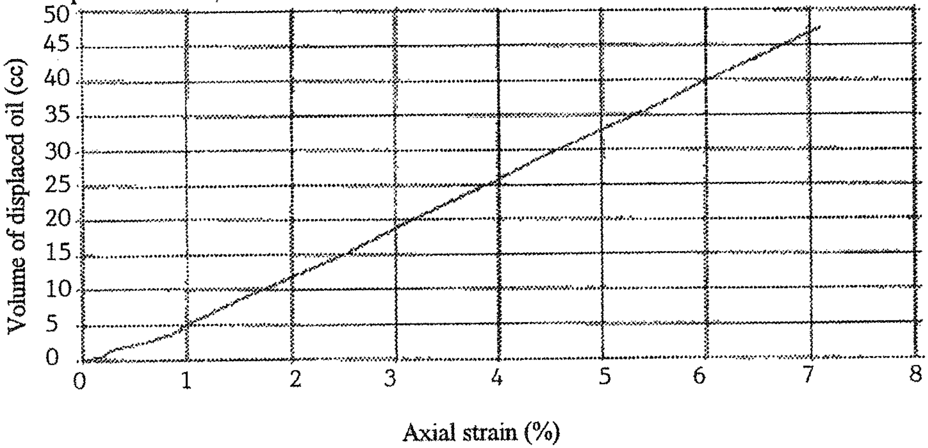
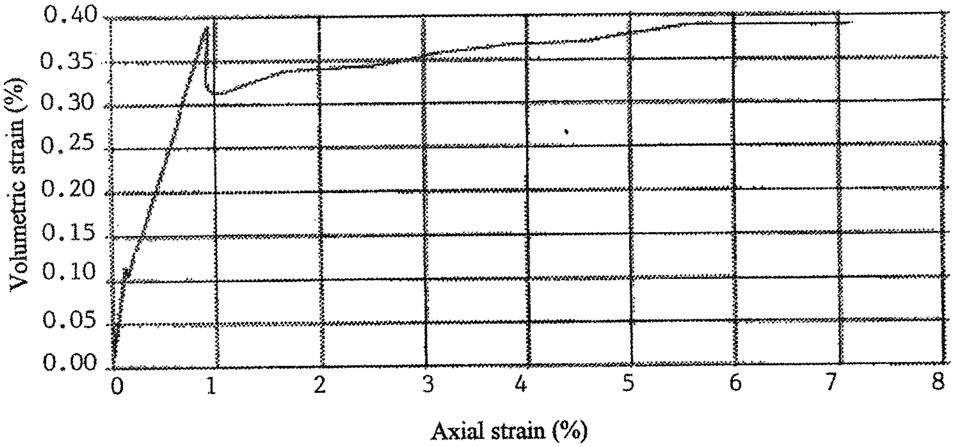


Stress-strain plot for a jointed specimen, saw cut joint with 60 degrees orientaion, confining pressure = 10 MPa .

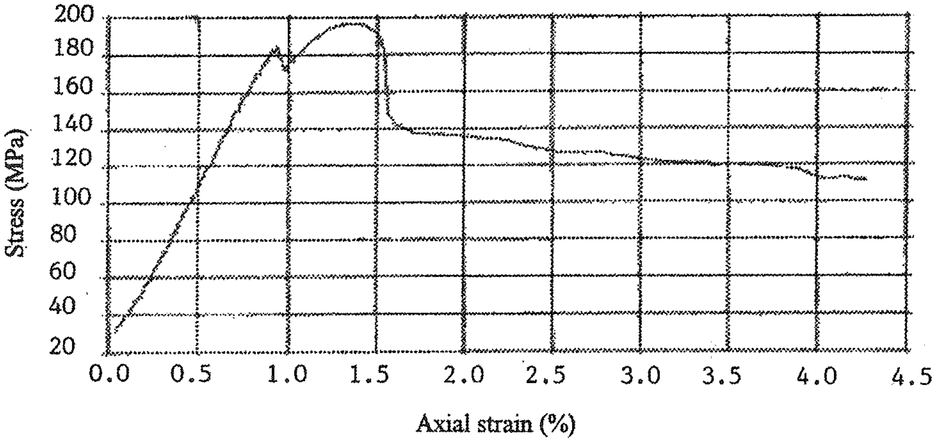


Displaced oil-axial strain plot for a jointed specimen, confining pressure = 10 MPa, joint type, saw cut with 60 DEG . orientation .

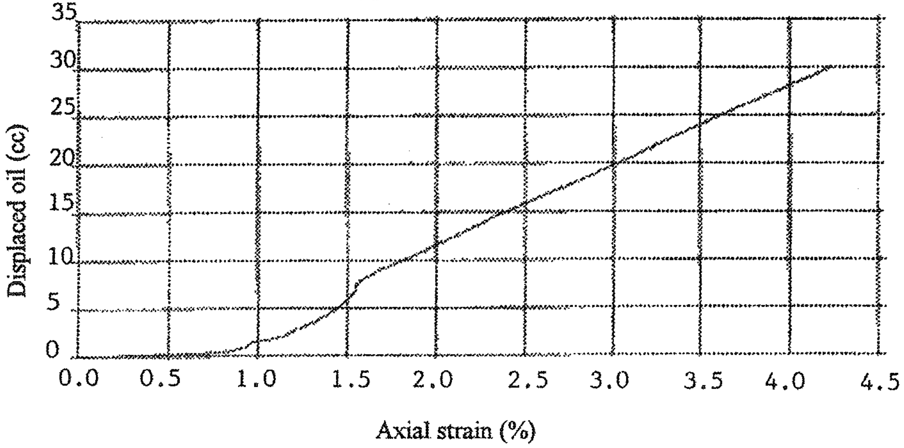


Volumetric strain-axial strain plot for a jointed specimen . Type of joint, saw cut, joint inclination = 60 degrees, confining pressure = 10 MPa

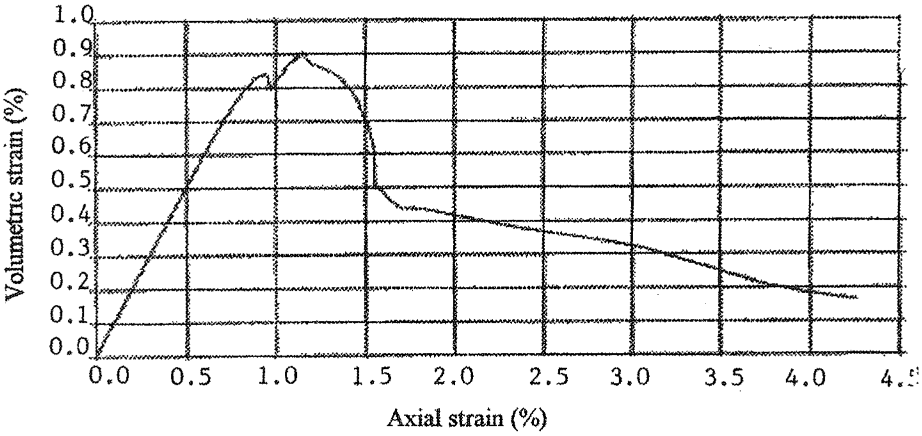
Figure (3) Typical Plots **Illustrating** the Correlation Between Axial Stress, Axial Strain And Volumetric **Changess** for a Saw Cut Jointed Specimen



Stress-strain plot for a jointed specimen, type of joint: natural with 45 DEG . inclination conlintion confining pressure = 15 MPa

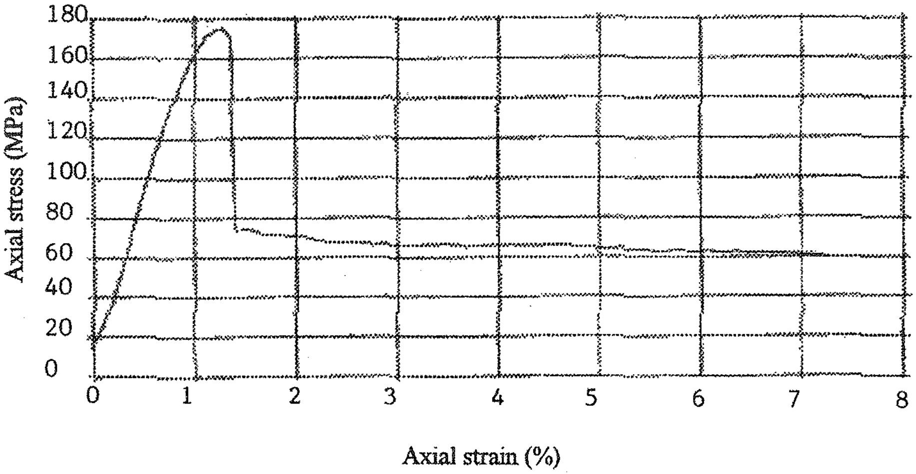


Displaced oil-axial strain plot for a jointed specimen, joint type, natural with 45 DEG inclination, confining pressure = 15 MPa .

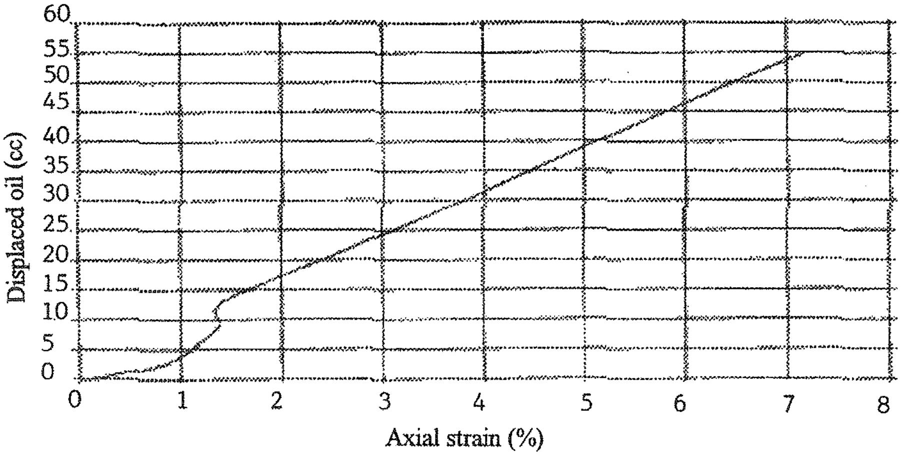


Volumetric stain-axial strain plot for a jointed specimen, type of joint, natural with 45 DEG. inclination, confining pressure=15 MPa

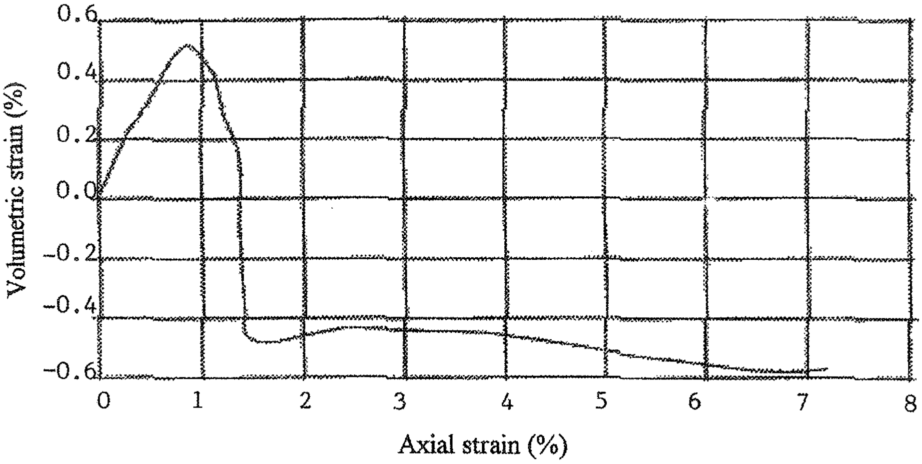
Figure (2) **Typical** Plots Illustrating The Corelation Between Axial **Stress, Axial** Strain and Volumetric Changes for a Naturally Jointed **Specimen.**



Stress-strain plot for an intact specimen, confining pressure = 15 MPa .



Displaced oil-axial strain plot for an intact specimen, confining pressure =15 MPa .



Volumetric strain-axial strain plot for an intact specimen, confining pressure =15 MPa

Figure (1) Typical Plots Illustrating the Correlation Between Axial Stress, Axial Strain and Volumetric Changes for an Intact Specimen

$$\nu = 1/2\,[1 - (\Delta V/V)/\varepsilon_1] \qquad (14)$$

Figures (1) to 3 illustrate three typical plots for and intact rock speciment (figure 1) and two artificially (saw cut) and naturally jointed specimens obtained through triaxial tests performed by the auther using a 5 MN servo-controlled stiff testing machine (Fahimifar, 1990). The middle plot in each figure was obtained directly by plotting the displaced oil from the triaxial cell versus the axial displacement (axial strain) for each test. The third plot in each figure shows the volumetric strain-axial strain curve which was obtained by a series of calculations based on the proposed method in this paper and using the displaced oil as row data in these calculations. The first plot shows the axial stress-axial strain curve for each test which is independent of the middle plot. Comparison of the three plots in each figure reveals that there is a very close correlation between the axial stress-axial strain and volumetric strain-axial strain plots for three types of intact and jointed specimens which is in fact an indication of a very high accuracy of the method for both intact and jointed specimens.

For the simplified case a program was written to calculate the volumetric strain lateral strain and instantaneous Poisson's ratio, and the plots in figures 1 to 3 obtaind by using this program.

Summary and Conclusions

An accurate approach for strain measurement on rock in constant confining pressure is described. The method is particulary useful where strain gages can not be employed, for example, on wet specimens, discontinuous specimens or when large strains are encountered. Typical plots obtained through triaxial tests performed on the basis of this technique indicate very good correlation between volumetric, axial and latteral strains for both intact and jointed specimens.

References:

[1]. Bridgman P. W., 1949, Volume changes in the plastic stages of simple compression, J. Sci., 15, 287- 96.

[2]. Crouch S. L., 1970 a, Experimental determination of volumetric strains in failed rock, Int. J. Rock Mech. Min. Sci., 7, 589-3.

[3]. Crouch S. L., 1972 a, A note on post failure stress-strain path dependence in norite, Int. J. Rock Mech. Min. Sci., 9, 197-4.

[4]. Fahimifar A., 1990, Experimental investigations on the mechanical properties of rocks containing a single discontinuity, Ph. D Thesis, Newcastle Upon Tyne, University, U. K.

[5]. Obert L. and W. I. Duvall., 1967, Rock mechanics and the design of structures in rock, Wiley, NewYork.

[6]. Paterson M. S., 1978, Experimental rock deformation-the brittle field, Springer-Verlag, printed in Germany.

[7]. Price A. M., 1979, The effect of confining pressure on the post-yield deformation characteristics of rocks, Ph. D. Thesis, University of Newcastle Upon Tyne.

[8]. Wawersik W. R., 1975, Technique and apparatus for strain measurements on rock in constant confining pressure experiments, Rock Mechanics, 7, 23-41.

Taking into account the elastic deformation of the ram entering the cell, V_R, is given by:

$$V_R = \pi r^2 l - \Delta V_R \qquad (3)$$

Where

r=Ram radius
l=Measured displacement of the ram and
ΔV_R=Volumetric change of the ram.

DV_R is given by (Obert and Duval, 1967).

$$\Delta V_R = \frac{\pi r^2 . l}{E} (\sigma_1 + 2\sigma_3)(1 - 2\nu_s) \qquad (4)$$

Compression is taken as positive.

To obtain the displaced oil related to volumetric change of the system (cell, O-ring, rubber membranes and platens) a series of triaxial calibration tests must be carried out on a cylinder of a material of known elastic constants (such as steel, aluminium and so on) of the same dimensions and confining pressures as the rock specimens. In this case, the volumetric change corresponding to the system, V_{sys} is given by:

$$V_{sys} = V_c . f - (\Delta V_s + \Delta V_{ro}) \qquad (5)$$

where

V_c=Displaced oil through the calibration test.
f=Oil compressibility factor
ΔV_s=Volumetric change of steel cylinder
ΔV_{ro}=Volumetric change of the loading ram in calibration test.

ΔV_s and ΔV_{ro} are given as (Obert and Duval, 1967):

$$\Delta V_s = \frac{\pi r_s^2 . H_s}{E} (\sigma_1 + 2\sigma_3)(1 - 2\nu_s) \qquad (6)$$

$$\Delta V_{ro} = \frac{\pi r^2 l_s}{E} (\sigma_1 + 2\sigma_3)(1 - 2\nu_s) \qquad (7)$$

where

r_s=Radius of the steel cylinder
H_s=Specimen height
l_s=Measured axial displacement of the ram in calibration test
E and ν_s are steel's modulus of elasticity and poison's ratio.

Substituting equations 6 and 7 in 5, and 4 in 3 and then, the resultant equations in 2, the volumetric strain of the rock specimen (in%) is given by:

$$\Delta V/V = 100/V\, [(V_0 - V_c) . f - \pi r^2 . l + \pi/E\, (\sigma_1 + 2\sigma_3)(1 - 2\nu_s)(r_s^2 . H_s + r^2 . l_s + r^2 . l)] \ \% \qquad (8)$$

In a simplified case, where confining pressure is not very high (below 70 Mpa) the elastic deformation of system may be neglected, and therefore, volumetric strain is given by:

$$\Delta V/V = 100/V\, \{f . V_0 - \pi r^2 . l\, [1 - (1 - 2\nu_s)(\sigma_1 + 2\sigma_3)/E]\} \ \% \qquad (9)$$

where

V=the specimen original volume.

The average axial strain of the specimen, ε_1, is given by:

$$\varepsilon_1 = 100 l/L\, [1 - (\sigma_1 - 2\nu_s . \sigma_3)] \qquad (10)$$

where

L=the original specimen length.

Using the equation (Jaeger and Cook, 1979):

$$\Delta V/V = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 \qquad (11)$$

That reduces here to:

$$\Delta V/V = \varepsilon_1 - 2\varepsilon_2 \qquad (12)$$

Radial strain, ε_2 is given by:

$$\varepsilon_2 = 1/2\, (\varepsilon_1 - \Delta V/V) \ \% \qquad (13)$$

and instantaneous Poisson's ratio, ν, is given by:

In addition, all of the techniques are nearly impossible to use in triaxial testing of jointed specimens successfully, where a large shear and normal displacements occurs through the joint. There is, however, a technique as described in the following,which is practical to use on jointed specimens tested triaxially for small and large sliding movements.

Principle of the Technique

The technique based on the principle that when a specimen immersed in a full fluid vessel and is stressed, its volume changes; the volumetric change can be measured directly by collecting the displaced liquid in a graded cylinder. In a triaxial test, with a constant confining pressure, application of axial load to the specimen results in axial and radial deformations. If the system is closed, and therefore the amount of confining fluid is held constant, as the stress is raised a change in confining pressure occurs. If the confining pressure is to be maintained constant, as indeed is expected from this type of tests, it is important to allow a certain amount of the confining fluid to be removed from the system. The quantity of the fluid is proportional to the changes in volumetric strain, and by monitoring continuously the amount of fluid during the test one can calculate the change in volumetric strain that the specimen suffered during the test.

Bridgman (1949) used this method for the first time by using a dilatometer in his testing system. Since 1949 this technique has been adopted by different workers (Crouch, 1970 a, 1972 a; Wawersik, 1975; Price, 1979), and has successfully been used in triaxial test by designing and employing appropriate apparatus in order to control and measure the volume change.The technique of strain measurement described in this paper chooses the same basic approach but is shown to be very accurate and more versatile for both intact and jointed specimens.

Measurement Procedure

In measuring the displaced oil due to volume change of the specimen the same apparatus was used as price (1979). The displaced oil is collected in a graded cylinder by adjusting a relief valve manually.

Calculation Procedure

Applying axial load and confining pressure on the specimen deforms not only the specimen, but also the other parts of the system i. e.: loading ram, end platens, triaxial cell, rubber membranes and displaced oil. Therefore, a very accurate procedure to calculate true volumetric, axial, and lateral strains, is required to take into account all the components affected during a test.

As the oil released from the triaxial cell expands, due to the reduction in pressure, the true volume of oil displaced, V_t, is given by:

$$V_t = fV_0 \qquad (1)$$

Where

V_0=The measured volume of oil displaced, and

f=A factor of compressibility, depending upon the type of hydraulic oil which is used in the experiment. It can be taken from the technical notes supplied by productor.

The true volume of oil (V_t) composed of three components:

- -The oil displaced by the loading ram entering the cell (V_R);
- -The oil displaced by the volumetric change of the specimen (ΔV), and
- -The oil displaced by the volumetric change of the system (V_{sys}).

The volumetric change of the system (V_{sys}) includes: the end specimen platens, the O-rings, the rubber membranes, and the triaxial cell. Consequently, the specimen volumetric change is given by the following expression.

$$\Delta V = V_t - (V_{sys} + V_R) \qquad (2)$$

A Technique for Volume Change Measurements in Triaxial Testing of Jointed Rock

A. Fahimifar

Assist. Prof. Dept. of Civil Eng.
Amirkabir University of Technology.

Abstract:

An indirect method to measure volumetric strains on intact rock cylinder and joint deformations in jointed specimens subjected to triaxial compression is described. It relies on the principle that when a specimen immersed in a full fluid vessel and is stressed its, volume changes. For this purpose a 5 MN servocontrolled stiff testing machine was employed and cylindrical specimen were tested triaxially up to 70 MPa.

In measuring the volume change a particular apparatus is connected to triaxial cell and the displaced oil due to volume change of the specimen is collected in a graded cyliner by adjusting a relief valve manually.

A very accurate procedure to calculate the volumetric, axial and lateral strains is presented taking into account all the components affected during a test.

Typical plots obtained through this technique reveals that there is a close correlation between axial stress-axial strain and volumetric strain-axial strain plots for intact and both natural and artificial jointed specimens. The close correlation is in fact an indication of a very good accuracy of the method.

Introduction

Axial, radial and volumetric strains are significant factors to study deformational behaviour and failure mechanism of rocks. Several techniques (directly and indirectly) are available to measure strains on rock specimens subjected to a constant confining pressure. The most commonly used direct method of measuring volumetric strains in the triaxial testing of rock relies on the use of resistance strain gauges which are mounted axially and circumferentially on the rock specimens. This is however, the most convenient method for obtaining the small volumetric strains that occur prior to brittle failure (Paterson, 1978). It has been also indicated that all of the methods, direct and indirect, have the disadvantages of:

a) Only measuring over a limited portion of the specimen and
b) Most are impractical under triaxial conditions (Price, 1979).