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MEMBRANE CORRECTION FOR LATEX AND NEOPRENE/LATEX MEMBRANE AT TRIAXIAL COMPRESSION TEST

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ABSTRACT

The influence of a rubber membrane is crucial in a triaxial compression test. Previous research has introduced methods such as compression shell theory and hoop tension theory to suggest a membrane correction for different types of specimen deformation during tests. Latex membranes often do not perform well if sharp particles are present due to membranes being punctured easily. Neoprene/Latex membranes perform better in triaxial compression tests as they are more resistant to punctures. In this research, a maximum error due to membrane performance was calculated for latex and Neoprene/Latex membranes using two analytical methods. The results indicate that errors for Neoprene/Latex membranes are greater than errors for latex membranes. Numerical modeling of Neoprene/Latex membranes shows that membrane diameter increases approximately linearly with corresponding lateral membrane pressure when specimens deform via buckling.

KEYWORDS: Triaxial Test, Membrane Correction, Neoprene/Latex, Hoop Tension Theory, Compression Shell Theory.

INTRODUCTION

In a triaxial compression test using a soil triaxial cell confining pressure is applied to a specimen via a fluid, where a rubber membrane (between fluid and specimen) encloses the specimen to prevent fluid penetration. Lateral deformation of specimens during tests deforms membranes; membrane resistance to deformation may affect triaxial test results. Previous researchers such as Henkel [1], Duncan [2], Ramana [3], Rochelle [4] and Frost [5] have studied the effects of rubber membranes in triaxial tests; noting that membrane errors may be assumed negligible in some cases. According to ASTM D4767-11 [6] recommendations, membrane errors less than 5% of the deviatoric stress are negligible. Applied confining pressure and thickness of a membrane are parameters that affect rubber membrane behavior during triaxial compression tests (Henkel 1952). Latex membranes have low resistance to deformation and are often chosen for triaxial compression tests. However, latex membranes are weak and can suffer punctures by sharp particles. In triaxial compression tests on broken rock, latex membranes are frequently punctured by sharp particles and the tests fail prematurely. Neoflex (neoprene/latex) membranes are a type of membrane with improved resistance to puncture, making Neoflex membranes more suitable for triaxial compression tests on broken rock.

Henkel [1], Bishop [7] and Baxter [8] recommended a method to determine the mechanical parameters of membranes in tension. This method involved stretching a one-inch wide loop of a membrane and measuring the relative axial deformation. Figure 1 shows a sketch of the method. Equations (1), (2) and (3) are the formula used by the researchers in evaluating parameters.

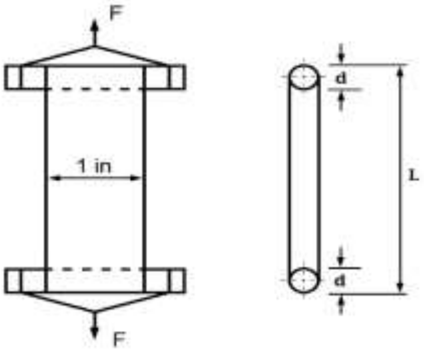

Figure 1. Sketch for measuring extension modulus of a rubber membrane, after Bishop [7]

$$L_m = 2(L - d - 2t) + \pi(d + t) \qquad (1)$$
$$F_{in} = \frac{F}{2} \qquad (2)$$
$$M = \frac{F_{in}}{\varepsilon} \qquad (3)$$

Where F is axial force, d is the diameter of the bar, t is the membrane thickness, L is overall length of the membrane ring in the test, L_m is the mean length of the membrane, F_{in} is the load per inch stiffness, M is the extension modulus of the membrane and ε is membrane axial strain.

Neoprene/latex mixed membranes are generally considered of better performance in triaxial tests on broken rock due to their resistance to puncture by sharp grains. Both latex and Neoprene/latex mixed membranes were investigated in this research work. Figure 2 shows stress-strain curves that were determined via the above method. Figure 3 illustrates Newton per meter stiffness curve for the membranes tested, showing that the latex membranes have lower resistance to deformation than the neoprene/latex membranes.

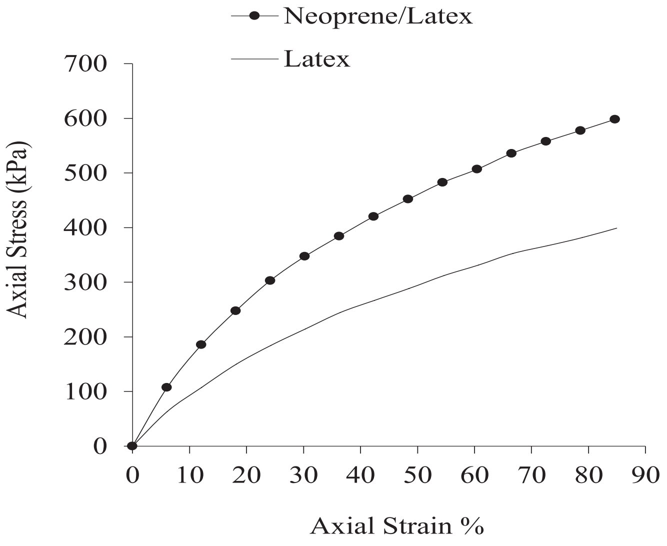

Figure 2. Stress- strain curve of membranes

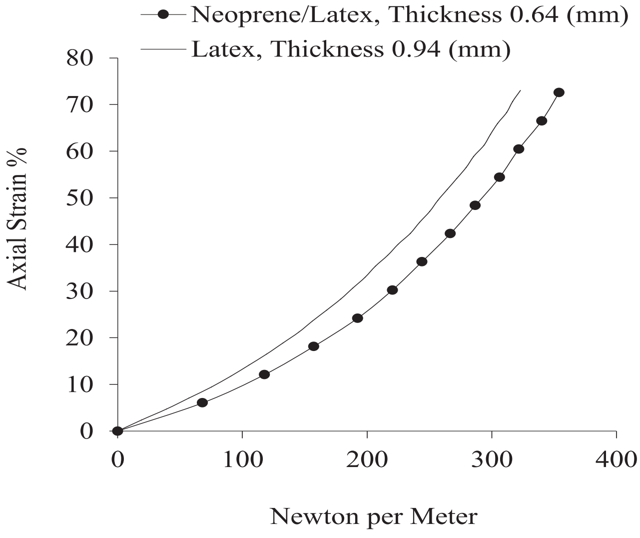

Figure 3. Newton per Meter curve for membrane

To determine a membrane restraint correction, analytical methods have previously been developed based on specimen and membrane deformed shape. Henkel [1], Rochelle [4] and Baxter [8] developed a compression shell theory to determine the deformation of rubber membranes, where the membrane deforms as a cylindrical shell under axial compression and does not buckle during the test. Rochelle [4] believed that at high confining pressure, the membrane would be held tightly in place with respect to the specimen; such that, the membrane and specimen would deform together with no buckling.

Henkel [1] used hoop tension theory to calculate the lateral stress generated at the membrane during bulging deformation in triaxial tests. In buckling, an increased diameter of a specimen caused circumferential tension in the membrane as the membrane resisted lateral deformation of the specimen. The induced lateral tension in the membrane acted as additional incremental confining pressure around the specimen. To correct such a membrane error, the induced lateral tension in the membrane should be added to the cell confining pressure to establish the total effective confinement. In this paper, the lateral resistance of the rubber membrane has been calculated using three different approaches; compression shell theory, hoop tension theory and numerical modeling.

COMPRESSION SHELL THEORY

Henkel [1] explained when there is no buckling deformation, the membrane deforms like a cylindrical shell under axial compression, and the correction can be calculated through Equation (4).

$$\sigma_r = \frac{\pi D M_e \varepsilon(1-\varepsilon)}{A_0} \qquad (4)$$

Where D is the initial diameter of the specimen, M_c is the compression modulus of the membrane (N/m), ε is the axial strain of the specimen and A_0 is the initial area of the specimen.

Henkel [1] and ASTM [9] recommend subtracting the membrane correction factor from the major axial stress to determine the correct deviatoric stress. Equation (5) shows the corrected deviatoric stress considering the membrane correction.

$$Deviatoric\ Stress = \sigma_1 - \sigma_3 - \sigma_r \qquad (5)$$

Figure 4 illustrates Neoprene/Latex and Latex membranes correction via Equation (4). In Figure 4, the initial diameter of the specimen was 0.07 m and the average compression modules for the Neoprene/Latex and Latex membranes were 928.5 and 735.5 N/m respectively.

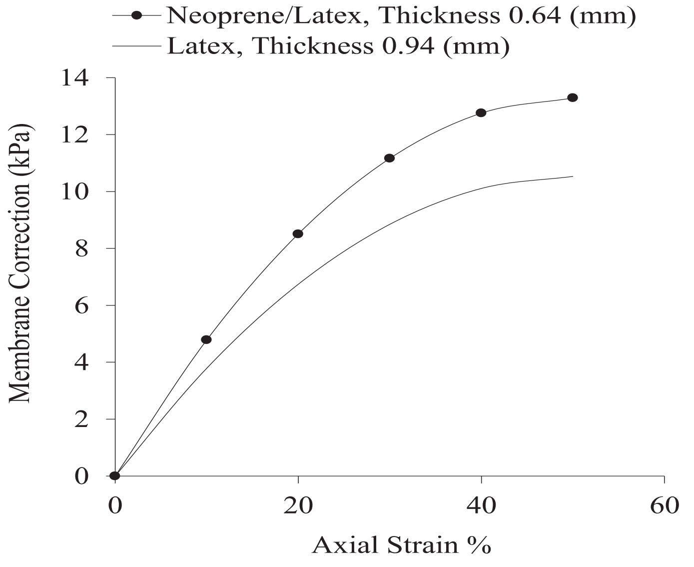

Figure 4. Lateral confining pressure correction using compression shell theory

HOOP TENSION THEORY

Henkel [1] investigated membrane error correction in buckling deformation of specimens where the membrane acted like a rubber belt resisting lateral deformation of the specimen. The induced lateral tension in the membrane functions as an increase in confining pressure on the specimen. Henkel [1] introduced Equation (6) to determine membrane error considering hoop tension theory in buckling deformation.

$$\sigma_r = \frac{2M\left(1-\sqrt{1-\varepsilon}\right)}{D(1-\varepsilon)} \qquad (6)$$

Where D is the initial diameter of the specimen, M is the compression modulus of the membrane (N/m), ε is the axial strain of the specimen.

Figure 5 shows the correction for Neoprene/Latex and Latex membranes using hoop tension theory, where the initial diameter of the specimen was 0.07 m. The estimated membrane correction using Hoop theory for Neoprene/Latex membrane is lower than for the Latex membrane, although the thickness of the Neoprene/Latex membrane was smaller than the Latex membrane.

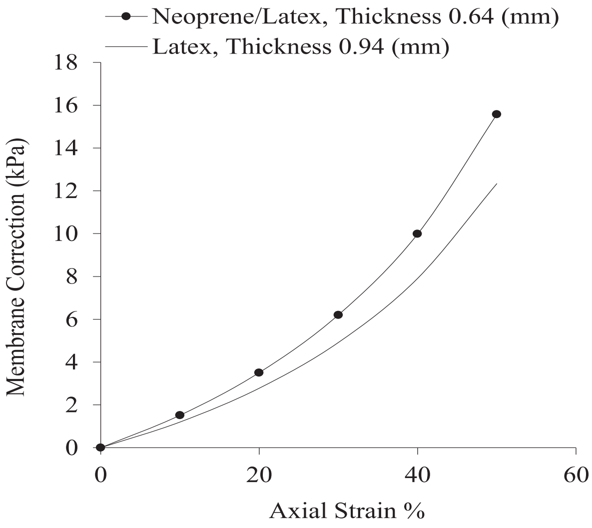

Figure 5. Lateral confining pressure correction through hoop tension theory

NUMERICAL MODELING

A numerical model for the Neoprene/Latex membrane was generated via ABAQUS to better understand the behavior of a membrane under buckling specimen deformation. A cylindrical membrane was created of 0.64 mm thickness, 63.5 mm diameter and 140 mm height. The stress-strain curve in Figure 2 for Neoprene/Latex membrane was applied to the model as hyperelastic behavior. The steps followed for membrane numerical modeling were:

- Generate the geometry of the membrane
- Assign the mechanical properties
- Apply boundary conditions and load
- Assign a mesh to the model
- Execute the model

The rubber membrane cylindrical geometry developed was an axisymmetric model. The boundary conditions of model were set based on the membrane performance in the lab tests; the membrane height effectively decreasing as the specimen buckled. As such the bottom boundary of the model was restrained in both x and y direction, but the upper boundary was restrained only in x direction and permitted to move in the y direction.

To develop buckling deformation at the membrane a curved rigid element was pushed towards the membrane. The rigid element did not deform and no frictional resistance was applied between the rigid element and the membrane. When the rigid element was pushed towards the membrane, the average generated stress was equivalent to the lateral stress due to the membrane deformation. Figure 6 shows a 3D view of the deformed membrane analogous to the specimen deformation in an actual lab test.

Figure 6. Membrane buckling in numerical modeling

The maximum lateral displacement of the modeled membrane and the average generated stress between the rigid element and membrane was recorded in Figure 7. Results showed that the maximum membrane correction was 8.62 kPa at a lateral strain of 0.50. The lateral strain of the membrane and corresponding lateral membrane pressure (membrane correction) are directly related and has a linear relationship.

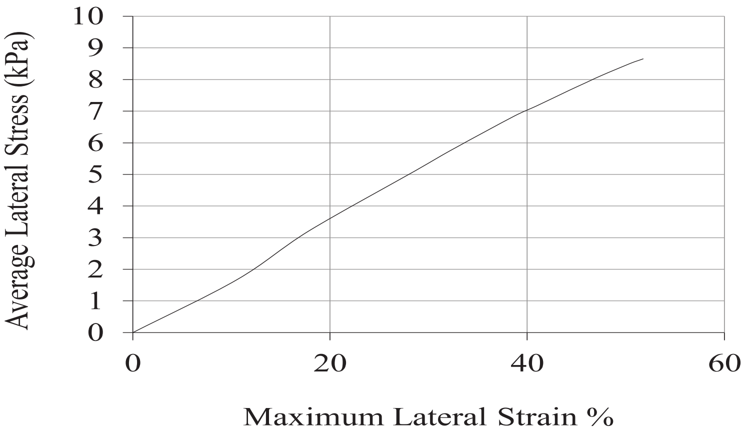

Figure 7. Average lateral correction stress and maximum lateral strain of membrane

CONCLUSION

The maximum membrane error was calculated by two analytical methods: compression shell theory and hoop tension theory. At high confining pressure, compression shell theory is an improvement over hoop tension theory as the buckling deformation of a specimen occurs at low confining pressure. Compression shell theory provides a higher membrane correction than hoop tension theory until 0.45 axial strain for the same membrane type conditions. The Neoprene/Latex membrane created higher membrane errors than the latex membranes; however, for a triaxial compression test on broken rock Neoprene/Latex membranes work better than latex membranes because they are more resistant to puncture by sharp particles. The numerical modeling of a Neoprene/Latex membrane for buckling deformation was found to have a maximum of 8.62 kPa membrane pressure with a lateral strain of 0.50. Numerical modeling showed a linear relationship between the membrane diameter increase and corresponding lateral membrane pressure.

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