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Dynamic Properties of Rubber Specimens

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ABSTRACT

Resonant column and bender element tests were conducted on rubber specimens to study their dynamic properties, namely, shear modulus (G), damping ratio (D) and Poisson's ratio (ν). It was found that similar to soil specimens, with an increase in strain level, the shear modulus of rubber decreases continuously whereas the damping ratio increases.

The tests were also carried out to find the effect of confining pressures on the rubber specimens. It was observed that for the rubber with the lesser hardness, there was a slight increase in the shear modulus and a decrease in the damping ratio values as the confining pressures (σ_3) was increased from 50 kPa to 500 kPa. This type of trend was, however, not observed for the rubber having greater hardness.

Using bender and extender elements test, with the measurements of the travel times of the shear (S) and primary (P) waves, the variation of Poisson ratio (ν) was determined for the rubber specimens with respect to change in confining pressures (σ_3). No significant change in the values of ν was found for both the rubber specimens with respect to change in σ_3.

INTRODUCTION

Rubber is a very vital engineering material which we use in our daily life. In vibration isolation, rubber is the material that is very widely used for both passive and active isolation. It is used as vibration isolation and noise control right from washers or O rings in screws to rubber pads for machine isolation or base isolation. Rubber is extensively used as rubber bearings in seismic isolators due to its high damping properties. It has also found important use in soil mechanics as reinforcing material such as waste tire chips etc. In this study it is intended to determine the low strain dynamic properties of two rubber specimens of different hardness. For this purpose Resonant column and bender element tests were conducted to study the dynamic properties, namely, shear modulus (G), damping ratio (D) and Poisson's ratio (ν). Bender/extender elements and resonant column tests are often used to determine the dynamic properties of different soils. While the bender and extender elements tests are normally used to obtain the maximum moduli of the sample, the resonant column test can be employed to determine the variation of moduli and the damping ratio of the sample with changes in the strain level. The resonant column test is often used to measure the dynamic properties (shear/elastic modulus and damping ratio) of soils and other materials (Richart et al. 1970; Hardin and Drnevich 1972). The basic principle of the resonant column test is to excite a cylindrical specimen in a fundamental mode of vibration, usually in torsion. Once the first fundamental mode is established, the resonant frequency and the amplitude of the vibrations are measured. The shearing strain amplitude during vibration is calculated by using the measurements of the acceleration amplitude and the frequency of vibration. From the theory of wave propagation, the velocity of the shear wave propagation is calculated by using measured values of resonant frequency, specimen size and the mass polar moment of inertia of the drive mechanism. A coil-magnet drive plate, attached to the top of the soil specimen, is often used to excite the sample. Due to the complicated design of the driving mechanism, the mass polar moment of inertia of the driving mechanism is usually determined from a number of separate tests on calibration bars (Kumar and Clayton 2007). In the present paper, a number of resonant column test were carried out to find the modulus degradation for increase in strain on the rubber sample. Bender and extender elements tests were also carried out to measure the travel times of the S and P waves.

MATERIALS TESTED

A natural rubber, 55A shore hardness and a synthetic rubber, 75A shore hardness was used for the study. Fig 1 shows the picture of the two rubber specimens. The natural rubber originally derived from a milky colloidal suspension, or latex, found in the sap of rubber trees. The synthetic rubber used is polyurethane rubber which offers the elasticity of rubber combined with the toughness and durability of metal.

Fig. 1. The photographs of two chosen rubber specimens.

APPARATUS CALIBRATION AND TESTING

The resonant column apparatus, along with bender/extender elements test setup, supplied by GDS Ltd., UK, was used in this research program. Calibration tests were carried out in the resonant column apparatus by using aluminum bars of different stiffness and using additional weights. The calibration test procedure adopted was that of Kumar & Clayton (2007). Figure 2 presents the variation of mass polar moment of inertia (J) with $1/\omega^2$. From this figure, the mass polar moment of inertia of the driving mechanism was obtained. The bender/extender elements used for the study combined consist of P and S wave transducers of two elements inserts. In the apparatus, the elements are wired in two alternate ways in order to generate and receive P and S waves. At the top of the sample, S-wave source/P-wave receiver is kept. On the other hand, P-wave source/S-wave receiver is placed at the bottom of the sample.

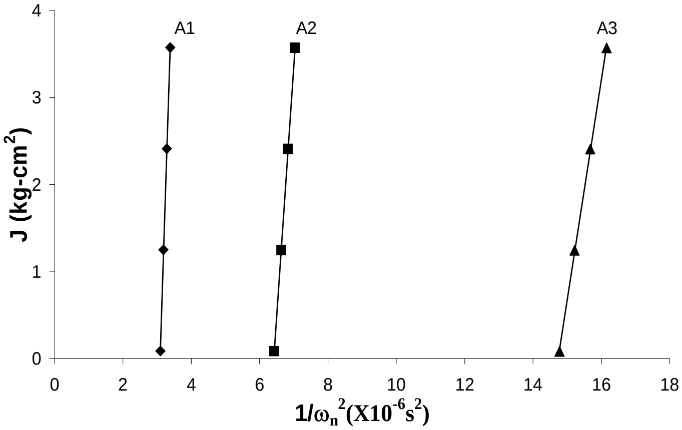

Fig. 2. Variation of J with $1/w^2$ for different specimens

After placing the sample, and with the application of an effective confining pressure, the bender and extender elements tests were then carried out to find the travel times of S and P waves. Thereafter, the resonant column tests, in torsional mode, were performed to determine the variation of shear modulus (G) associated with different values of shear strain level (γ) from which the value of maximum shear modulus (G_{max}) was determined; for the computation of shear wave velocity, using the resonant column test, the paper of Kumar & Clayton (2007) can be referred. Subsequently, the testing was carried out for the new value of the effective confining pressure. All the tests were carried out on the two rubber specimens at four different values of effective confining pressure (σ_3), namely, 50 kPa, 100 kPa, 300 kPa and 500 kPa.

DETERMINATION OF TRAVEL TIME IN BE TEST

In order to find the times of travel from source to receiver, three different methods, namely, (i) the first time of arrival, (ii) the first peak to peak, and (iii) the cross-correlation method (Mancuso et al. 1989 Viggiani & Atkinson 1995 and Kumar and Madhusudhan 2009), were used.

RESULTS AND DISCUSSION

Shear Modulus and Damping Ratio Variation with Shear Strain

Figure 3a presents the shear modulus variation with shear strain for natural rubber specimen. The shear modulus decrease with an increase in the strain level and also the shear modulus increases as the confining pressure on the sample increases.

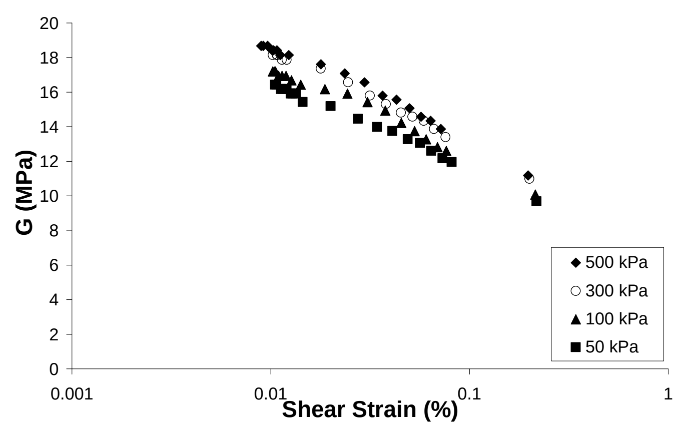

Fig. 3a. The variation of shear modulus with shear strain for natural rubber specimen.

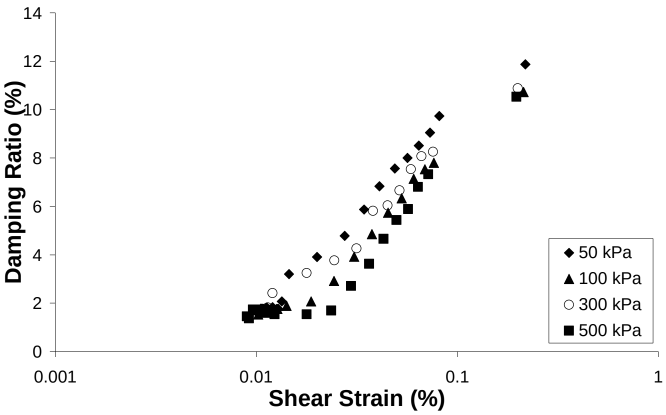

Fig. 3b. Variation of Damping Ratio with shear strain for natural rubber specimen.

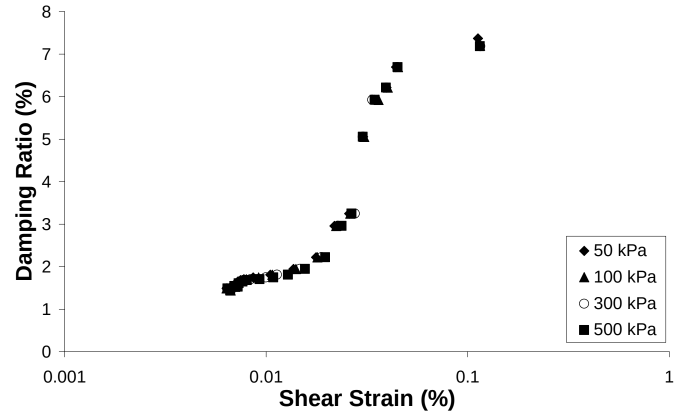

Fig. 4b. The variation of damping ratio with shear strain for synthetic rubber specimen.

It is observed that for shear strain smaller than 0.01%, the magnitude of shear modulus becomes almost constant. However, after increasing the shear strain beyond 0.01%, the shear modulus is found to decrease continuously similar to that shown by Payne (1962). Figure 3b presents the damping ratio variation with shear strain for natural rubber specimen. It can be noted that the damping ratio increases with an increase in the shear strain. Also, with an increase in confining pressure there is considerable decrease in the value of damping ratio.

Figures 4a and 4b presents the variation of shear modulus and damping ratio with shear strain, respectively for synthetic rubber specimen. Here, there is marginal decrease in shear modulus with increase in strain level. Damping ratio increases as the shear strain increases. There is no much effect of confining pressure on both shear modulus and damping ratio values, since the sample is having greater hardness value.

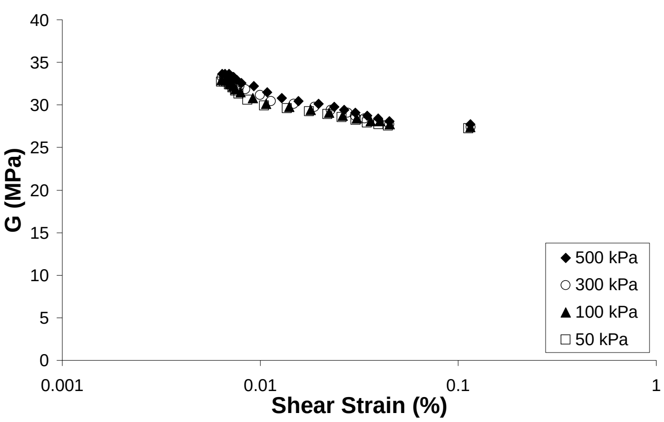

Fig. 4a. The variation of shear modulus with shear strain for synthetic rubber specimen.

<u>Elastic Wave Velocities</u>

Figure 5 describes the effect of confining pressure on shear wave propagation in natural and synthetic rubber samples. The S wave velocity increases as the confining pressure was increased for the natural rubber whereas for the synthetic rubber no such trend was observed. In order to obtain the correct arrival time in the bender element test, the average arrival time is calculated as per the three methods given earlier i.e; (i) the first time of arrival, (ii) the first peak to peak, and (iii) the cross-correlation method. As expected, the synthetic rubber of higher hardness provided greater S wave velocities than the natural rubber (lower hardness). It is interesting to observe there is a difference of 20m/s in the s wave velocity for synthetic rubber specimen when tested using BE and RC, whereas no such difference in s wave velocity was observed for the natural rubber specimen.

Figure 6 presents the effect of confining pressure on primary wave propagation in natural and synthetic rubber samples. With an increase in σ_3, the P wave velocity is found to increase in case of natural rubber whereas for the synthetic rubber specimen, the P wave velocity is found to be constant regardless of the applied confining pressure.

The synthetic rubber specimen having greater hardness provides higher P wave velocities than the natural rubber (lower hardness).

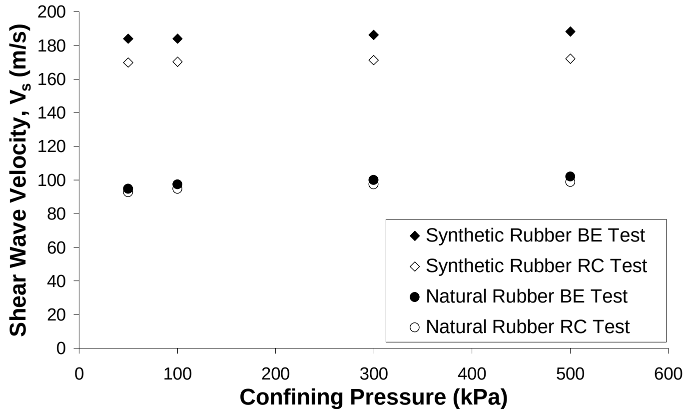

Fig. 5. Effect of confining pressures on shear wave velocities in rubber specimen.

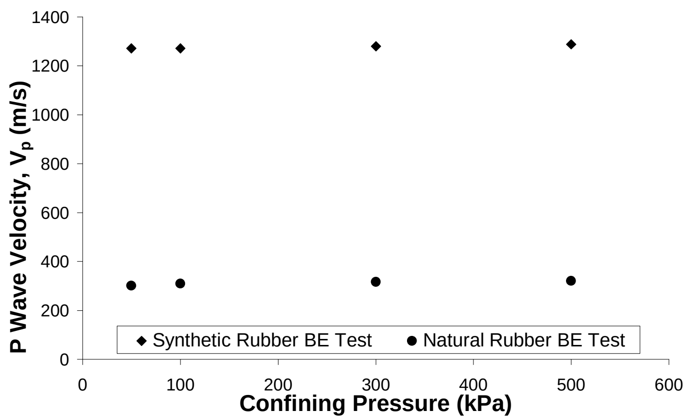

Fig. 6. Effect of confining pressures on primary wave velocities in rubber specimen.

<u>Poisson's Ratio</u>

The Poisson's ratio for the rubber sample is determined by using the following equation given by Richart (1970)

$$\nu = \frac{0.5V_P^2 - V_S^2}{V_P^2 - V_S^2}$$

In case of natural rubber the Poisson's ratio was found to decrease very marginally as the confining pressure on the sample was increased (0.489-0.483). Whereas in case of synthetic rubber a constant value of 0.449 was obtained.

CONCLUSIONS AND REMARKS

The shear modulus increases and the damping ratio decreases as the confining pressure was increased on the natural rubber specimen. However, no effect of the confining pressure was noted for the synthetic rubber specimen. Due to greater hardness values, the synthetic rubber specimens provide greater shear and primary wave velocities as compared to the natural rubber. As compared to the natural rubber specimen, the value of Poisson ratio was found to be a little higher in case of synthetic rubber specimen.

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