

ABSTRACT

The soil strata is often subjected to various kinds of vibrations such as that caused by earthquakes, water waves, traffic loads, wind power plants, construction related equipments, pile driving and vibratory machines. The strains induced in a soil mass due to the vibrations generated by these different sources often lie in a range of 0.0001% - 0.1%. The estimation of the shear modulus (G) and damping (D) of soils in this strain range becomes an important aspect for performing the analysis and design of various geotechnical structures subjected to different kinds of vibrations. Strain amplitude, effective confining stress, void ratio/relative density, number of vibration cycles and cyclic strain history are some of the key parameters that influence the modulus and damping characteristics of sands. Although, the effects of strain amplitude, confining pressure and relative density have been studied quite extensively in literature, only limited studies seem to have been reported in literature to examine the effects of the cyclic strain history and the vibration cycles on these dynamic properties. The objective of this thesis is to study the effects of the cyclic strain history and the number of vibration cycles on the shear modulus and damping ratio of dry sands in a strain range of 0.0001% to 0.1%.

A number of resonant column tests have been performed on dry sand specimens to examine the effect of the cyclic shear strain history, by including both increasing and decreasing strain paths, on the shear modulus and damping ratio for different combinations of relative densities (D_r) and confining pressures (σ_3); an increasing strain path intends to simulate a situation when a vibratory machine is just started before reaching a steady state of vibration, and on the other hand, the decreasing strain path matches a condition when the

machine is shut down after running continuously in a steady state for some time. The specimen has been subjected to a series of cycles of increasing and decreasing shear strain paths approximately in a shear strain range of 0.0006% - 0.1%. For chosen values of relative density and confining pressure, two different series of tests beginning with either (i) an increasing strain path or (ii) a decreasing strain path, were performed. In addition, the influence of the numbers of the vibration cycles which are used to measure the resonant frequency of the specimen, referred to as the cycle constant, on the values of shear modulus has also been analyzed.

Irrespective of the strain path adopted to commence the test or the cycle constant used to perform a resonant column test, for a given strain amplitude, the shear modulus along the increasing strain path has been found to be always greater than the corresponding modulus value along the decreasing strain path. For the series of tests which were commenced with the increasing strain path, the shear modulus corresponding to the first increasing strain path becomes always the highest as compared to the subsequent strain paths. For a given strain cycle, irrespective of relative density of sand, the difference between the values of G associated with the increasing and decreasing strain paths becomes always the maximum corresponding to a certain shear strain level. The maximum reduction in the shear modulus, due to the cyclic variation of the shear strain, was noted to be approximately one fourth of the maximum shear modulus (G_0). This reduction in the shear modulus, on account of the cyclic variation of the shear strain, increases generally with decrease in the values of both relative density and confining pressure. The damping ratio for a given shear strain for the increasing strain path was noted to be lower than the corresponding value for the decreasing strain path except for the first increasing strain path. For a particular strain level, the series of tests

started with the decreasing strain path resulted in a lower value of shear modulus for all the cyclic strain paths as compared to the tests which were commenced with the increasing strain path. The modulus reduction curve for the first increasing strain path was noted to be more or less the same irrespective of the value of the chosen cycle constant. For the subsequent strain paths, an increment in the cycle constant value caused a reduction in the shear modulus at a particular shear strain level.

In order to match a situation when the machine is running continuously in a steady state of vibration, resonant column tests were conducted in a torsional mode by inducing a large number of the vibration cycles with the shear strain amplitude in a range of 0.0005% - 0.05%. Corresponding to a given input voltage of the drive mechanism, the specimens were subjected to a number of vibration cycles ranging from 1,000 to 50,000. The values of shear modulus and damping ratio, before and after the application of vibration cycles, were determined for several input voltages ranging from 0.001 V (minimum) to 0.3 V (maximum). The tests were carried out for different combinations of relative densities and confining pressures. For the chosen relative densities, hardly any influence of vibration cycles on the values of G and D were noted for the strain amplitude below the threshold strain level (0.0024% - 0.0044%). Beyond the threshold strain level, an induction of the vibration cycles leads to a continuous increment in the shear strain which eventually causes (i) a decrease in the shear modulus, and (ii) an increase in the damping ratio. This effect was found to become especially more significant for lower values of relative densities as well as confining pressures. The percentage changes in the values of (i) shear strain, (ii) shear modulus, and (iii) damping ratios after the introduction of vibration cycles were noted to increase with an increment in the number of vibration cycles. However, for a given increment of the vibration

cycles, the changes in the values of shear modulus and damping ratio were generally noted to subside with an increase in the number of the vibration cycles.

At various strain levels, the magnitude of the shear modulus was observed to increase continuously with an increase in the values of both relative density and confining pressure. For the shear strain greater than the threshold strain (0.0024% - 0.0044%), a reduction in the damping ratio values was also noted with an increase in the magnitudes of the confining pressure. On the other hand, the influence of relative density on the damping ratio was found to be relatively negligible. The shear modulus reduction curves from the present tests' data were found to compare reasonably well with the empirical curves proposed in the literature, especially for low values of the confining pressure. A deviation of the present modulus reduction curves from the empirical curves was observed generally at large shearing strains. However, the damping values obtained from the present study were noted to be lower than the values predicted by the existing empirical correlations, particularly for low values of the confining pressure.

An attempt has also been made to improve the accuracy of the measurement of the arrival times of both primary (P) waves and shear (S) waves while conducting bender/extender element tests. For this purpose, a series of laboratory tests were performed on dry sand at different frequencies, varying between 1 kHz and 10 kHz, for medium dense and very dense sands with different values of the confining pressures. While determining the times of arrival of both P and S waves, two corrections have been proposed to incorporate (i) the presence of an initial offset in the input signal, and (ii) the time lag due to an existence of peripheral electronics between the input and received signals when the source and receiver elements are kept in direct contact with each other. The absolute magnitude of the resultant

of these two corrections was found to reduce with an increase in the frequency of the input signal. The determination of the *P*-wave arrival time does not pose much difficulty. It has been noted that it becomes equally accurate to measure the arrival times of the *S*-wave provided the proposed corrections are incorporated. The maximum shear modulus values measured from the resonant column tests and the bender element tests by incorporating these two corrections were found to compare reasonably well with each other.

The thesis brings out the effects of the cyclic strain history and the vibration cycles on the shear modulus and damping ratio of dry sand. The results obtained are expected to be useful while doing the analysis and design of geotechnical structures subjected to different kinds of vibrations.