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EFFECT OF CONFINING PRESSURE, RELATIVE DENSITY AND SHEAR STRAIN ON THE POISSON'S RATIO OF CLEAN SAND

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ABSTRACT

In comparison to other dynamic properties of soil, Poisson's ratio is mostly considered as an elastic constant. The effect of different parameters on the Poisson's ratio of soil is neglected in most of the available literature. Proper estimation of the Poisson's ratio is required as it signifies the stress and deformation characteristics of the soil. In this study a series of resonant column tests were performed to determine the variation of Poisson's ratio with confining pressure, relative density and shear strain.

Clean sand free from fines content was used in this study. The tests were performed on sand sample of size 50 × 100 mm compacted at relative densities of 30%, 50% and 75%. The sample preparation was done by using a split mold. By using a funnel, the sand was gently poured into the split mold. Then each layer was compacted by means of a tamping rod which weighs 150 g. The sample preparation was done in 5 equal thick layers. By performing few trial sample preparations, the number of blows required per layer for a desired relative density was determined. A fixed free type of resonant column was used in this study. By performing the resonant column test in torsional mode as well as flexural mode of excitation, it is possible to estimate the Poisson's ratio of the soil. The confining pressure was varied from 100 kPa to 800 kPa. The shear strain varied from 10^{-4} % to 10^{-1} %.

Figure 1 gives the variation of Poisson's ratio with confining pressure for various relative densities. From the figure it is observed that there is a continuous decrease in Poisson's ratio of the soil with an increase in the confining pressure as well as relative density. The percentage reduction in Poisson's ratio obtained for the soil subjected to a confining pressure of 800 kPa as compared to soil subjected to 100 kPa confining pressure is 19 %, 21 % and 22% for 30 %, 50 %, 75 % relative densities of the soil. In addition, the percentages reduction in Poisson's ratio of sand prepared at 75 % relative density as compare to 30 % relative density are 14 %, 15.7 %, 16.7 % and 17.6 % for sand subjected to 100 kPa, 400 kPa, 600 kPa and 800 kPa respectively. It can be concluded that the percentage reduction in Poisson's ratio increases with the increase in confining pressure as well as relative density.

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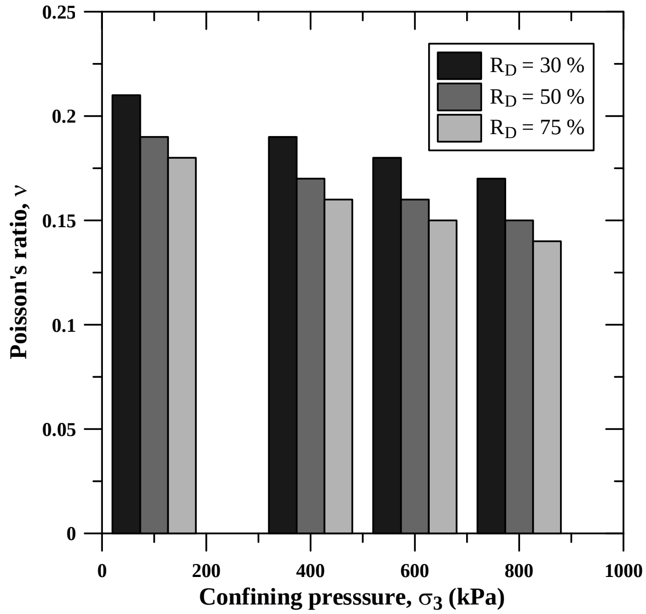

Fig. 1 Variation of Poisson's Ratio with confining pressure

Figure 2 gives the variation of Poisson's ratio with confining pressure for different shear strain values. It is observed that Poisson's ratio increases with increase in shear strain. This increase is found to be less for lower values of shear strain. For shear strains higher than 0.025 % there is a tremendous increase in Poisson's ratio of the soil. It is also seen that the percentage reduction in Poisson's ratio with confining pressure is higher for higher values of shear strain.

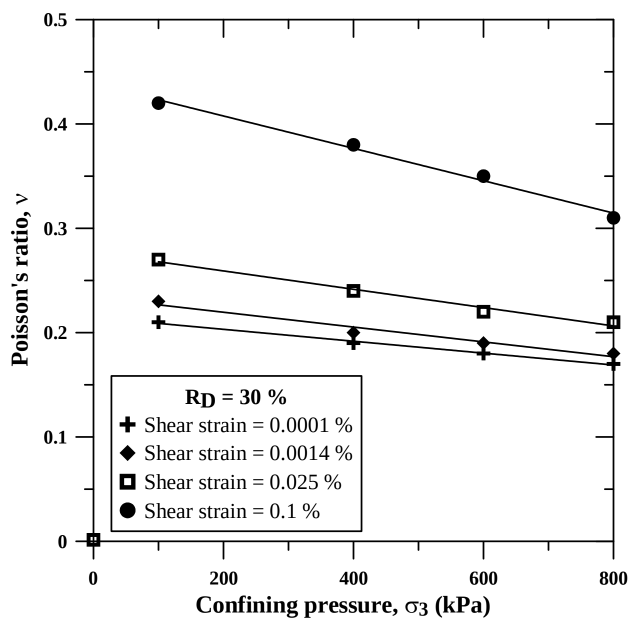

Fig. 2 Variation of Poisson's ratio with confining pressure for various shear strain

Keywords: Poisson's ratio, resonant column test, clean sands, shear strain

EFFECT OF CONFINING PRESSURE, RELATIVE DENSITY AND SHEAR STRAIN ON THE POISSON'S RATIO OF CLEAN SAND

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ABSTRACT: In comparison to other dynamic properties of soil, Poisson's ratio is mostly considered as an elastic constant. The effect of different parameters on the Poisson's ratio of soil is neglected in most of the available literatures. In this study a series of resonant column tests were performed to determine the variation of Poisson's ratio with confining pressure, relative density and shear strain. It is observed that there is continuous decrease in Poisson's ratio of the soil with increase in confining pressure as well as relative density. However with the increase in shear strain there is increase in the Poisson's ratio of the soil.

INTRODUCTION

In the past few decades an extensive amount of research has been undertaken to determine the dynamic properties of soil. Numerous tests are available for determining the dynamic properties of the soil which includes both laboratory and field tests. The dynamic properties which are given due consideration are the shear modulus and damping ratio of the soil. Resonant column test is usually performed to determine the dynamic properties of the soil. The testing procedure and data acquisition has been dealt in numerous studies performed so far [1, 2]. Dynamic properties of soils are dependent on lot of factors. For sands, the important factors which govern the dynamic properties of soil are confining pressure, shear strain and relative density of the soil [3, 4, 5, 6, 7, 8 and 9]. However limited research has been available on the determination of Poisson's ratio of soil [10, 11, 12, and 13]. Proper estimation of the Poisson's ratio is of paramount importance as it signifies the stress and deformation characteristics of the soil. By performing the resonant column test in both torsional and flexural mode of excitation it is possible to estimate the Poisson's ratio of the soil. Cascante et al. [14] had shown the data reduction for the flexural mode of excitation. Kokusho [10] by performing series of cyclic triaxial tests on Toyoura sand concluded that Poisson's ratio of the soil decreases with increase in confining pressure and increases with the increase in void ratio of the soil. Kumar and Madhusudhan [11] by performing bender and extender element tests on sands of various grain sizes stated that Poisson's ratio invariably decreases with the increase in confining pressure as well as relative density and this decrease is found to be more for fine grained soil as compared to coarse grained. Gu et al. [12] by performing bender element tests on sand inferred that Poisson's ratio increases with the increase in void ratio and decreases with the increase in confining pressure. Sas et al. [13] by performing resonant column test on clayey sand observed that Poisson's ratio decreases with increase in shear wave velocity and increases with increase in shear strain. In this study an attempt has been made to find the variation of Poisson's ratio with confining pressure, relative density and shear strain of the soil.

MATERIAL PROPERTIES

The sand used in this study is clean sand free from fines content. The sand is properly washed to remove any fines content passing 75 micron sieve present in the sand. The grain size distribution, maximum and minimum void ratio and specific gravity tests were performed on the sand. The grain size distribution curve of the sand is shown in figure 1. The material properties of the sand are given in table 1. The sand is classified as poorly graded sand with letter symbol SP according to the unified soil classification system (USCS).

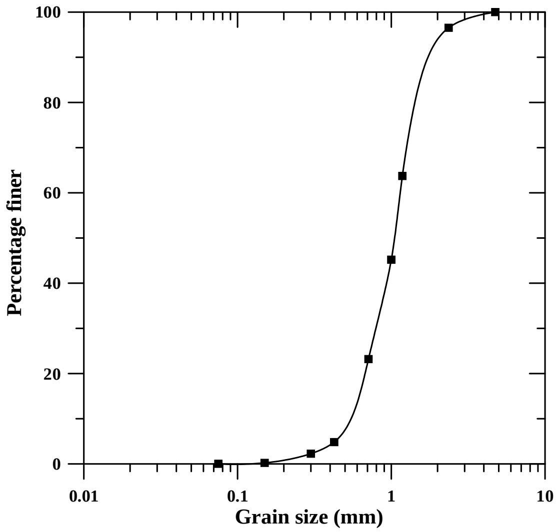

Fig. 1 Grain size distribution curve for sand

Table 1 Basic Properties of sand [15]

Property	Value
Specific gravity, G_s	2.63
Maximum dry density ($\gamma_{d\ max}$): kN/m^3	15.84
Minimum dry density ($\gamma_{d\ min}$): kN/m^3	13.98
Maximum void ratio (e_{max})	0.88
Minimum void ratio (e_{min})	0.66
D_{10} : mm	0.47
Coefficient of uniformity, C_u	2.55
Coefficient of curvature, C_c	0.87
Degree of roundness of particle	Angular

SPECIMEN PREPARATION

The preparation of sand specimen was done in the resonant column apparatus itself. A rubber membrane is fixed to the bottom pedestal using a set of O-rings. A split moult is placed outside the rubber membrane. The top part of the rubber membrane is stretched and rolled over the split mould. By applying a constant vacuum, the entrapped air between the mould and the membrane is removed so that the membrane sticks onto the mould. The sand is gently poured into the mold by means of a funnel. Then each layer is tamped by using a tamping rod which weighs 150 g. Preparation of the sample is done in five equal layers. By performing a few trial sample preparations, the number of blows required for each layer is obtained. The specimens were prepared at 30 %, 50 % and 75 % relative densities. To ensure same relative density throughout the test, the dimension of the specimen is measured once before and once after the test.

RESONANT COLUMN APPARATUS

A GDS make fixed free type of resonant column apparatus was used in the study. In this apparatus, the bottom of the specimen is fixed to the pedestal while the top surface is left free. Resonant column apparatus can be used to perform tests under both torsional and flexural modes of excitation by using an electromagnetic drive system. The drive system consists of four electromagnets. For performing the test in both torsional as well as flexural mode, four electromagnets were used in two different directions. During the torsional mode the four pair of magnets work in series which apply a net torque to the soil specimen. For applying the flexural mode only two pair of magnetic coils work to apply a net horizontal force at the top of the specimen. A frequency sweep is performed to obtain the resonant frequency of the soil specimen. Initially a low value of frequency is applied. After that the frequency is gradually increased. The frequency at which it shows a peak value of amplitude gives the resonant frequency of the specimen.

Determination of shear wave velocity

Shear wave velocity, *Vs* can be determined from the resonant frequency obtained from the torsional mode of excitation.

$$V_s = \frac{2\pi fL}{\beta} \quad (1)$$

where, f = resonant frequency (Hz); L = length of the specimen; β = a factor that can be obtained from equation (2).

$$\frac{I}{I_o} = \beta.\tan(\beta) \quad (2)$$

where, I = mass polar moment of inertia of the soil specimen; and I_o = mass polar moment of inertia of the electromagnetic drive system.

The mass polar moment of inertia of the electromagnetic drive system is determined experimentally through a calibration procedure due to its complex geometry.

Determination of Poisson's ratio

For determining the Poisson's ratio of the soil sample, resonant column tests has to be performed in both torsional and flexural modes of excitation.

Cascante et al. (1996) gave the circular resonant frequency for a soil specimen of length L by using Rayleigh's method and considering N distributed mass m_i as:

$$\omega_f^2 = \frac{3EI_b}{L^3\left[\frac{33}{140} m_T + \sum_{i=1}^{n} m_i h(h0_i, h1_i)\right]} \quad (3)$$

$$h(h0i, h1i) = mi\left[1 + 3\frac{(h1i + h0i)}{2L} + \frac{3}{4}\left(\frac{h1_i^2 + h1ih0i + h0_i^2}{L}\right)^2\right] \quad (4)$$

where, $h0_i$ and $h1_i$ are the heights at the bottom and top respectively, of mass i, measured from the top of the soil specimen; ω_f = circular resonant frequency in flexural mode; E = Young's modulus of the soil specimen; I = area moment of inertia; m_T = mass of the soil specimen.

Equation (4) can also be expressed in terms of centre of gravity, y_{ci} and area moment of inertia, with respect to centre of gravity, I_{yi} of each mass, m_i .

$$h(y_{ci}, I_{yi}) = 1 + \frac{3y_{ci}}{L} + \frac{9}{4L^2}\left[\frac{I_{yi}}{m_i} + y_{ci}^2\right] \quad (5)$$

Due to complex geometry, area moment of inertia I_y for the drive system is determined experimentally.

Now the Poisson's ratio is determined using:

$$\upsilon = \frac{1}{2}\frac{V_{LF}^2}{V_s^2} - 1 \quad (6)$$

Where, V_{LF} = longitudinal wave velocity which can be calculated using equation (7).

V_s = shear wave velocity calculated using equation (1).

$$V_{LF} = \sqrt{\frac{E}{\rho}} \quad (7)$$

where, E = Young's modulus of the soil specimen determined using equation (3); ρ = density of the soil specimen.

RESULTS AND DISCUSSIONS

The Poisson's ratio of soil is significantly influenced by the increase in confining pressure and relative density. Figures 1 and 2 give the variation of Poisson's ratio with increase in confining pressure and relative density of the sand respectively. It is seen that Poisson's ratio decreases with the increase in confining pressure as well as relative density. The percentages reduction in Poisson's ratio obtained for the soil subjected to a confining pressure of 800 kPa as compared to soil subjected to 100 kPa confining pressure are 19 %, 21 % and 22% for 30 %, 50 %, 75 % relative densities of the soil. Figures 4, 5, and 6 give the variation of Poisson's ratio with confining pressures for different values of shear strain. It is observed that with the increase in shear strain, Poisson's ratio of the soil specimen increases. This increase in Poisson's ratio is very less from shear strains 0.0001 % to 0.014 %. However with further increase in shear strain there is considerable increase in the Poisson's ratio of the soil. It is observed that there is tremendous increase in Poisson's ratio of the soil from shear strains 0.025 % to 0.1 %. Moreover, it is also seen that the reduction of Poisson's ratio with confining pressure is very high for higher values of shear strain. The percentages reduction in Poisson's ratio of soil subjected to 800 kPa confining pressure as compared to soils subjected to 100 kPa and prepared at 30 % relative density are 19 %, 21.7 %, 22.2 % and 26.1 % for 0.0001 %, 0.0014, 0.025 % and 0.1 % respectively. Similar observation was made for sands prepared at 50 % and 75 % relative densities as well.

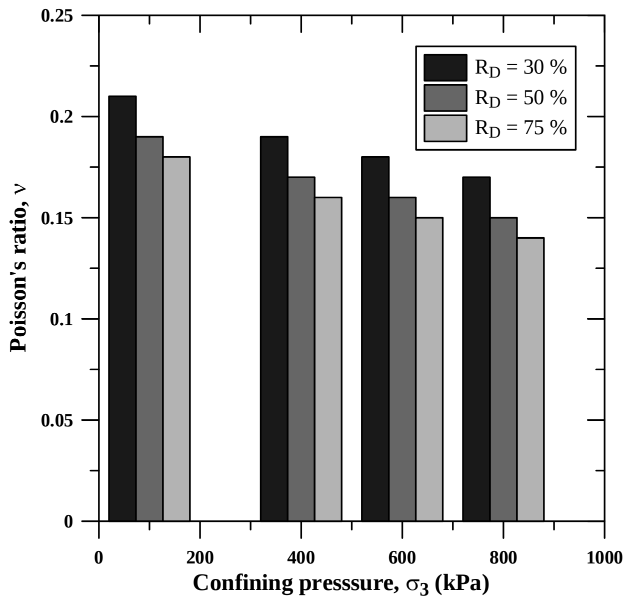

Fig. 2 Variation of Poisson's Ratio with confining pressure

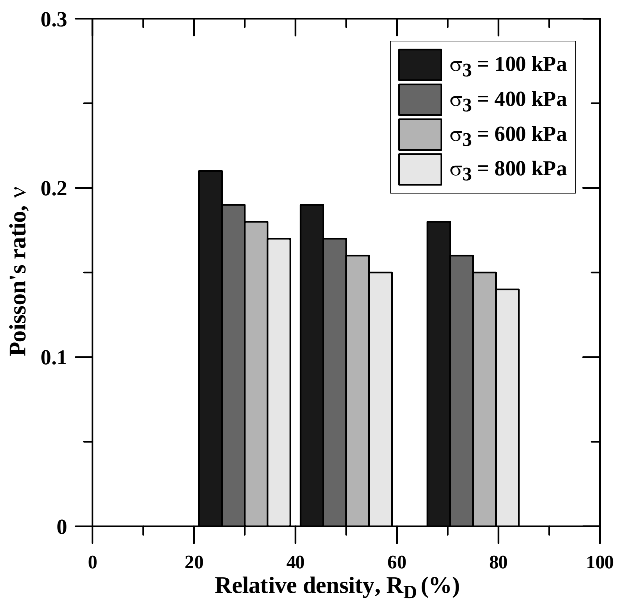

Fig. 3 Variation of Poisson's ratio with relative density

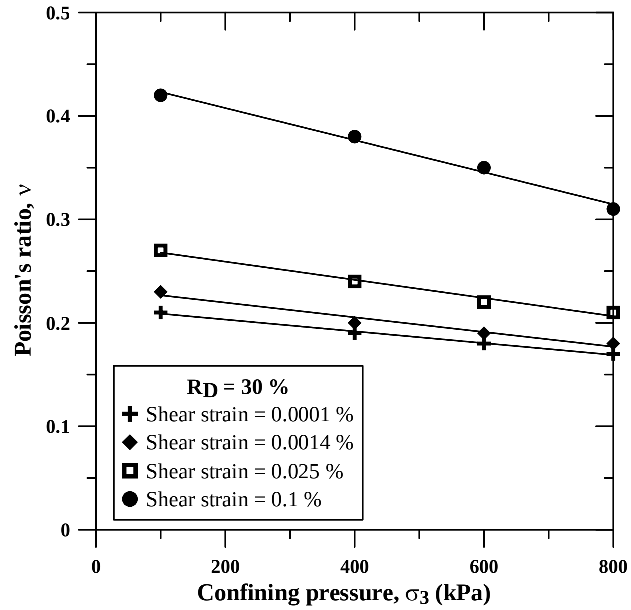

Fig. 4 Variation of Poisson's ratio with confining pressure for various shear strain for R_D= 30 %

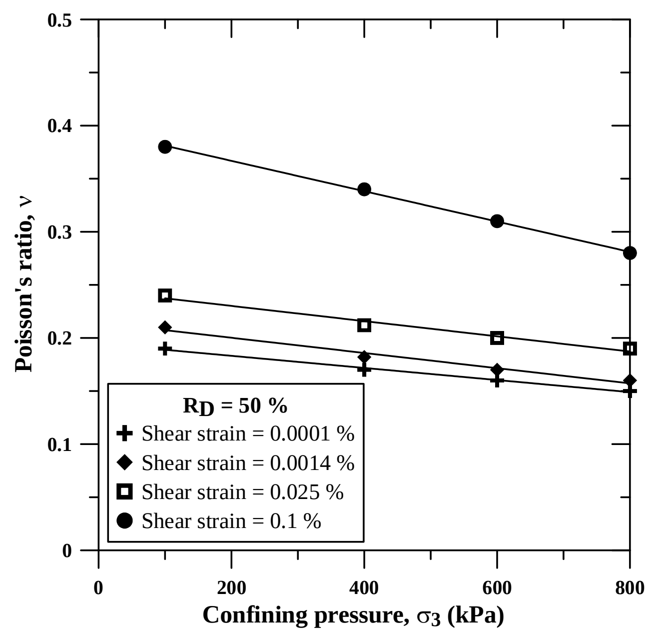

Fig. 5 Variation of Poisson's ratio with confining pressure for various shear strain for R_D= 50 %

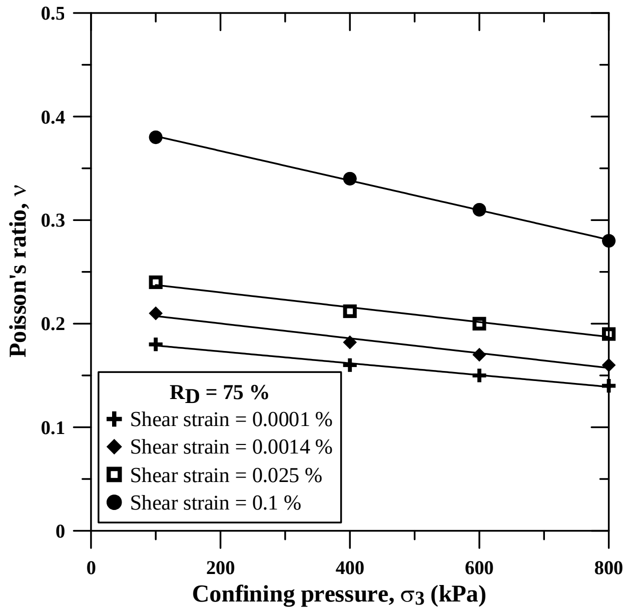

Fig. 6 Variation of Poisson's ratio with confining pressure for various shear strain for R_D= 75 %

CONCLUSIONS

By performing resonant column tests on clean sand, it is possible to determine the Poisson's ratio of the soil. It is observed that Poisson's ratio is significantly influenced by the confining pressure, relative density and shear strain of the soil. With the increase in confining pressure and relative density of the soil, Poison's ratio decreases. This percentage decrease is higher for higher values of confining pressure as well as relative density. Moreover with the increase in shear strain, the Poisson's ratio of the soil increases. This increase is found to be less for lower values of shear strain and for shear strain higher than 0.025 % there is tremendous increase in Poisson's ratio of the soil. It is also seen that the percentage reduction in Poisson's ratio with confining pressure is higher for higher values of shear strain. The variation of Poisson's ratio with degree of saturation can be a scope for further study.

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