Evaluation of Dynamics Properties and Liquefaction Potential of Kasai River Sand by Cyclic Triaxial Test

Satya Prakash Vikal and Paramita Bhattacharya

Abstract The present research work examines the dynamics shear modulus, cyclic pore pressure ratio and liquefaction potential of locally available Kasai river sand at medium dense state and at high strain level (>10^{-4}) by displacement-controlled cyclic triaxial test**.** Kasai river is located in Paschim Medinipur district of West Bengal. This region is seismically bounded by several faults such as Garhmayna Khanda-Ghosh fault, Pingla fault and Eocene Hinge zone. Although this area is under Seismic Zone III, a good number of earthquakes of magnitude around 5.0 in Richter scale have been experienced in recent past. It is known that earthquakes destruction is largely dependent upon dynamic properties. Therefore the study is carried out to keep in mind the safety of the important structures. The dynamic shear modulus and excess pore pressure ratio of Kasai river sand at fully saturated state have been determined for different values of shear strain and confining pressure. The tested sand specimen has been prepared at relative density of 50%. In the displacement-controlled cyclic test, the axial strain amplitude is chosen to be 0.2, 0.3 and 0.5% and frequency is 1 Hz. The shear modulus is decreased and excess pore pressure ratio is increased due to an increase in number of cycles of loading. However the excess pore pressure ratio depends on the magnitude of cyclic shear strain.

Keywords Shear modulus · Excess pore pressure ratio · Liquefaction potential · Kasai river sand · Medium dense sand · Cyclic triaxial

1 Introduction

Soil liquefaction is commonly occurred in saturated soil for the loss of its effective stress and stiffness during earthquake. During liquefaction the effective stress ($\sigma'3$) of the saturated soil reduces to zero. A series of investigations available in the literature related to dynamic properties of soils are divided into (i) large strain (>10^{-4}) analysis [6, 12, 14, 16] and (ii) small strain (<10^{-4}) analysis [5, 9, 10]. These work deal with

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the damping ratio and dynamic shear modulus for sand prepared at different relative densities and cycles of load. There are few research works available on pore pressure generation by Belkhatir et al. [4], Xenaki and Athanaspoulos [15]. These works basically deal with variations of pore pressure with void ratios, relative densities and fine contents. There are some research works in literature by Ishihara et al. [8, 11, 13] dealing with in-situ soil characteristics for evaluation of residual strength, safety factor, liquefaction potential indices and critical depth required for liquefaction.

From literature it is understood that the study of dynamic properties of foundation soils and its liquefaction are important for the safety of any structures built over it. Several important structures like road and rail bridges, embankment etc. are existing over the Kasai river. There is a twin bridge located at either banks of the Kasai river which eventually connect Kharagpur and Medinipur cities in Paschim Medinipur district of West Bengal. Although the study area is under Zone-III in the Map designed based on the seismic activity in India, a good number of earthquakes are recorded in recent past of magnitude around 5.0 in Richter scale. Moreover the presence of several faults such as Garhmayna-Khanda-Ghosh fault, Pingla fault and Eocene Hinge zone has increased the possibility of seismic activity in this region. Since there is no data available on building up of pore pressure and dynamic shear modulus of Kasai river sand under displacement-controlled (strain controlled) cyclic loading so the present work has studied the liquefaction potential, pore pressure ratio and dynamic shear modulus of Kasai river sand at medium dense state under cyclic loading at high strain rate (> 10^{-4}).

2 Soil Characterization

Dry sand sample from Kasai river bed was collected. Sand sample passing through 4.75 mm sieve and retained by 75 μm was used for sample preparation. Fig. 1 shows

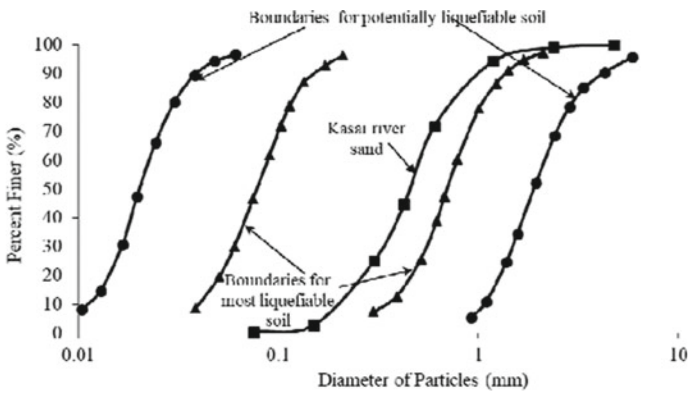


Fig. 1 Grain size distribution curve

Table 1 Characterization of soil

Soil parameter	Value
Specific gravity	2.67
Uniformity coefficient, C_u	2.5
Coefficient of curvature, C_c	1.16
Maximum void ratio, $e_{\max}$	0.84

a typical grain size distribution curve of the sample. Table 1 provides the index properties of the sample.

2.1 Index Properties and Gradation of Sand

The distribution of soil grain is shown in Fig. 1. It shows the soil sample is poorly graded sand. Moreover this distribution curve of grain size is found to lie within the bounds for potentially liquefiable soil.

2.2 Shear Strength Parameters of Kasai River Sand by CD Triaxial Test

The peak friction angle (ϕ_{peak}) and critical state friction angle (ϕ_{cr}) of sand sample have been determined by conducting consolidated drained (CD) triaxial tests. Total four CD tests have been performed at relative density $R_d = 50\%$ for confining pressures ($\sigma'3$) equal to 50, 100, 150 and 200 kPa. The strain rate at all CD tests is kept at 1.25 mm/min as per ASTM D7181-11 [1]. The CD test results are shown in Fig. 2. The values of ϕ_{peak} and ϕ_{cr} determined from experiments are 34.6° and 5°, respectively.

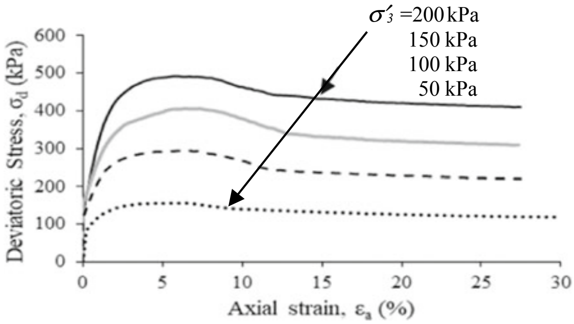


Fig. 2 Deviation stress versus axial strain in CD triaxial test at $Rd = 50\%$

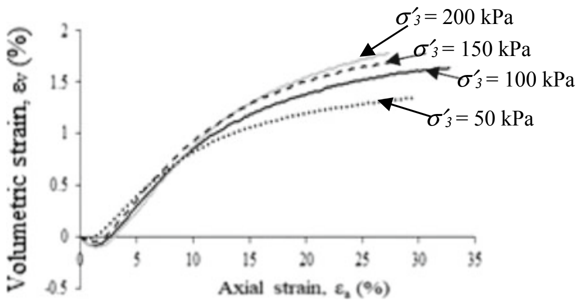


Fig. 3 Volumetric strain versus axial strain curve at *Rd* = 50%

3 Sample Preparation

Each cylindrical sand specimen of size 50 mm × 100 mm has been prepared and placed on the pedestal. The specimen has been covered by a rubber membrane with the help of split mould. In this case the size of the split mould used is 50 mm (dia.) × 100 mm (height). First weight of oven dried sand at 50% relative density is calculated. The tamping method described in ASTM D5311-11 [2] was used for the sample preparation. In this method the soil sample was prepared in three layers of oven dried sand. So the required dry weight of the sand for each layer was determined. Then the weighed sand was allowed to pour through a funnel with long tube to the mould maintaining zero dropping height. Thereafter each layer of the poured sand in the mould is tamped so that the every layer has a height equal to 1/3rd of the mould's height. The second and third layers are filled in the mould following similar steps. In order to keep the sample stiff and ensure minimum disturbance of the specimen at the time of removal a little suction is provided to the specimen. Then the split mould is removed. Then de-aired water is used to saturate the sample. Back pressure is applied to accelerate the saturation process. Keeping $\sigma'3$ around 15–20 kPa the amount of applied back pressure was gradually increased as long as the Skempton's parameter related to pore pressure B (= $\Delta u/\Delta\sigma$, Δu = change in pore pressure, $\Delta\sigma$ = change in confining pressure) becomes equal to or more than 0.95. Thereafter the sand specimens were isotropically consolidated at a required $\sigma'3$ (Fig. 3).

4 Testing Procedure

The experiment has been conducted by the automated hydraulic cyclic triaxial testing equipment made by M/s. HEICO, India. The loading system is comprised of a loading frame of maximum 50 kN load carrying capacity and a hydraulic actuator which is capable to perform both strain and stress-controlled tests for a wide range of frequency varying from 0.1 to 10 Hz. The automated triaxial testing system has six transducers including one submersible type load cell of ± 5 kN capacity for monitoring the axial load, a displacement transducer of ± 50 mm capacity for measuring the vertical displacement, four transducers for recording pore water pressure, confining pressure, back pressure and volume change. The data acquisition card and analysis software confining ASTM 3999 [3] and ASTM 5311 [2] are also provided for analysis purpose. Cyclic loading is applied to the sample using displacement-controlled method so that the frequency of the sinusoidal axial displacement remains constant at 1 Hz. The tests have been performed at different amplitudes of cyclic axial strain such as 0.2%, 0.3% and 0.5% and $\sigma'3$ values of 100 and 200 kPa. Using the results obtained from the tests the analysis software plotted the deviator stress versus axial strain curve. The nature of this curve is hysteresis loop for every loading cycle. The dynamic Young's modulus (E) in Eq. (1) is defined by the slope of the secant line which connects two extreme points of the loop:

$$E = \frac{\sigma_d}{\varepsilon_a} \tag{1}$$

where σ'_d and ε_a are amplitude of deviator stress at any cycle of loading and amplitude of axial strain, respectively. Thereafter the dynamic shear modulus G and amplitude of cyclic shear strain (γ) are calculated by using the theory of elasticity as written below:

$$G = \frac{E}{2(1+\mu)} \tag{2}$$

$$\gamma = (1+\mu)_{\mathrm{a}} \tag{3}$$

here μ is Poisson's ratio of soil which equals to 0.5 for saturated sand.

5 Results and Discussions

A series of displacement-controlled dynamic triaxial tests have been performed with sand collected from Kasai river bed at 50% relative density considering two different $\sigma'3$ values say 100 and 200 kPa and for three different axial strain amplitude say, 0.2, 0.3 and 0.5%. All the dynamic tests have been conducted with sinusoidal wave with 1 Hz frequency. Figures 4, 5, 6, 7, 8 and 9 represent the test results of sand sample.

Figures 4 and 5 show the variation of dynamic shear modulus with number of loading cycles at $\sigma_3' = 100$ kPa and 200 kPa, respectively. The magnitude of dynamic shear modulus of soil decreases due to an increase in number of loading cycle for constant values of σ_3'.

The dynamic shear modulus has been reduced considerably at 10th cycle. The reduction of dynamic shear modulus is found to be more prominent in case of higher strain amplitude for both σ_3'. The effect of number of loading cycles on pore pressure ratio for Kasai river sand at 50% relative density has been presented in Figs. 6 and

Fig. 4 Shear modulus versus no. of cycles at $\sigma 3' =$ 100 kPa

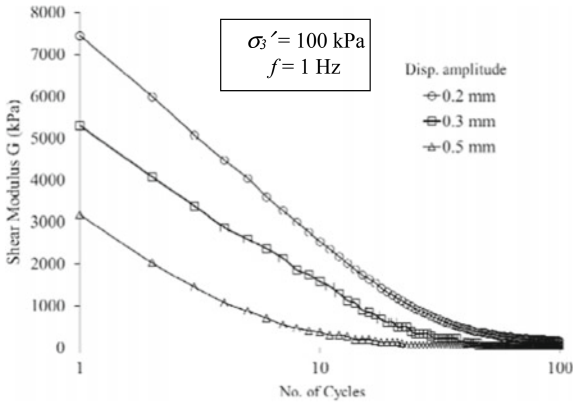


Fig. 5 Shear modulus versus no. of cycles at $\sigma 3' =$ 200 kPa

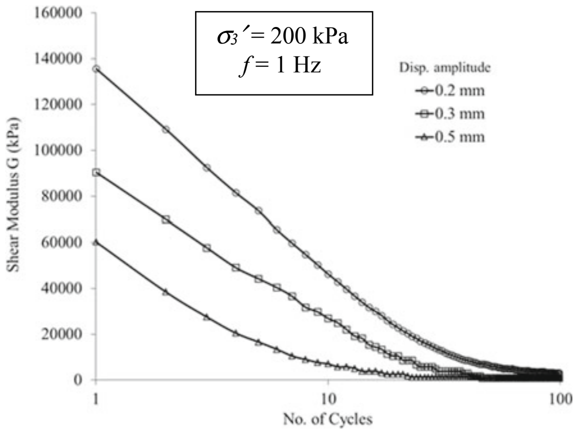
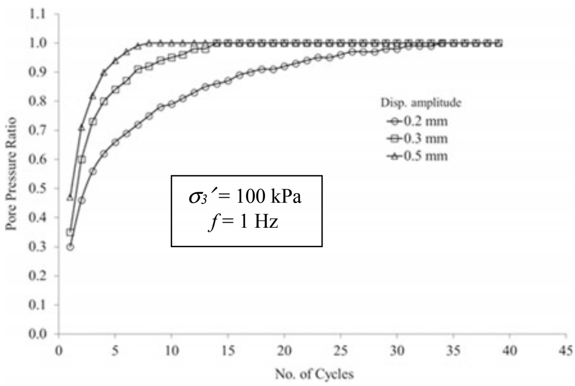


Fig. 6 Pore pressure ratio versus no. of cycle at $\sigma 3' =$ 100 kPa



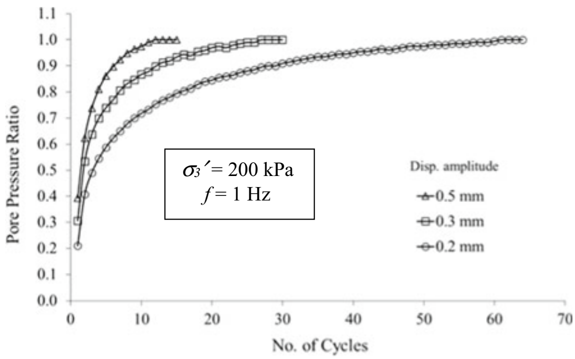


Fig. 7 Pore pressure ratio versus no. of cycle at $\sigma 3' =$ 200 kPa

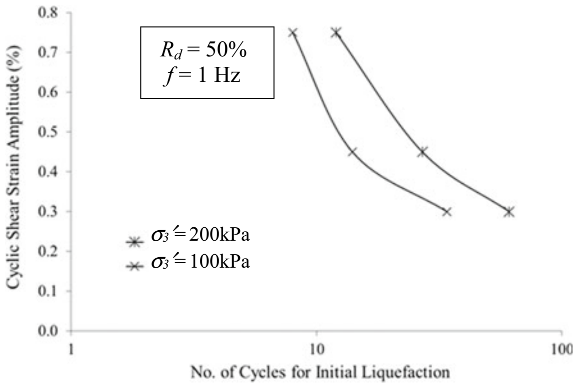


Fig. 8 Cyclic resistance curve for Kasai river sand at 50% relative density

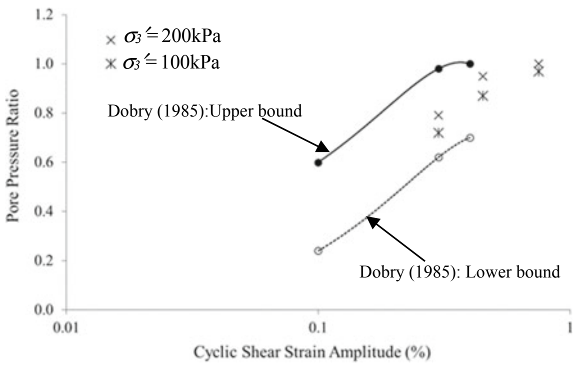


Fig. 9 Variation of pore pressure ratio with cyclic shear strain amplitude for Kasai river sand at 50% relative density

7 for $\sigma_3{}' = 100$ kPa and 200 kPa, respectively. When the excess pore pressure ratio defined as the ratio of excess pore pressure to confining pressure becomes equal to 1, the liquefaction of soil sample occurs. In this case the pore pressure ratio increases continuously due to an increase in loading cycle till liquefaction of soil initiates.

The number of cycles for initial soil liquefaction versus amplitude of γ has been presented in Fig. 8 for $\sigma_3{}' = 100$ and 200 kPa. In this case for 0.75% cyclic shear strain Kasai river sand at 50% relative density can liquefy at 8 no. of cycles and 12 no. of cycles for confining pressure equals to 100 kPa and 200 kPa, respectively. Similarly for $\gamma = 0.3\%$ Kasai river sand at 50% relative density can liquefy at 35 no. of cycles and 61 no. of cycles for $\sigma_3{}' = 100$ kPa and 200 kPa, respectively. Hence the Kasai river sand can easily liquefy at less number of loading cycles for higher magnitude of cyclic shear strain. Fig. 9 illustrates the variation of pore pressure ratio with cyclic shear strain at 10th loading cycle for the Kasai river sand. Dobry [7] provided the upper and lower bound curves for variation of pore pressure with γ at 10th loading cycle which is shown here. The present results are found to match well with the range provided by Dobry [7].

6 Conclusions

The present experimental work reveals that the cyclic shear strain and confining pressures are the two important factors on which liquefaction potential of Kasai river sand depends for a particular relative density. The magnitude of cyclic shear strain amplitude has greatest influence in the value of dynamic shear modulus reduction and pore pressure generation. From the experiments it has been found that Kasai river sand is highly liquefiable at higher cyclic shear strains at 50% relative density and for $\sigma 3'$= 100–200 kPa. The built up pore water pressure is also found to be a function of cyclic shear strain at 10th loading cycle and lies between the upper and lower bounds proposed by Dobry 1985. Therefore proper care is necessary prior to construction of important structure on this soil.

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