Effect of Sample Size and Shear Strain Rate on Cyclic Behavior of Pond Ash

Swaraj Chowdhury[1] and Nihar Ranjan Patra[2]
[1] Research Scholar, Civil Engineering Department, Indian Institute of Technology, Kanpur-208016, India
swaraj@iitk.ac.in

[2] Professor, Civil Engineering Department, Indian Institute of Technology, Kanpur- 208016, India
nrpatra@iitk.ac.in

Abstract. This paper studies the effect of sample size and shear strain rate on cyclic behavior of pond ash samples, collected from an ash dyke of Panki thermal power plant, Kanpur, India (seismic zone III). Laboratory tests have been carried out on ash samples to determine its basic geotechnical properties. To study the effect of sample size, the samples of 50mm × 100mm, 70mm x 140mm and 100mm x 200mm have been chosen for experimental study. A series of consolidated undrained (CU) cyclic triaxial tests at a constant loading frequency of 1 Hz have been performed on these three types of pond ash samples. These tests were carried out with varying cyclic strain rates (0.2%, 0.3% and 0.4%) over a constant confining pressure of 50 kPa to study the effect of shear strain rate. Results show that 100 mm diameter sample exhibit better liquefaction potential and secant shear modulus than 50 mm and 70 mm diameter pond ash samples. The secant shear modulus decreases with increase in cyclic strain rate (0.2% to 0.4%) for every size of samples. The number of cycles for initiation of liquefaction increases 23% to 57% for 100 mm diameter sample as compared to 70 mm and 50 mm diameter samples.

Keywords: Sample Size, Strain Rate, Liquefaction Resistance, Secant Shear Modulus, Material Damping Ratio.

1 Introduction

In India, Thermal power plants are the main resource of power generation where pulverized coal is burnt to generate power. A large amount of coal ash is generated from this. According to Dhadse [1] annual production of ash is about 112 million tons and only 38 million tons from which are being used for construction purposes. Disposal of this ash is a huge problem as it requires huge amount of space and responsible for environmental pollution. In India, for disposal of coal ash 26,325 ha of land is used. To minimize this environmental and disposal problem ash has been deposited for raising of upstream and downstream. This is essential to find out more ways to use waste material like pond ash in construction purposes. To utilize pond ash as a geo-structural material in embankment construction particularly in earthquake prone areas, it is important to study the liquefaction behaviour of pond ash samples with varying strain rate.

Perlea et al. [2] reported that low plastic silts are very prone to liquefaction. Pandian [3] concluded that fine grained ash particles are venerable to liquefaction. Dey and Gandhi [4] emphasized that pond ash in saturated condition possess low shear strength and becomes more liquefiable. According to Jakka et al. [5] the inflow ash sample possess more shear strength than outflow ash sample. Jakka et al. [6] reported that the outflow ash samples are more liquefiable than inflow ash samples. Mohanty and Patra [7] conducted a series of strain controlled cyclic triaxial tests on compacted pond ash samples collected from different locations of Seismic Zone III and Zone IV in India to study the effect of relative density, cyclic strain amplitude, frequency of loading and confining pressure on pond ash samples. Vijayasri et al. [8] conducted strain controlled cyclic triaxial tests on geotextile reinforced Renusagar pond ash samples considering parameters like loading frequency, reinforcing layers, strain amplitude and confining pressure. From the above discussions, it can be concluded that study on the effect of sample size and strain rate on cyclic behavior of pond ash samples is limited.

In present study, experimental investigations have been carried out on Panki pond ash samples of different sizes to study the effect of sample size and strain rate on the cyclic behavior of pond ash samples. Strain controlled cyclic triaxial (CU) tests have been performed on ash samples of three different sizes (50mm x 100mm, 70mm x 140mm and 100mm x 200mm) at three different strain rate (0.2%, 0.3% and 0.4%). The effective confining pressure have been chosen 50 kPa for these tests.

2 Materials and Methodology

2.1 Pond Ash

Pond ash used for experimental study has been collected from an ash dyke of Panki power plant, Kanpur, India. Collection point of pond ash was 350 meter away from the slurry disposal point that's why the pond ash contains relatively finer size of particles. Initial investigations were carried out on Panki pond ash samples to find out its basic physical properties. The physical properties of pond ash may vary with the depth and distance of the collection point from the slurry disposal point.

2.2 Testing Program, procedure and Sample Preparation

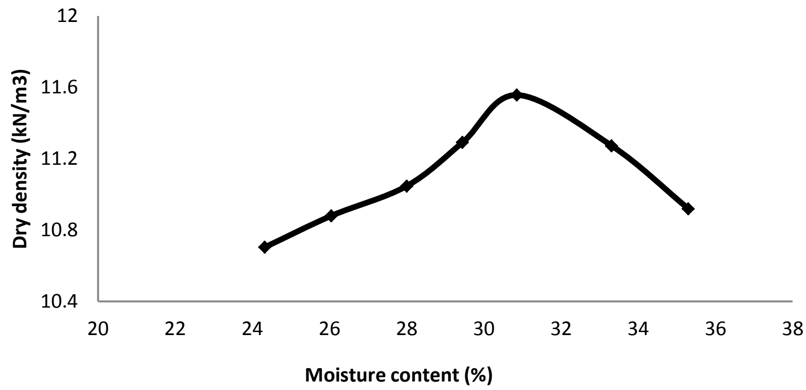
The basic physical properties of Panki pond ash like specific gravity, particle size distribution, compaction characteristics and consolidation behavior have been performed as per IS: 2720 Part III [9], IS: 2720 Part IV [10], IS: 2720 Part VII [11], IS: 2720 Part XIV [12], IS: 2720 Part XV [13] standards. 50mm x100mm, 70mm x 140mm and 100mm x 200mm samples have been prepared at optimum moisture content to investigate the effect of sample size on cyclic behavior of compacted pond ash samples. The cyclic triaxial (CU) tests at a constant loading frequency have been carried out at a confining pressure of 50 kPa on compacted pond ash samples. Cyclic strain rate has been varied from 0.2% -0.4% to study the strain rate effect over a constant loading frequency. The cyclic behavior of ash samples of different sizes have been investigated as per ASTM D5311-92 [14] and ASTM D3999-91 [15].

The Panki pond ash mainly consists of silt size particles, presence of silt sized particles is more than 70% (i.e. 70.94%). Hence, moist-tamping technique suggested by Silver et al. [16] is to be suitable for making compacted pond ash sample. The water according to optimum moisture content was mixed with oven dried pond ash. Then the mixture was placed in the split mold of different sizes (50mm x100mm, 70mm x 140mm and 100mm x 200mm) in four number of layers and every layer was relatively compacted by a tamping tool up to the required density. The density of each layer was checked after compaction, by measuring the height from top of the mold. After compaction each layer was scratched by knife for better interlocking. After that filter paper along with boiled porous stones were kept at top and bottom of the sample of different sizes. Then the sample was covered by a rubber membrane and sealed using four O-rings. After that saturation tube was attached with upper base plate. Then saturation process was started using back pressure saturation system and it continued until B parameter reaches 0.9 which implies 90% saturation. Then the consolidation process was allowed at 50 kPa effective confining pressure and the volume change was recorded during consolidation; after that shearing of sample was pursued without changing the effective confining pressure.

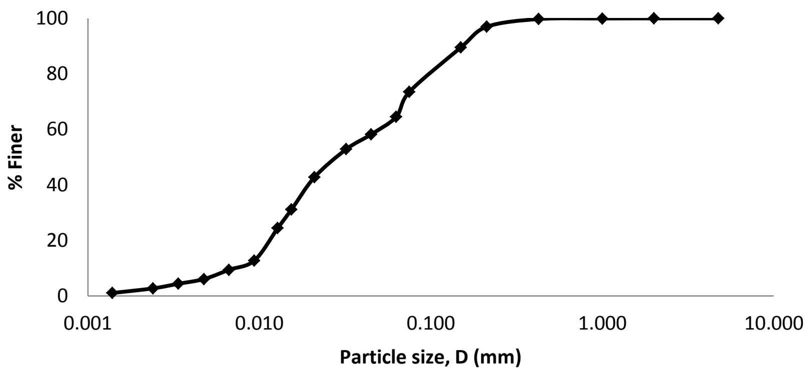
3 Results and Discussions

3.1 Basic Physical Properties of Panki Pond Ash

Panki pond ash mainly consists of silt-sized particles (70.94%), sand sized particles (26.22%) and clay sized particles (2.6%). The maximum dry density is 11.56 kN/m^3 and its corresponding optimum water content is 30.86%. The value of coefficient of uniformity (C_u) was 8.83 and coefficient of curvature (C_c) was 0.49. The grain size distribution curve obtained from sieve and hydrometer analysis and compaction curve obtained from standard proctor compaction are shown in Fig 1. The Coefficient of permeability value was 2.11 x 10^{-7} m/sec and compression index was 0.046. The detailed basic physical properties of Panki pond ash samples are shown in Table 1 [17].



(a)



(b)

Fig. 1. (a) Compaction curve and (b) Grain size distribution of Panki pond ash sample.

Table 1. Basic physical properties of Panki pond ash.

Physical properties	Value
Specific gravity (G)	2.21
Gravel size particles (>4.75 mm)	Nil
Fine sand size particles (0.075-0.425 mm)	26.22%
Silt size particles (0.002-0.075 mm)	70.94%
Clay size particles (<0.002 mm)	2.6%
Coefficient of uniformity (C_u)	8.83
Coefficient of curvature (C_c)	0.49
Maximum dry unit weight	11.56 kN/m^3

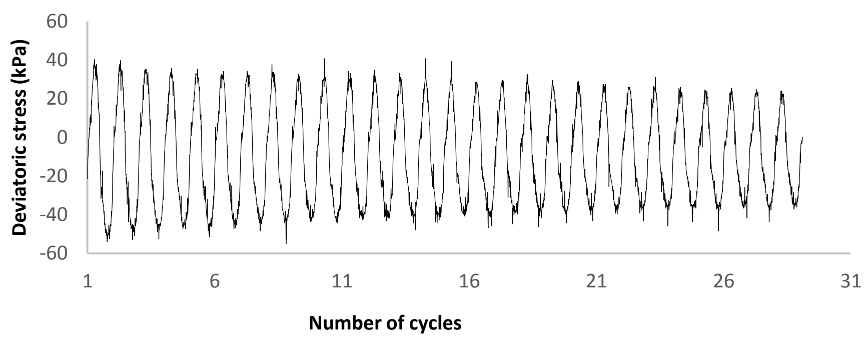
Maximum void ratio (e_{max})	1.78
Minimum void ratio (e_{min})	1.11
Optimum moisture content	30.86%
Plastic Limit	Nil
Coefficient of permeability (k)	2.11 x 10^{-7} m/sec
Compression index	0.046

3.2 Cyclic Behavior and Liquefaction Resistance of Panki Pond Ash

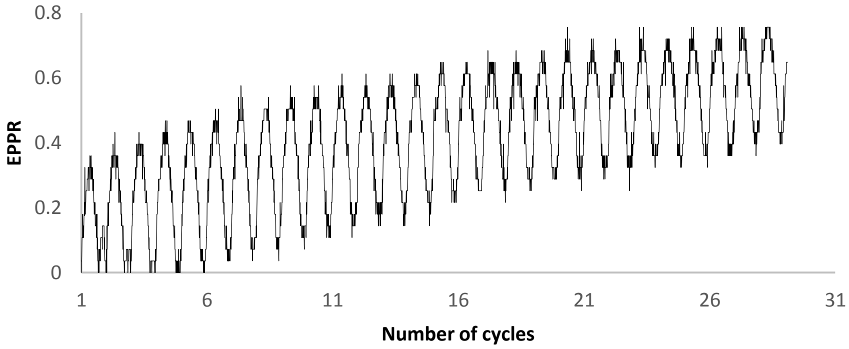
The cyclic behavior of Panki pond ash samples of different sizes (50mm x100mm, 70mm x 140mm and 100mm x 200mm) have been investigated considering the effect of strain (0.2, 0.3 and 0.4%) at a constant confining pressure of 50 kPa. The variation of deviatoric stress with cycle numbers and excess pore pressure ratio (EPPR) with cycle numbers have been investigated. Typical results of 50 mm, 70 mm and 100 mm diameter samples at 50 kPa confining pressure and 0.4% strain rate are shown in Fig 2. It is observed that EPPR increases with number of cycles causing reduction in deviatoric stress. It is also observed that EPPR builds up comparatively at a faster rate for 50 mm diameter pond ash samples.

In cyclic triaxial test, when the excess pore pressure reaches about 80% or above it is considered as initiation of liquefaction. From results, it is observed that the number of cycles responsible for liquefaction decreases as strain rate increases from 0.2% – 0.4%. This happens because the higher strain rate accelerates the failure of sample under cyclic loading. The decrease is about 75% for 50 mm diameter sample, 71.6% for 70 mm diameter sample and 67% for 100 mm diameter sample.

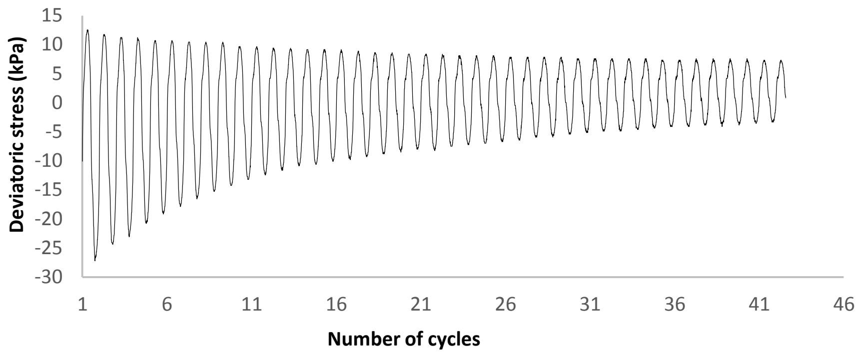
The deviator stress's variation with axial strain for pond ash samples of different sizes have been investigated. Typical result of 100 mm diameter sample tested at strain rate 0.4% is shown in Fig 3. It is found that the hysteresis loop becomes flatter as deviatoric stress decreases due to increase in pore water pressure.



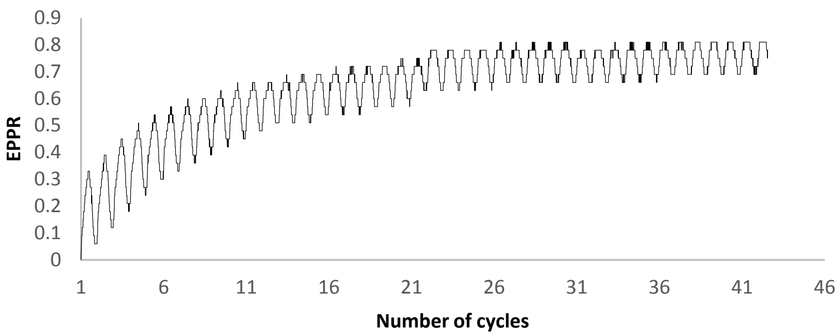
(a)


0.8
0.6
0.4
0.2
0
EPPR
1
6
11
16
21
26
31
Number of cycles

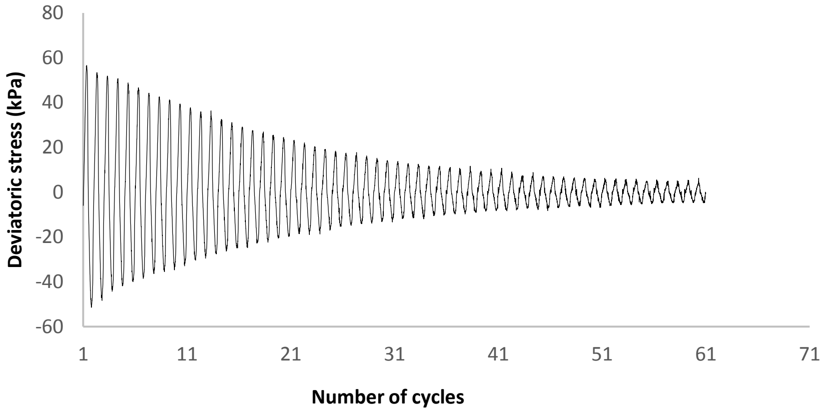
(b)


15
10
5
0
-5
-10
-15
-20
-25
-30
Deviatoric stress (kPa)
1
6
11
16
21
26
31
36
41
46
Number of cycles

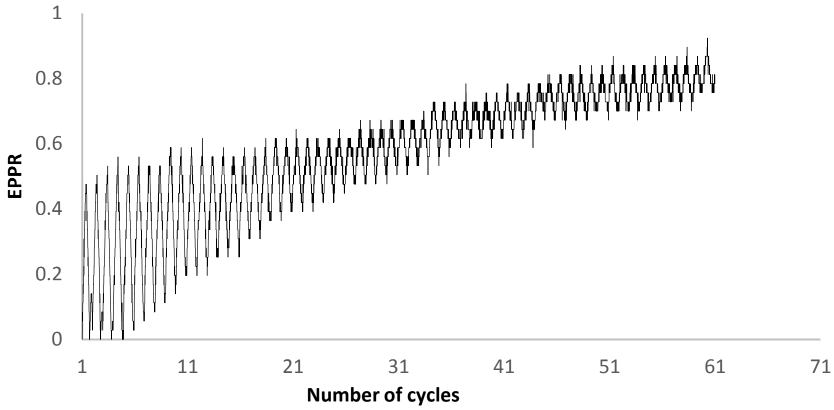
(c)


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
EPPR
1
6
11
16
21
26
31
36
41
46
Number of cycles

(d)



(e)



(f)

Fig. 2. Variation of deviatoric stress and excess pore pressure ratio (EPPR) with number of cycles for (a, b) 50 mm diameter; (c, d) 70 mm diameter; (e, f) 100 mm diameter pond ash sample at 50 kPa confining pressure and 0.4% strain rate.

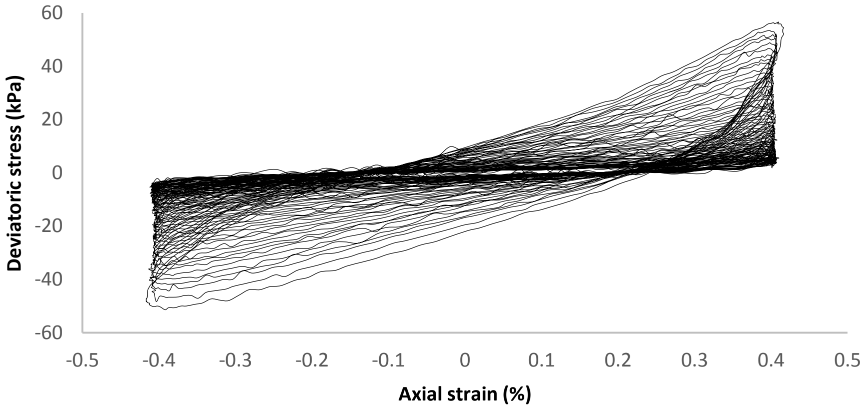


Fig. 3. Variation of deviatoric stress with axial strain (hysteresis loop) for 100 mm diameter pond ash sample at 50 kPa confining pressure and 0.4% strain rate.

Effect of Sample Size. Three different sample size of samples (50 mm, 70 mm and 100 mm diameter) have been chosen to observe the effect of sample size on liquefaction resistance of Panki pond ash samples. The variation of number of cycles responsible for liquefaction with strain rate for all size of samples have been shown in Fig 4. It is observed that cycles responsible for liquefaction increases with size of the samples for every strain rate. The increase is about 27.6% - 44.8% for 70 mm diameter samples and 56.9% - 106.9% for 100 mm diameter samples as compared to 50 mm diameter pond ash samples.

Effect of Strain Rate. Three different cyclic strain rate at an equal interval are chosen for cyclic triaxial tests (0.2%, 0.3% and 0.4%). The variation of number of cycles with cyclic strain rate for 50 mm diameter, 70 mm diameter and 100 mm diameter pond ash samples have been investigated and shown in Fig 4. It is evident that the number of cycles for liquefaction decreases as strain rate increases from 0.2% – 0.4% because higher strain rate accelerates the liquefaction of the sample. The decrease is about 75% for 50 mm diameter sample, 71.6% for 70 mm diameter sample and 67% for 100 mm diameter sample.

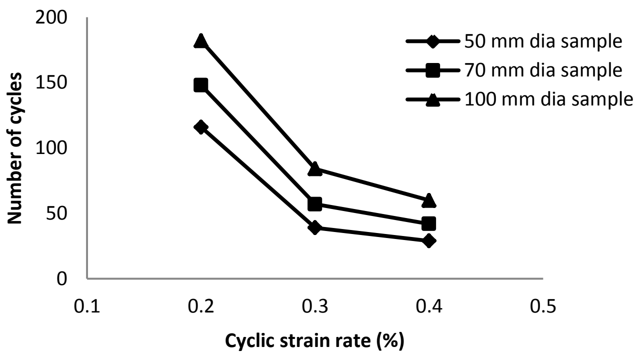


Fig. 4. Effect of sample size and strain rate on liquefaction resistance of Panki pond ash samples tested at 1 Hz loading frequency.

Secant Shear Modulus of Different Sized Pond Ash Samples. Secant shear modulus is the important dynamic property to be investigated. Hysteresis loop which involves deviatoric stress (σ_d) and axial strain. The value of Young's modulus (E_{sec}) can be determined from hysteresis loop. Secant Young's modulus (E_{sec}), dynamic secant shear modulus (G_{sec}) and shear strain (γ) are defined in the following equations.

$$E_{sec} = \frac{\sigma_d}{\epsilon} \tag{1}$$

$$G_{sec} = \frac{E_{sec}}{2(1+\mu)} \tag{2}$$

$$\gamma = (1+\mu) \times \varepsilon \tag{3}$$

Where, μ = Poisson's ratio, it is taken as 0.3 suggested by Newcomb and Birgisson [18], ε = axial strain (%).

The variation of secant shear modulus with strain rate is shown in Fig. 5 for 50 mm diameter, 70 mm diameter and 100 mm diameter pond ash samples. All the results have been given in Table 2. It is observed that the secant shear modulus decreases as strain rate increases from 0.2% to 0.4%. The decrease is about 78.35% for 50 mm diameter samples, 60.8% for 70 mm diameter samples and 36.25% for 100 mm diameter pond ash samples. It is also observed that secant shear modulus increases as sample size increases form 50 mm diameter to 100 mm diameter. The increase is about 7% - 94% for 70 mm diameter samples and 22.7% - 261% for 100 mm diameter samples as compared to 50 mm diameter pond ash samples.

Based on the observations it may be concluded that as sample size increases the shear modulus of Panki pond ash samples increases.

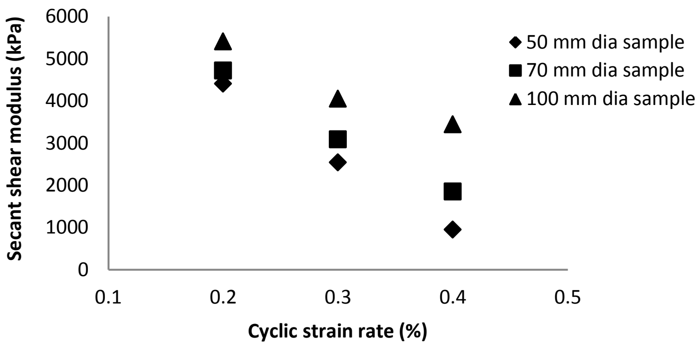


Fig. 5. Effect of sample size and strain rate on secant shear modulus of Panki pond ash samples tested at 50 kPa confining pressure and 1 Hz loading frequency.

Table 2. Comparison of shear modulus and liquefaction resistance of 50 mm diameter, 70 mm diameter and 100 mm diameter compacted Panki pond ash samples tested at 50 kPa confining pressure and 1 Hz loading frequency.

Strain rate (%)	Tested samples	Secant shear modulus (kPa)	Number of cycles for liquefaction
0.2	50 mm diameter pond ash sample	4407	116
0.3	50 mm diameter pond ash sample	2542	39
0.4	50 mm diameter pond ash sample	954	29
0.2	70 mm diameter pond ash sample	4723	148
0.3	70 mm diameter pond ash sample	3090	57
0.4	70 mm diameter pond ash sample	1852	42
0.2	100 mm diameter pond ash sample	5409	182
0.3	100 mm diameter pond ash sample	4057	84
0.4	100 mm diameter pond ash sample	3448	60

4 Conclusion

Present study emphasis on effect of shear strain rate and sample size on cyclic behavior of Panki pond ash samples. Cyclic triaxial (CU) tests have been performed on compacted ash samples with varying cyclic strain rate (0.2, 0.3 and 0.4%) and sample size (50 mm, 70 mm and 100 mm diameter) at a constant confining pressure and loading frequency. The following conclusions are drawn from the present study:

For 50 mm diameter pond ash samples the EPPR develops comparatively faster than the higher diameter pond ash samples.

The number of cycles for initiation of liquefaction decreases as strain rate increases (0.2% - 0.4%) for all size of samples. The decrease is about 75% for 50 mm diameter sample, 71.6% for 70 mm diameter sample and 67% for 100 mm diameter sample.

The number of cycles for liquefaction increases with size of the samples. The increase is about 27.6% - 44.8% for 70 mm diameter samples and 56.9% - 106.9% for 100 mm diameter samples as compared to 50 mm diameter pond ash samples.

Secant shear modulus decreases as strain rate increases from 0.2% to 0.4%. The decrease is about 78.35% for 50 mm diameter samples, 60.8% for 70 mm diameter samples and 36.25% for 100 mm diameter pond ash samples. Secant shear modulus increases as sample size increases. The increase is about 7% - 94% for 70 mm diameter samples and 22.7% - 261% for 100 mm diameter samples as compared to 50 mm diameter pond ash samples.

Based on this study, it may be concluded that liquefaction resistance and shear modulus of Panki pond ash samples increase as sample size increases and decrease as strain rate increases.

References

1. Dhadse, S., Kumari, P., Bhagia, L. J.: Fly ash characteristics, utilization and government initiatives in India: A review. J. Sci. Ind. Res. 67(1), 11–18 (2008).
2. Perlea, V. G., Koester, J., Prakash, S.: How liquefiable are cohesive soils? In: 2nd Int. Conf. on Earthquake Geotechnical Eng., vol. 2, pp. 611–618. ISSMGE, Lisbon, Portugal (1999).
3. Pandian, N. S.: Fly ash characterization with reference to geotechnical applications. J. Indian Inst. Sci. 84(6), 189–216 (2004).
4. Dey, A. K., Gandhi, S. R.: Evaluation of liquefaction potential of pond ash. In: 2nd Int. Conf. on Geotechnical Engineering for Disaster Mitigation and Rehabilitation, pp. 315–320. Springer, Berlin (2008).
5. Jakka, R. S., Ramana G. V., Datta M.: Shear strength characteristics of loose and compacted pond ash. Geotech. Geol. Eng. 28(6), 763-778 (2010b). doi: 10.1007/s10706-010-9337-1.
6. Jakka, R. S., Datta M., Ramana G. V.: Liquefaction behaviour of loose and compacted pond ash. Soil Dyn. Earthquake Eng. 30(7), 580-590 (2010a). doi: 10.1016/j.soildyn.2010.01.015.
7. Mohanty, S., Patra, N. R..: Cyclic behavior and liquefaction potential of Indian pond ash located in seismic zones III and IV. J. Mater. Civ. Eng. 26(7), 06014012 (2014). doi: 10.1061/(ASCE)MT.1943-5533.0000946.
8. Vijayasri, T., Patra N. R., Raychowdhury, P.: Cyclic behavior and liquefaction potential of Renusagar pond ash reinforced with geotextiles. J.Mater. Civ. Eng. 28(11), 04016125 (2016). doi:10.1061/(ASCE)MT.1943-5533.0001633.
9. Bureau of Indian Standards. : Tests for soils for determination of specific gravity (reaffirmed 2002). IS: 2720 (Part III). New Delhi, India (1980b).
10. Bureau of Indian Standards. : Tests for soils for grain size analysis. IS: 2720 (Part IV) (reaffirmed 2006). New Delhi, India (1985b).

11. Bureau of Indian Standards. : Test for soils for determination of water content—Dry density relation using light weight compaction. IS: 2720 (Part VII) (reaffirmed 2011). New Delhi, India (1980a).
12. Bureau of Indian Standards. : Determination of density index (relative density) of cohesion less soils. IS: 2720 (Part XIV) (reaffirmed 2006). New Delhi, India (1983).
13. Bureau of Indian Standards. : Tests for soils for determination of consolidation properties. IS: 2720 (Part XV) (reaffirmed 2002). New Delhi, India (1986).
14. American Society for Testing Materials.: Standard test method for load controlled cyclic triaxial strength of soil. ASTM D5311 standards. ASTM International, West Conshohocken, PA (1992).
15. American Society for Testing Materials.: Standard test method for determination of the modulus and damping properties of soils using the cyclic triaxial test apparatus. ASTM D3999 standards. ASTM International, West Conshohocken, PA (1996).
16. Silver, M.L., Chan, C.K., Ladd, R.S., Lee, K.L., Tiedemann, D.A., Townsend, F.C., Valera, J.E. and Wilson, J.H.: Cyclic triaxial strength of standard test sand. Journal of Geotechnical and Geoenvironmental Engineering 102, 511-523 (1976).
17. Chowdhury, S., Patra, N. R. : Effect of strain rate on cyclic behavior of pond ash reinforced with geocell. In: SUCI, GeoMEast International Congress and Exhibition, Accepted. Springer, Cairo (2019).
18. Newcomb, D. E., Birgisson, B.: Measuring in situ mechanical properties of pavement subgrade soils. National Academy Press, Washington, DC (1999).