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Dynamic Behaviour of Pond Ash Mixed with Crumb Rubber

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Abstract.The demand for electricity is ever increasing and the pond ash generation in huge capacities has grown into a serious problem all over the world. Since the coal ash are hydraulically deposited in slurry form in pond ash, it is highly susceptible to liquefy during dynamic loading such as earthquake. The reclamation of land from ash ponds in earthquake-prone zones needs a comprehensive understanding of its dynamic behaviour. Crumb rubber being another material generated from the tyre waste has found various applications in the field of civil engineering. This study looks to gauge the dynamic behavior of pond ash mixed with crumb rubber such that its suitability as a foundation material could be determined when subjected to dynamic loading. For a greater accuracy, a sample size of 70 mm diameter and 140 mm height has been used for dynamic triaxial test. A series of strain controlled Cyclic Tri-axial tests have been carried out for compositions of pond ash and crumb rubber with proportion of crumb rubber varying from 0 to 20% at an interval of 5%, an amplitude of 1.12 mm and a frequency of 0.4 Hz. The composition having 15% crumb rubber and 85% fine pond ash by weight took more cycles to fail when compared to 100% fine pond ash thereby decreasing its liquefaction potential. Shear modulus of all the mix compositions till the respective liquefaction cycles have also been compared.

Keywords: Pond ash, Crumb Rubber, Cyclic tri-axial test, Liquefaction, Shear modulus, Crumb rubber

1 Introduction

India having a population of 1.21 billion Census (2011) and growing at a rapid rate is creating a tremendous pressure on its resources. Coal is one such resource that is burnt by Thermal power plants (TPPs) to generate electricity. For electricity generation, the coal is burnt to produce steam, fly ash and bottom ash. Fly ash and bottom ash are generally 12-20% by weight of coal (Chen *et al.*, 1991). Fly ash and bottom ash remains as waste for TPPs after coal is burnt. For disposal of this waste two methods are in practice namely dry disposal and wet disposal approach. In India, wet disposal approach is widely implemented, in which bottom ash and fly ash are

amalgamated, mixed with water in 1:10 to make it slurry and transported to ash ponds through dykes (Singh and Singh, 2019). After the slurry reaches ash ponds it is then allowed to settle down and the settled slurry is called Pond ash. Though there are various areas where pond ash is being used but its utilization is approximately 67% of the total ash produced by weight of which 25% is used by cement industry and rest by Bricks & Tiles, Ash Dyke Raising, Mine filling, Reclamation of low lying area, Roads and Flyovers and likewise still leaving 33% ash unused (CEA, 2019). A large area of land is required for the disposal of this pond ash and this area is generally treated as a waste land. Geotechnical engineering practices give us a chance to reclaim this waste land so that pressure on our important resource i.e. land can be eased out. Geotechnical characterization of ash has been studied by Horiuchi *et al.* (1995); (Sawa *et al.* (2002); Kaniraj and Gayathri (2004); Pandian (2004); Singh *et al.* (2019). Ash when used as railway subgrade material experiences a cyclic load due to continuous loading applied on rails by wheels of train. Similar condition occurs when a structure built on ash pond is subjected to earthquake loading. In order to reclaim the land from ash pond, the understanding of static and dynamic behaviour of pond ash becomes very essential. The main objective of the current investigation is to study the dynamic behaviour of Pond ash collected from Guru Gobind Singh SuperTPP (Rupnagar, Punjab). It is important to have a good understanding of dynamic behaviour of soils because the regional conditions sometimes effect the response of soil-structure interface pre and post construction. Dynamic tricycle testing is carried out on the soils when it is necessary to assess their strength and deformation characteristics under dynamic loading conditions. These conditions may include dynamic loading from earthquakes, vehicle and train travel, tidal waves, wind, vibration engines, *etc.*

Pond ash is liquefiable and the liquefaction resistance of ash reinforced with geosynthetic fiber/ mesh distributed randomly has been determined by Boominathan and Hari (2002). Zand *et al.* (2009) studied the relationship between cyclic stress amplitude, density and the number of cycles taken by fly ash to liquefaction. Jakka *et al.* (2010) compared the liquefaction resistance behaviour of loose pond ash and compacted pond ash. Mohanty and Patra (2012, 2016a, 2016b) in their study found that the dynamic response of coal ash under medium seismic loading is satisfactory. It has been found that the pond ash is more susceptible to liquefaction when under cyclic loads than river sand by Chattaraj and Sengupta (2017) and the role of specific gravity, unit weight and grain size distribution is also vital while determining cyclic strength of geotechnical materials. Reddy *et al.* (2017) worked on improvement of static performance of pond ash by reinforcing it with optimum geogrid layer.

Over the past two decades, there has been a steep growth vehicular sales and thereby an incremental growth in generation of waste rubber tiers across the globe. These waste rubber tires get accumulated and in return pose a significant environmental problem. The disposal of this environmentally hazardous scrap tires is a challenge that is faced by environment and geotechnical engineers especially in a developing country like India. A significant work has been reported for the

improvement in the geotechnical aspects of coarse grained soils by several scholars using different types of waste rubber tires, specifically fibres, chip, shreds and crumbles (Ahmed and Lovell, 1993; Edil and Bosscher, 1994; Foose *et al.*, 1996; Tatlisoz *et al.*, 1998; Moo-young *et al.*, 2003; Zornberg *et al.*, 2004; Attom, 2006; Rao and Dutta, 2006; Edincliler *et al.*, 2013; Karabash and Cabalar 2015). Kim and Kang (2013) have explored the effects on geotechnical characteristic due to inclusion of bottom ash and crumb rubber by making a composite geomaterial. Priyadarshie *et al.* (2015) have done a simultaneous comparison of the performance of crumb rubber with fly ash and clay. Yadav and Tiwari (2016) studied compaction characteristics of clay soil mixed with crumb rubber and the percentage of crumb rubber by weight varied from 2.5 to 10% and size between 0.8 and 2 mm. In the previous studies most of the work is focused on pond ash and crumb rubber individually, also aspect of dynamic behaviour of pond ash mixed with crumb rubber is untouched and this is the reason for conducting the current study. Size of pond ash is silty sand and crumb rubber in the current study varies from 75 -425 microns. This size is available in market but the research on smaller size of crumb rubber in the dynamic loading is scanty.

This study aims to gauge the dynamic behavior of pond ash mixed with crumb rubber by conducting dynamic triaxial tests on fully saturated samples. Also the suitability of the mix as a foundation material needs to be determined when subjected to dynamic loading.

2 Materials

Pond ash has been collected from Ash pond of Guru Gobind Singh Super TPP (Rupnagar, Punjab). The power plant is a coal based power plant with an installed capacity of 1240 MW, now only 840 MW output is achieved. The representative sample of pond ash has been collected from approximately 300 m away from the partition dyke as shown in Fig. 1. The second material that is crumb rubber has been collected from industrial area in Jalandhar (Punjab).



Fig. 1. Satellite image of Ash pond of Ropar TPP (Punjab). (Source: Google Maps)(Accessed on 21-May-2020)

3 Plan of Experiment and Characterisation of Material

Pond ash (PA) and crumb rubber (CR) have been mixed by weight with 0-20 % variation in crumb rubber. In total five compositions have been tested as shown in Table 1.

Table 1. Composition of sample mix

Fine Pond Ash (PA) % (by wt.)	Crumb Rubber (CR) % (by wt.)	Denotation
100	0	PA
95	5	PA5CR
90	10	PA10CR
85	15	PA15CR
80	20	PA20CR
0	100	CR

The materials that are used in this study are waste material produced from power and tire industry, whose geotechnical properties are enumerated in Table 2. Specific gravity of the mix compositions as per (IS-2720-Part-3:1980) varied from 1.81 for PA20CR sample to 1.98 for PA sample.

Table 2. Physical properties of PA and CR mix compositions.

	PA	PA5CR	PA10CR	PA15CR	PA20CR	CR
Specific gravity (G)	1.98	1.95	1.90	1.87	1.81	1.14
Gravels (>4.75 mm) (in %)	0	0	0	0	0	0
Coarse sand (4.75 - 2.0 mm) (in %)	0.16	0.15	0.37	0.60	0.38	0.00
Medium sand (2 - 0.425 mm) (in %)	0.82	2.99	4.12	4.65	5.31	5.54
Fine Sand (0.425 - 0.075 mm) (in %)	46.73	46.63	47.33	48.11	49.55	63.28
Silt (0.075-0.002 mm) (in %)	50.52	49.31	46.46	44.04	42.76	31.11
Clay (< 0.002 mm) (in %)	1.77	0.92	1.62	2.60	2.00	0.07
D ₁₀ (mm)	0.02	0.03	0.03	0.02	0.02	0.16
D ₃₀ (mm)	0.06	0.06	0.06	0.06	0.06	0.20
D ₆₀ (mm)	0.09	0.09	0.09	0.09	0.10	0.25
D ₅₀ (mm)	0.08	0.08	0.08	0.08	0.08	0.23
C _u	3.70	3.33	3.14	4.27	4.35	1.56
C _c	1.72	1.48	1.36	1.74	1.62	0.95
Max. Dry Density (MDD) (kN/m ³)	10.24	10.35	10.37	10.28	9.76	-
Optimum Moisture Content (%)	40.3	34	36	32.5	35.5	-
Bulk Density (kN/m ³)	14.37	13.87	14.11	13.62	13.22	-

The grain size analysis is performed for all the mix compositions as per (IS-2720-Part-4:1985 Reaffirmed- May 2015) as shown in Fig. 2. Hydrometer method has been used to determine the gradation curve for particles finer than 75 microns. The mix compositions are therefore described as non-plastic silt sized fractions.

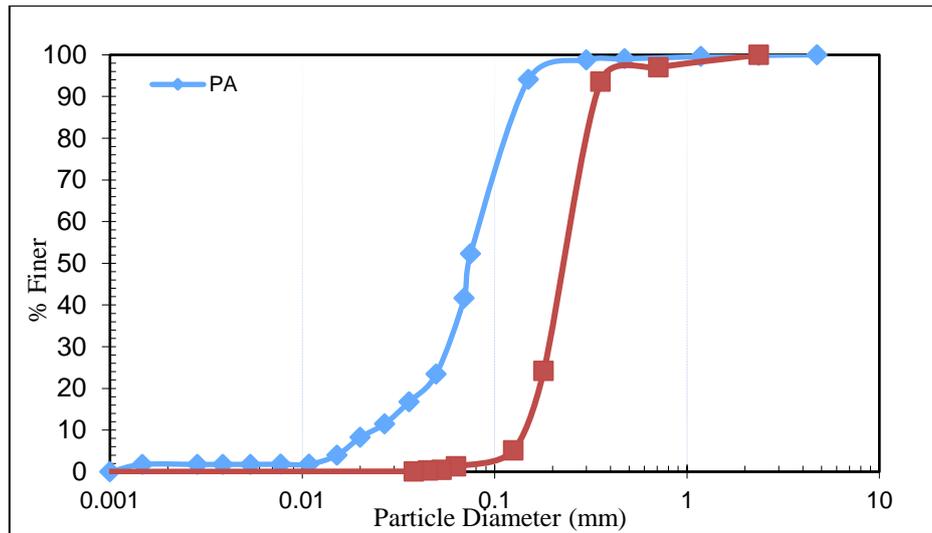


Fig. 2(a). Grain size distribution of Pond ash and Crumb Rubber used in this study.

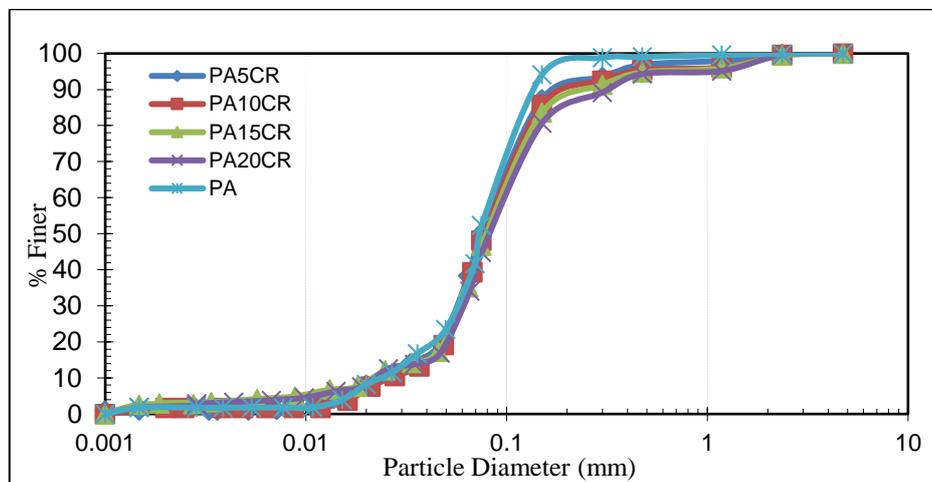


Fig. 2(b). Grain size distribution of mixture of Pond ash and Crumb Rubber used in this study.

The maximum dry unit weight has been calculated using Standard Proctor Test as per (IS-2720-Part-7:1980) as shown in Fig. 3. The decrease in dry density of PA and CR mix can be attributed to the lower specific gravity of CR.

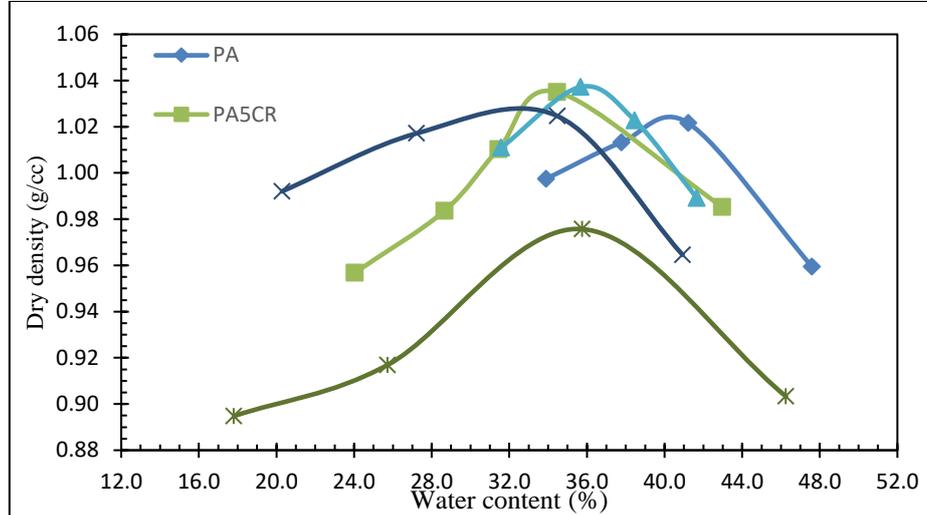


Fig. 3. Standard Proctor test curves of mixture of Pond ash and Crumb Rubber used in this study.

4 Experimental Setup

In the current study cyclic tri-axial test has been performed on a Cyclic triaxial testing machine as per ASTM 3999 and ASTM 5311. The machine has seven components namely a pneumatic pressure cylinder attached with air filter device, a pressure panel with various pressure regulating knobs, a cyclic loading machine, a double walled tri-axial cylinder, a vacuum pump, a de-airing chamber and a computer as shown in Fig. 4.

Before starting the cyclic tri-axial tests, the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of respective samples needs to be determined. For the current study the samples were prepared at 95% MDD because it is usually the maximum density that can be achieved at site. Samples are prepared in a cylindrical mould with length of sample (140 mm) being twice its diameter (70 mm). The larger size of sample gives more accurate results. After the sample is prepared it is then attached to the cyclic tri-axial cell with filter paper porous stones on top and bottom, O-rings and a platen at the top. Membrane is checked for leakages, then the tri-axial cell is placed and sealed using silicon sealant over the pond ash sample. Air is removed from cell using a vacuum pump and the piston of tri-axial cell is placed on platen such that the base of piston sticks with top of platen. Water from de-airing chamber is then filled in triaxial cell through the pneumatic control panel. After the water is filled, an initial confining pressure and back pressure of 1 and 0.8 kPa respectively is applied to the sample for saturation purpose. Pore pressure reaches the back pressure with time and the saturation of sample starts. Saturation at any point of

time is determined by Pore pressure parameter 'B' (ratio of change in pore pressure after back pressure valve is closed to the change in confining pressure). When value of B reaches near 1, the sample is consolidated at 100 kPa effective stress. After consolidation the cyclic tri-axial cell is attached to load sensor and the load valve is opened. Back pressure is closed when performing the cyclic test. Cyclic tri-axial cell is then connected to loading frame and lock on it is released such that the assembly act as a single unit. A file is saved in Computer at desired location. Tare load and Displacement seen on computer screen before starting the test. The test is over when the pore water pressure reaches confining pressure.



Fig. 4. Dynamic Triaxial testing apparatus used in the present study.

A series of strain controlled Cyclic Tri-axial tests have been carried out for compositions of pond ash and crumb rubber with proportion of crumb rubber varying from 0 to 20% at an amplitude of 1.12 mm and frequency of 0.4 Hz.

6 Results and Discussions

The excess pore pressure v/s number of cycles has been obtained from a series of strain controlled dynamic tri-axial tests performed on samples as shown in Fig. 5. It may be established from the current study that the number of cycles to liquefaction depends on the quantity of crumb rubber used. Sample fails when soil sample liquefies and in this case sample liquefies when excess pore pressure reaches equal to effective confining pressure of 1 kg/cm^2 because the tests have been performed at 100 kPa effective confining pressure. It has been observed from the experiments that it took 12 cycles to reach excess pore pressure 1 kg/cm^2 for PA case as depicted in Fig. 5(a). It takes lesser cycles to liquefy due to the early generation of pore pressure and dissipation of effective pressure. As the percentage of crumb rubber increases the number of cycles taken by sample to liquefy also increases thereby increasing the liquefaction resistance of the mixture. The pore pressure generation in crumb rubber added mixtures gets delayed with increment in cycles due to increased density of mix composition till PA15CR. When Crumb rubber percentage increases to 5% the number of cycles increases to 18 as evident from Fig. 5(b). It takes 30 cycles to failure when Crumb rubber percentage is 10% as shown in Fig. 5(c). When Crumb rubber percentage further increases to 15%, this case witness the maximum liquefaction resistance because the number of cycles to failure raises up to 43 as shown in Fig. 5 (d). After this point any further increase in Crumb rubber percentage don't decrease liquefaction potential of mix composition and for PA20CR sample only 22 cycles are needed to liquefy the sample as shown in Fig. 5(e). This decrease is due to decreased unit weight of PA20CR sample from PA15CR sample.

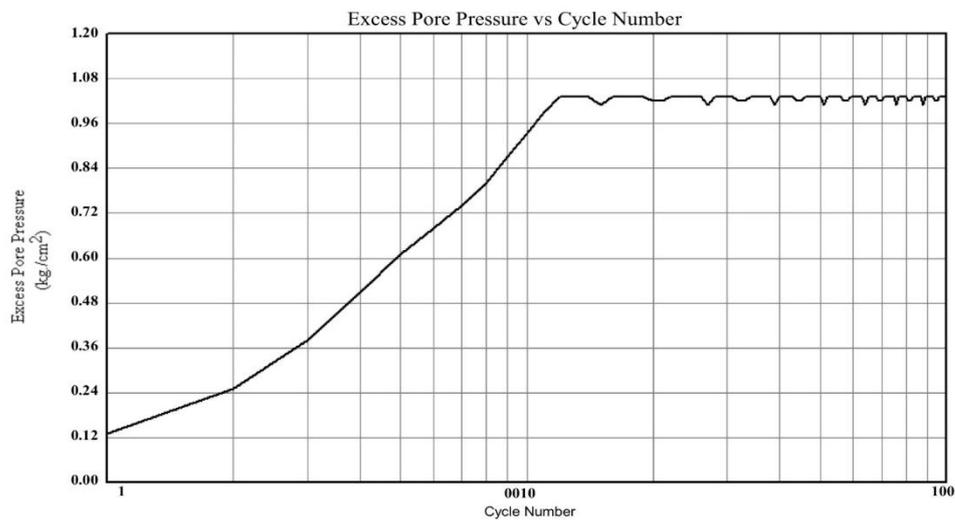


Fig. 5(a). Excess Pore Pressure v/s Cycle number for PA sample

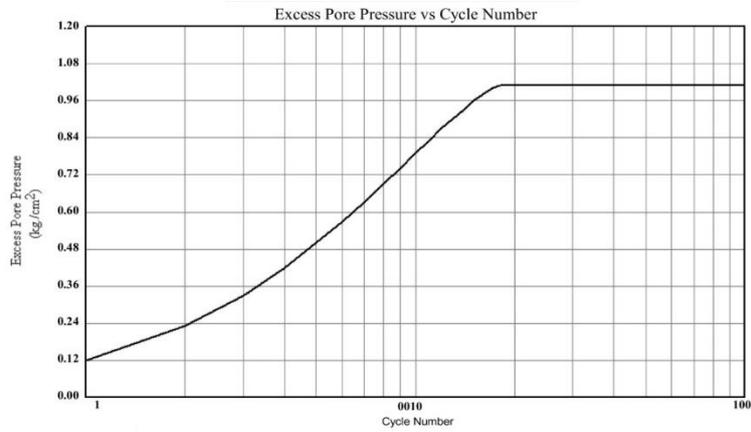


Fig. 5(b). Excess Pore Pressure v/s Cycle number for PA5CR sample

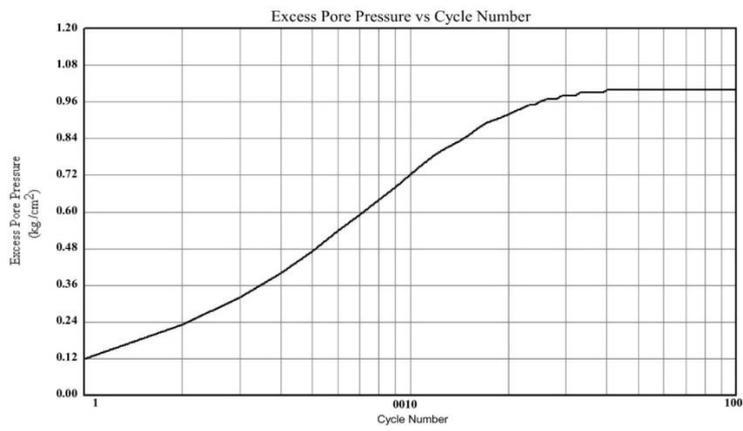


Fig. 5(c). Excess Pore Pressure v/s Cycle number for PA10CR sample

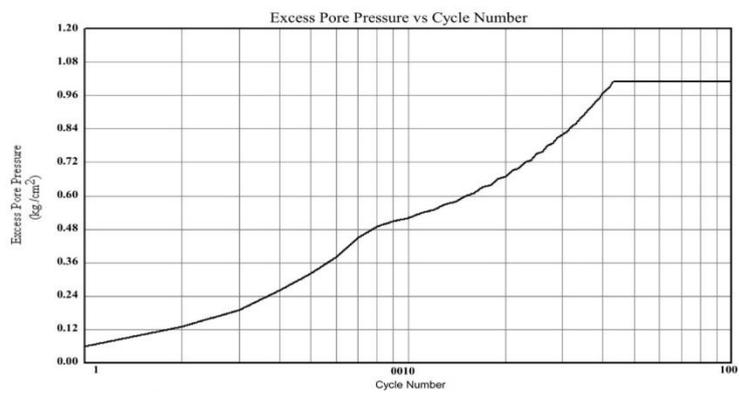


Fig. 5(d). Excess Pore Pressure v/s Cycle number for PA15CR sample

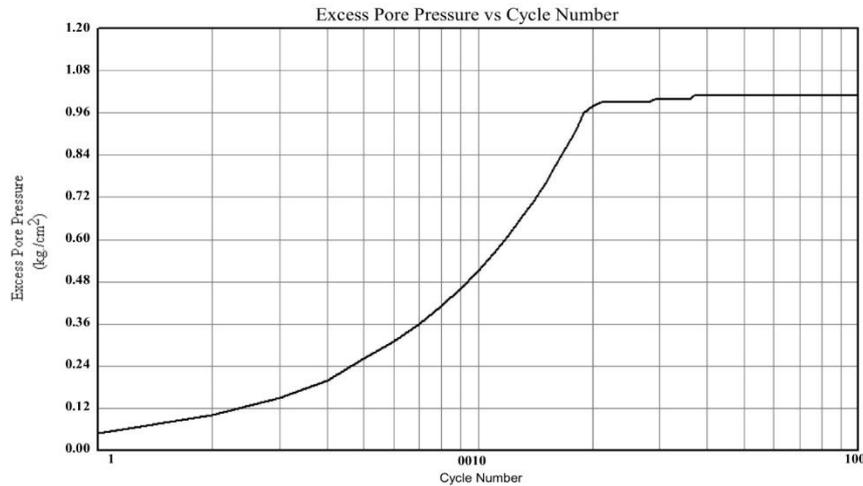


Fig. 5(e). Excess Pore Pressure v/s Cycle number for PA20CR sample

Liquefaction takes place when pore water pressure in soil exceeds the difference between cell pressure and back pressure. In the current study when pore pressure reaches unity the sample liquefies. Initially when no Crumb rubber is mixed with pond ash the water in Pond ash sample exerts more pressure on ash particles, thereby taking lesser number of cycles to liquefaction compared to Crumb rubber mixed with Pond ash samples. The number of cycles to failure increases from 12 to 43 for the samples with Crumb rubber 0% to 15% and further increase in percentage of Crumb rubber to 20% decreases the liquefaction resistance as depicted in Fig. 6. This decrease can be attributed to the lesser specific gravity of Crumb Rubber particles.

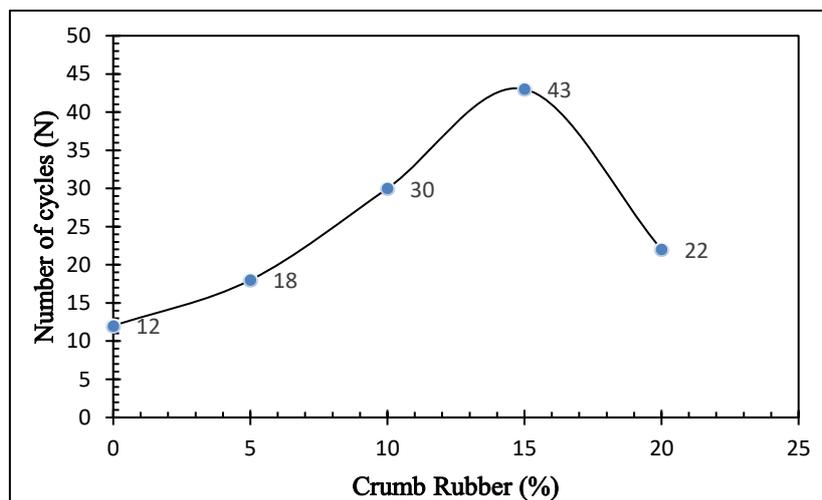


Fig. 6. Number of cycles to Liquefaction v/s Percentage of CR in mixture

Shear modulus is defined as the ratio of shear stress to shear strain. Greater value of shear modulus means the material is stiffer and shear strength of material is also higher for the sample. In the current study Secant shear modulus for each cycle till the sample liquefies have been calculated and shown in Fig.7. Addition of crumb rubber to Pond ash decreases the shear modulus, voids are filled adequately by crumb rubber in PA10CR and PA15CR for crumb rubber mix samples, but crumb rubber is lighter and possess less Shear strength compared to Pond ash and therefore Pond ash sample takes maximum shear followed by PA15CR, PA5CR, PA10CR and PA20CR as evident form Fig. 7. Experimentally, Pond ash sample showed maximum shear modulus to be greater when compared to the rest of mix composition because 100PA show greater stiffness than the rest. This change in shear modulus can be attributed to the inter-particle bonding and lesser stiffness offered by crumb rubber. Also, the density of the mixture increases till PA15CR mixture and then decrease may be attributed for the reason for higher value of shear modulus then PA5CR, PA10CR & PA20CR.

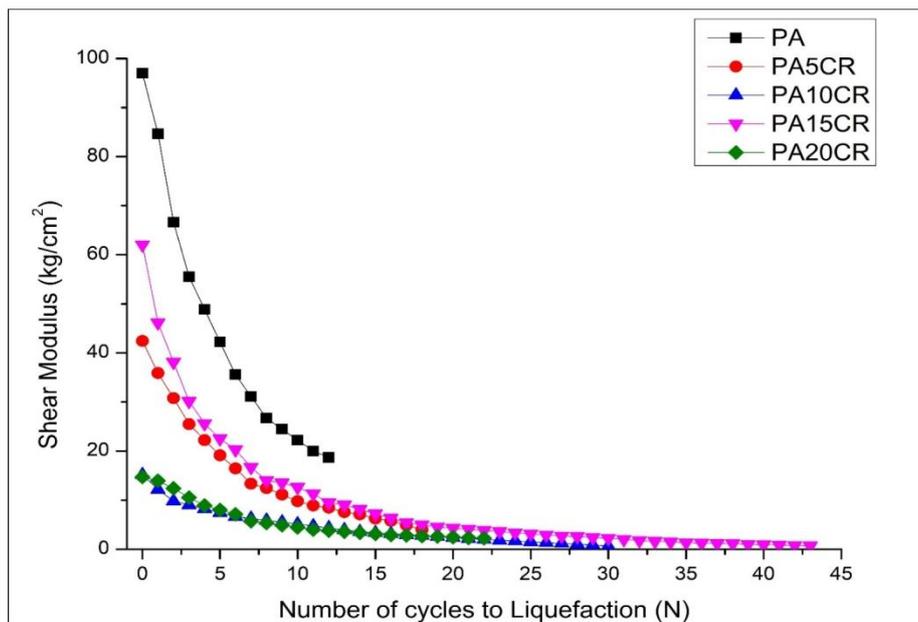


Fig. 7. Variation of shear modulus (G) with Number of cycles to liquefaction(N).

7 Conclusions

Cyclic tri-axial tests have been performed at 1.12 mm amplitude (0.8% axial strain) at 0.4 Hz to obtain the characteristics required for the analysis of the dynamic response

of the existing ash pond. Based on the current study, the general findings are as follows:

1. The geotechnical characteristics of the five compositions have been studied. Crumb rubber (CR) being lighter with Specific gravity of 1.14 fills the voids in mix composition initially to increase maximum dry density (MDD) but increment after 10% CR in the mix results in a lesser MDD. After addition of CR the optimum moisture content (OMC) decreases initially followed by a slight variation. The decrease can be attributed to better interlocking of particles at a lower water content.
2. The number of cycles taken by the compositions to liquefy depends on the percentage of crumb rubber mixed to pond ash up till 15% Crumb Rubber, after further increment the number of cycles starts to decrease. As the percentage of crumb rubber increases the number of cycles taken by sample to liquefy increases to 43 at 85PA+15CR composition thereby increasing the liquefaction resistance of the mixture. It can be concluded that the 15% CR sample shows better liquefaction resistance than the rest of samples tested.
3. Though 100PA sample shows better results in shear modulus comparison but it is the one that liquefies at least number of cycles. Whereas the sample of 85PA+15CR gives relatively better results for shear modulus and best liquefaction resistance.

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