EVALUATION OF LIQUEFACTION POTENTIAL OF POND ASH

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ABSTRACT :

Pond ash (fly ash) obtained from thermal power plants or similar plants which use the coal as a fuel, has spread over a large area of land in the country like India. A challenging task is to improve these areas for further construction of civil engineering structures like buildings, roads etc. Keeping this in view the studies on pond ash have been taken up. Pond ash is a very fine, non-plastic and loose material dumped over the ground usually for a height of 10 to 30 m. Such types of materials are normally susceptible to liquefaction. The aim of this paper is to study the liquefaction behavior of pond ash obtained from a particular thermal power plant of India. The samples of pond ash obtained from top 5 m were prepared at a relative density of 20%. The tests were conducted on small Shake Table in the laboratory at different accelerations varying from 0.1g to 0.5g, keeping the frequency of dynamic load constant. The liquefaction resistance was determined in terms of pore water pressure ratio (r_u). The liquefaction resistance is also determined based on the data collected from the field tests.

KEYWORDS: Liquefaction Potential, Pond Ash, Shake Table, Harmonic Excitation

1. INTRODUCTION

Significant damage due to liquefaction has been reported in literature. For example during the recent earthquakes such as Kobe (1995), Kocaeli (1999), Chi-chi (1999) and Bhuj (2001), the liquefaction was a major cause of damage to civil engineering structures. A number of researchers have studied liquefaction characteristics of sand e.g. Prakash (1981), Kramer (1996) and Saran (2006). A number of researches reported in literature demonstrate that liquefaction characteristics of a soil depend upon a large number of factors e.g. Seed and Lee (1966), Seed and Idriss (1971), Finn et al. (1976) and Seed et al. (1985). However, most of these studies are on sand and the liquefaction resistance of pond ash is rarely reported. Gandhi and Dey (1999), and Zand et al. (2007) presented liquefaction analysis of pond ash. Boominathan and Hari (2002) have demonstrated the effect of reinforced fibres on the liquefaction resistance of fly ash.

The liquefaction studies of large saturated samples excited on a shaking table offer many advantages over commonly used cyclic triaxial and simple shear tests. The major advantage is that uniform accelerations will be developed throughout the sample at low frequencies under plane strain conditions that correspond to the *in situ* propagation of shear waves. A number of vibration table studies for liquefaction are reported in the literature e.g. Florin and Ivanov (1961), Finn (1972), DeAlba et al. (1976) and Gupta (1977). Liquefaction behaviour of sands has been extensively studied and is currently a phenomenon that can be reasonably predictable. Perlea et al. (1999) reported that many silt and clay deposits with low plasticity index such as tailing materials have also been found vulnerable to liquefaction.

The aim of this paper is to evaluate the liquefaction resistance of pond ash. Since pond ash predominantly consists of non-plastic silt size particles of relatively low permeability than sand, it seems to be prone to liquefaction during earthquakes. Therefore, it is essential to study the liquefaction behaviour of pond ash. This study has significance, as the pond ash covers a large extent of the area, near thermal power plants in India. In the present study, a number of tests have been conducted on a small shake table imparting one–dimensional horizontal harmonic excitations to the ash samples. The tests have been conducted at different accelerations varying from 0.1 g to 0.5 g, keeping the frequency of dynamic load constant. In each test, shaking has been imparted to shake table for 60 seconds and pore pressure has been recorded after a regular number of cycles. The time for building-up of maximum pore pressure, duration for which maximum pore pressure stays and time for dissipation of pore water pressure has been measured during each test. The data are analyzed and salient features of the liquefaction behavior of the pond ash have been observed.

Also Standard Penetration Tests were conducted at the same site and index properties of samples are determined in the laboratory. Using the Seed and Idriss method, liquefaction resistance of pond ash was determined. From the results obtained from laboratory and field tests, it was concluded that the pond ash under investigation is not susceptible to liquefaction.

2. TEST SET UP AND INVESTIGATION

The tests were performed on a simple but indigenously fabricated vibration (shake) table (Gupta, 1977) in the Soil Dynamics Laboratory of the Dept. of Earthquake Engineering, IIT Roorkee, India. The test bin is a watertight tank 1.05 m long, 0.60 m wide and 0.60 m high, in which soil sample is prepared. The tank is mounted on a horizontal shake table. The sides of the tank consist of a rigid mild steel frame with 5 mm thick steel panels. The shake table consists of a rigid platform, which rests on four wheels supported on four knife-edges. This is driven in horizontal direction by a 3 H.P. A.C. motor through crank mechanism for changing rotary motion into translatory motion. The crank mechanism consists of a device for changing the amplitude of motion through two eccentric shafts. By changing the relative position of two shafts the amplitude can be fixed as desired. Changing diameter of pulleys on driven and driving shafts can change the frequency. The pore pressure measurement is performed with the help of glass tubes piezometers attached to the tank through rubber tubes. At the mouth of tubes porous stones were fixed. Complete test set up is shown in Figure 1.

Fig. 1: Liquefaction Table at Dept. of Earthquake Engineering, IIT Roorkee

The table can produce one-dimensional harmonic excitation of varying amplitude (0.05 to 1g) and frequency (0-10 Hz). The measurement of the pore water pressure was taken at three locations in the shake table. For this purpose, three pore-water pressure transducers (pick-ups) along the height of the tank have been installed. Their locations from the base of the tank are:

Bottom Pick-Up (B):	40 mm
Middle Pick-up (M):	125 mm
Top Pick-up (T):	200 mm

The total effective depth of the tank is 600 mm. The soil samples are filled for a height of 500 mm from the bottom, thus top layer of soil sample is 100 mm (approximately) from the top of the tank.

2.1 Properties of Pond Ash

The tests were conducted on the samples of fly ash collected from the site of Anpara-D thermal power plant, Anpara, Uttar Pradesh. Table 1 describes the properties of pond ash.

Table1: Properties of Anpara Pond ash

S. No.	Properties	Value
1.	Specific Gravity (G)	2.31
2.	Maximum Dry Density (γ_{dmax})	14.96 kN/m^3
3.	Minimum Dry Density (γ_{dmin})	9.96 kN/m^3
4.	% Optimum Moisture Content (OMC)	22.22
5.	Grain Size Distribution	
	(a) % of Gravels	2.34
	(b) % of Sand	63.70
	(c) % of Fines	33.93
6.	Plasticity Index (PI)	Non-Plastic
7.	Maximum Void Ratio (e_{max})	1.31
8.	Minimum Void Ratio (e_{min})	0.54

2.2 Procedure

A known quantity of water i.e. about 150 kg, sufficient to submerge the level of pick-ups, was taken in the tank. The ash was poured into the tank with the help of a funnel maintaining a constant height from the top of the water surface. Next, it was left for minimum twelve hours for saturation. As the saturation is over, the water overlying the ash sample was removed by siphoning and weighted accurately. Next, the top of completely submerged ash sample is leveled. Then with the help of dry weight of ash and amount of water left, the dry density, saturated density and relative density of deposit were computed.

Before starting the experiment, the frequency is fixed at desired level i.e. 5 cps and level of excitation is also fixed at desired level. The value of static pore water pressure is recorded using piezometers and noted. All the three pick-ups are extended upto the center of the tank. The flywheel is set to zero. Then the machine is switched on and hence vibration is imparted to the tank up to 60 s. The motor is stopped after 60 s. The rise of pore water pressures is recorded continuously with time until the pore water is completely dissipated after reaching a maximum value. At the end, the excess water overlying the sample is removed by siphoning and weighted accurately. Tests were performed on the saturated pond ash at four different accelerations. All the tests were performed at a constant frequency of 5 cps. Accelerations selected are 0.1g, 0.2g, 0.3g and 0.5g. These values of acceleration cover the range of all moderate and strong earthquakes.

3. TEST RESULTS

At each level of acceleration, variation in excess pore water pressure with time has been recorded using three piezometer tubes and stopwatch. As the test is conducted at four different acceleration levels by imparting the shaking for 60 s, the Figs. 2(a-d) show the variation in excess porewater pressure with time from the test results.

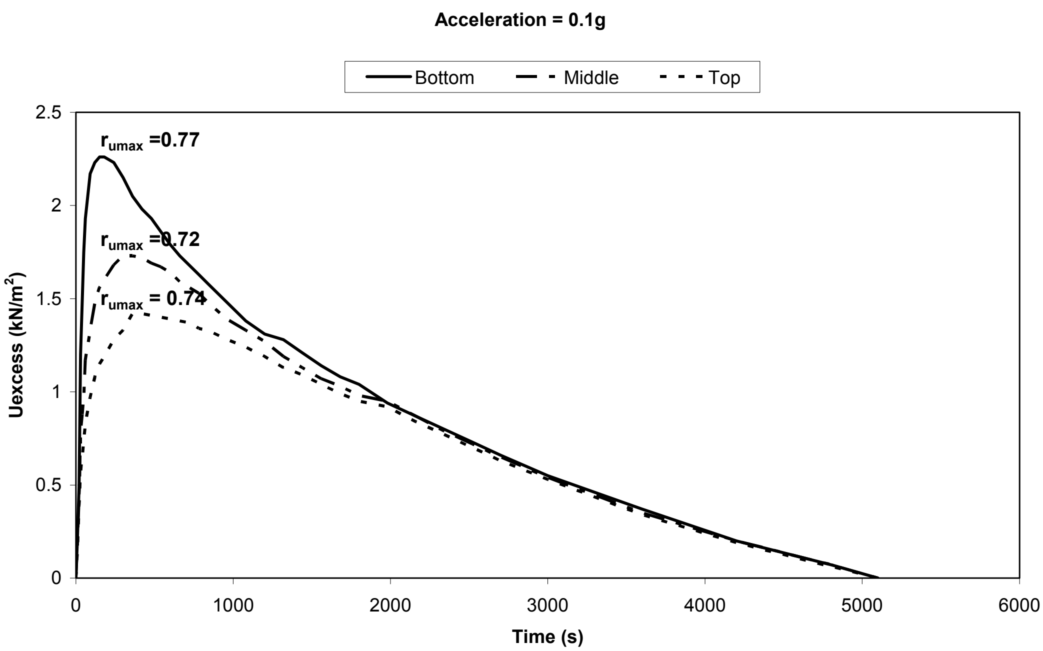

Fig. 2 (a): Excess pore water Vs time at acceleration level 0.1 g

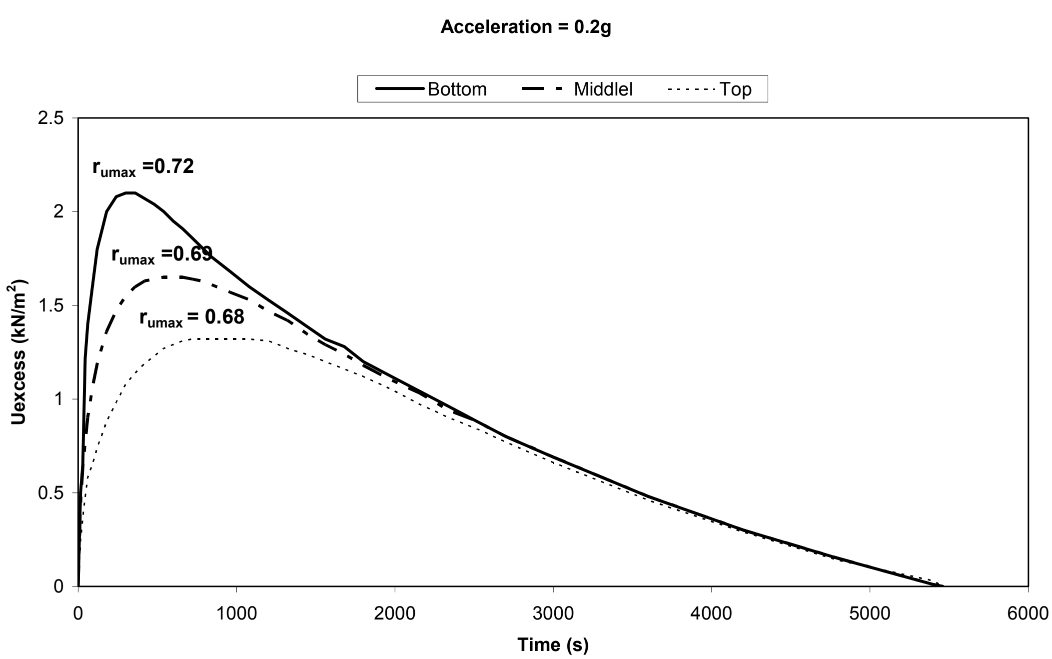

Fig. 2 (b): Excess pore water Vs time at acceleration level 0.2 g

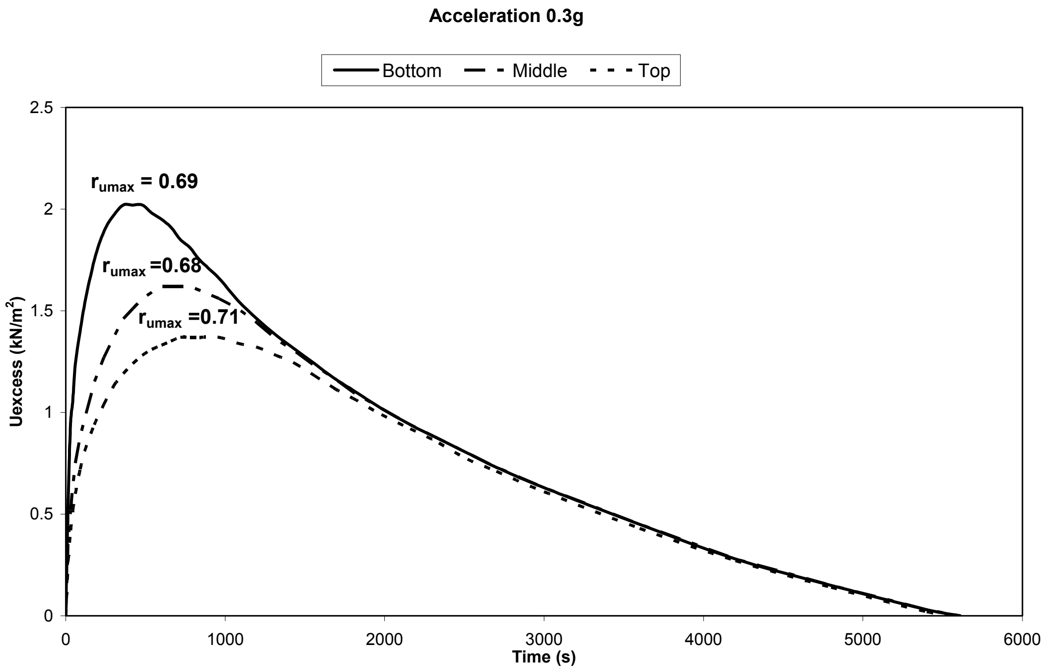

Fig. 2 (c): Excess pore water Vs time at acceleration level 0.3 g

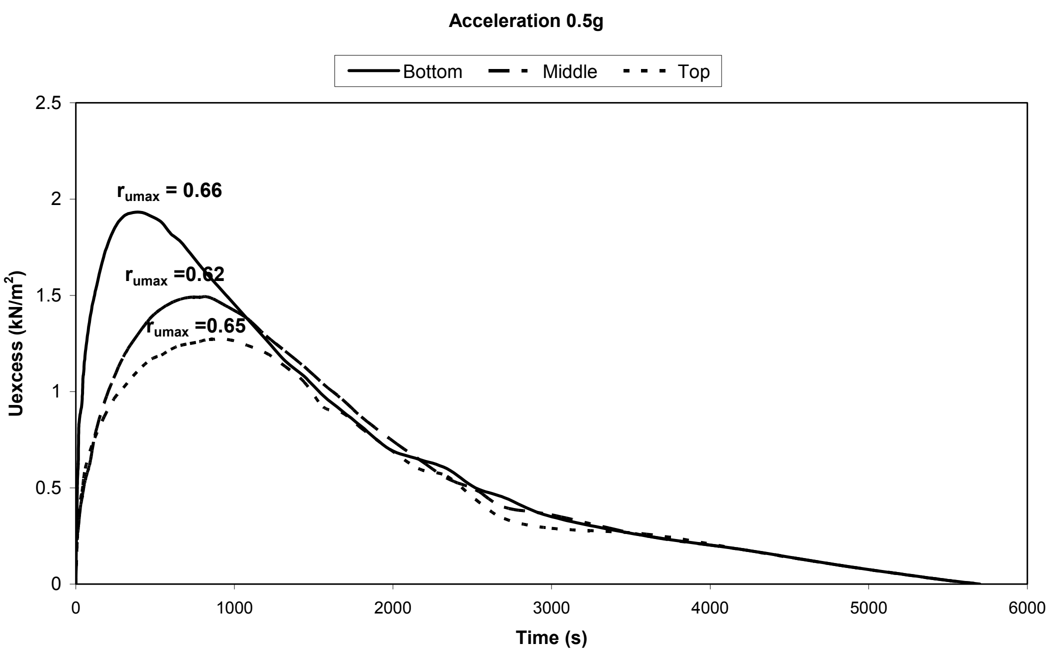

Fig. 2 (d): Excess pore water Vs time at acceleration level 0.5 g

It can be observed that the trend of results is very similar for all the levels of acceleration. In all cases the pore water pressure rises even after the shaking is stopped. In fact, the pore water pressure rises significantly after the shaking is stopped, then it remain constant for some brief duration before dissipation starts. Finally dissipation leads porewater pressure to zero, which occurs after more than an hour. Thus dissipation of porewater pressure takes very long time in pond ash compared to sands.

4. ANALYSIS OF TEST RESULTS

The Table 2 shows the rise in pore water pressure for three different pick-ups (Bottom – B, Middle –M, Top –T) with level of acceleration. Here U represents the porewater pressure at the end of shaking while U_{max} represent the maximum pore water pressure before dissipation starts. The last column of the Table 2 represents the effective overburden pressure at three different locations of the pick-ups which is used in computation of maximum porewater pressure ratio r_{umax} defined as follows:

$$r_{umax} = U_{umax} / \sigma_{vo}' \quad (1)$$

The values of this parameter are also shown in Figs. 2(a-d) for different locations of pick-ups. From all these four figures it can be observed that r_{umax} is in the range of (0.62 ~ 0.77) and it decreases with the level of acceleration. Since for all the cases the pore water pressure ratio r_{umax} is less than unity, it can be estimated that due to shaking the fly ash may loose its strength but may not liquefy.

Table 2: The maximum excess pressure at different accelerations

Acc^n (g)	U (kN/m^2)			U_{max} (kN/m^2)			σ_{vo}' (kN/m^2)
	B	M	T	B	M	T	
0.1	1.93	1.17	0.83	2.26	1.73	1.42	Bottom = 2.92
0.2	1.4	0.91	0.60	2.10	1.66	1.31	Middle =2.4
0.3	1.24	0.76	0.58	2.02	1.62	1.35	Top = 1.9
05	1.20	0.54	0.50	1.93	1.49	1.24	

It can be observed from Table 2 that with increase in level of acceleration both U and U_{max} decreases. The reason of this has been discussed in detail later. Further it can be observed that U_{max} for bottom pick-up is greater than that of middle pick-up and so on.

From Figs. 2(a-d), three time intervals i.e. time taken in building-up maximum pore water pressure (t_1), time during which the maximum pore pressure remains constant (t_2)and time taken in dissipation of excessive pore water pressure (t_3) is collected and represented in Table 3 for further analysis.

Table 3: The time (t_1, t_2 and t_3) at different accelerations

Acc^n (g)	Time to reach U_{max} t_1 (s)			Duration for U_{max} t_2 (s)			Duration for complete dissipation t_3 (s)		
	B	M	T	B	M	T	B	M	T
0.1	150	300	360	60	90	120	4860	4740	4560
0.2	255	510	720	105	150	300	5160	4860	4600
0.3	360	600	750	120	160	310	5490	5460	5400
05	370	690	840	130	180	320	5550	5510	5480

It can be observed that at all acceleration level time elapsed in dissipation (t_3) is greater than the time to reach U_{max} (t_1) which in turn greater than the duration for U_{max} (t_2). In fact time taken in dissipation is in the range of 4500~5600 s i.e. it is more than an hour at all levels of acceleration. Further all three times are increasing with the level of acceleration for all three pick-ups.

Normally in sands it is expected that increase in level of shaking (acceleration) increases the value of maximum pore water pressure (U_{max}) and decreases time to reach this pressure. However, the results presented in Table 2 and Table 3, are in contradiction to this and explained in detail in following section.

5. EFFECT OF LEVEL OF ACCELERATION

The variations in pore water pressure with time for different accelerations were put together for a particular pick-up. It was observed that the trend of results was similar for all the three pick-ups. One typical result for bottom pick-up is shown in Figure 3. For clarity the excess pore water pressure for 60 s (duration of shaking) is shown in Fig. 3. It can be observed that up to about 25 s, the porewater pressure increases with level of acceleration and then trend is just reversed. This type of the behavior may be attributed to the fact that in shake table, initially due to shaking the pore water pressure increase due to packing of pond ash, and the level of this compaction is greater for higher level of acceleration. However, once the fly ash is densified, the next interval of shaking reacts in a different way. Thus in Fig. 3, the point of fulcrum (from where the trend is reversing) shall be seen as the point where one is shaking an already densified material. In this connection it is important to note that the pond ash possesses low unit weight (10.05 kN/m^3) and high void ratio (e_{max} = 1.31).

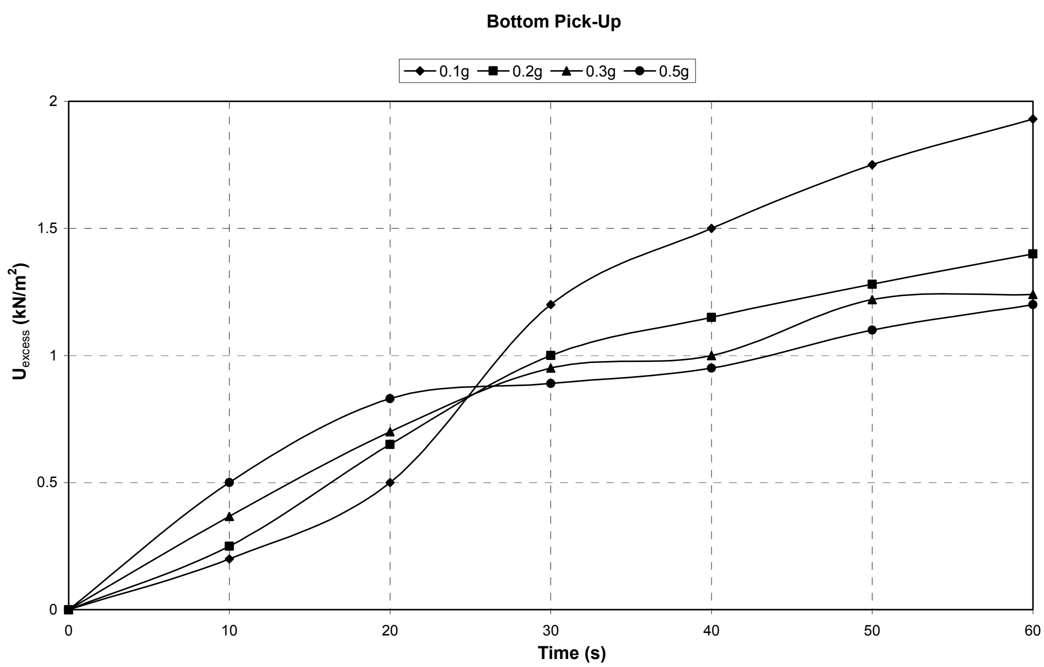

Fig. 3: Excess pore water Vs time (up to 60 s) at all acceleration levels for bottom pick-up

6. RESUTS OF FIELD TESTS

The Standard Penetration Tests were conducted in the field at two locations and the data collected were analyzed using Seed and Idriss Cyclic Stress Approach (Kramer 1996). It was observed that the measured N values were in very low range (3-9). The grain size distribution analysis of pond ash indicated the presence of non-plastic fines in the range of 35%. As the fine content of fly ash is very high, the analysis indicated no threat of liquefaction. However, it shall be noted that this analysis is based on an approach which is developed for sand and its applicability for pond ash is yet to be verified. This is still under investigation and the authors are continuing the research in this direction.

7. CONCLUSIONS

The liquefaction susceptibility of pond ash was evaluated in the laboratory using a shake table; it was observed that the pond ash under investigation is not susceptible to liquefaction as the maximum pore water pressure ratio r_{umax} remains less than unity. Further the effect of level of acceleration on pond ash is different than that normally observed in sands as the level of shaking decreased the value of r_{umax}. The methods based on field tests also indicated no liquefaction due to high percentage of fine contents. However, it shall be noted that these conclusions are only for a pond ash collected from a specific source and may not necessarily be applicable to all sites. Further authors recommend more laboratory tests, particularly those based on cyclic triaxial apparatus to arrive on a concrete conclusion.

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