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# Dynamic Behavior of Coal Ash

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**Abstract**

*Coal ash is deposited in large quantities in the ash pond. It is used as structural fill and for dyke construction. The behavior of ash under dynamic conditions is not well investigated. The present work attempts to quantify some of the parameters, which influences the dynamic stability especially liquefaction potential of coal ash. Several investigations conducted on coal ash suggest that ash fills have low SPT value. This supports the susceptibility of coal ash to liquefaction. Under steady-state vibrations induced into saturated ash mass and sand on shake table, the pore water pressure at different depths has been monitored for varying relative density, amplitudes and number of cycles of motion corresponding to liquefaction. The investigations suggest that liquefaction of coal ash is governed by relative density, amplitude and frequency of dynamic disturbance and gradation.*

***Keywords:*** *Coal ash, Ghagger Sand, Vibration Table, Liquefaction, Frequency*

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## INTRODUCTION

The coal ash which is produced in huge quantities by thermal power producing units may be used in low lying areas for land reclamation or construction of ash dykes, embankments for rail and roads. One of the major problems associated with filled up soils during an earthquake is failure of foundation soil in saturated conditions, which may behave just like liquid. In saturated conditions under earthquake loading it may liquefy. Therefore, prior to its use as a fill material thorough investigations on its liquefaction behavior are required. The liquefaction of coal ash is a compressed function of large number of parameters, which make this problem as complex one. No significant information is available till date on liquefaction behavior of coal ash. Some attempts are made to predict the behavior of coal ash using Cone Penetration Test (CPT) and Standard Penetration Test (SPT). It is observed that to sense the behaviour of coal ash on the basis of CPT and SPT may lead to erroneous results. Cunningham et al. [1] suggested that in loose conditions ash may liquefy under the impact of cone penetrometer or SPT resulting into lower penetration record. According to Leonard and Bailey [2] the behaviour of compacted ash can not be inferred from a SPT or CPT; largely because these tests do not adequately sense the effect of pre-stressing due to compaction. Therefore author carried out studies on liquefaction phenomenon on large size samples on horizontal vibration table. Gupta and Prakash (1980) used intensity of pore water pressure in relation to initial effective stresses as liquefaction criteria. According to this, the ash at any depth will liquefy completely if the intensity of pore water pressure at that depth is such that complete transfer of intergranular stress takes place and shear strength of ash is lost completely. The adopted theory for liquefaction of soil is that in saturated state.

$$\tau = (\sigma_n - u) \tan\phi \quad (1)$$

where, $\tau$ is the Shear strength, $\sigma_n$ = Normal pressure on any plane at depth z

$$= \gamma_{sat}\ z \quad (2)$$

$u = \gamma_w\, z$

$\phi$ = Angle of internal friction on a horizontal plane at depth z

Eq. (1) becomes $\tau = \sigma_n \tan\phi$ if $u = 0$

or $\tau = \gamma'\ z \tan\phi$

in which $\gamma_{say}$ is the unit weight of saturated soil, $\gamma'$ is the submerged unit weight of soil.

  

Now if there is an increase in pore water pressure
$\delta u = \gamma_w h_w$ due to shaking of ground, then

$$\tau = (\gamma' z - \delta u) \tan\phi \quad (3)$$

So with the development of additional positive pore water pressure, the strength of soil is reduced. For total loss of strength

$\gamma' z = =\gamma_w h_w$ or

$$h_w/z = \gamma'/\gamma_w = (G-1)/(1+e) = i_{cr} \quad (4)$$

where, G = Specific gravity of soil solids, e = void ratio
$i_{cr}$ = critical hydraulic gradient
Also if e=0.6, G=2.6, $i_{cr}$ = 1, $h_w$ = z

Which implies that for complete loss of strength to occur additional water head equal to depth of deposits is required. So loss of strength occurs due to transfer of inter granular stress from grains to pore water. And if this transfer is complete then there is complete loss of strength. Also if stress is only partially transferred from grains to pore water only partial loss of strength occurs. This phenomenon with respect to coal ash was compared with that of Ghagger sand.

## METHODS

Matsuo and Ohara (1960) studied the behaviour of loose saturated sand on a horizontal vibration table in a steel box 100x90x40 cm size. The sudden increase of pore pressures was observed at some definite acceleration. Florin and Ivanov (1961) carried out laboratory tests on loose saturated sand deposits 20 cm thick under impact and steady state vibrations. Changes in pore pressures were measured. It was observed that criteria of liquefaction should not be critical void ratio or density but critical values of intensity of dynamic disturbances, stress condition and hydraulic gradient. Finn, Emery and Gupta (1971) reported results from horizontal shake table on loose saturated sands under air pressure induced surcharge conditions. The specimen was subjected to sinusoidal vibrations. It was observed that there is a gradual build up of pore water pressure to about 60% of initial effective overburden pressure and then it rapidly increases to a value equal to effective overburden pressure. The resistance to liquefaction increases as the surcharge pressure is increased. The factors which control the liquefaction characteristics in such a study were grain size characteristics, initial relative density, initial intergranular stress, intensity and characteristics of disturbing forces and drainage characteristics. Gandhi et al. [3] has reported improvement in the density of loose ash deposits using blast liquefaction techniques. However, the improvement of density is not very significant in this case.

## MATERIALS

The coal ash obtained from ash lagoon of Guru Gobind Singh Super Thermal Power Plant, Ropar was used for studies. The sand used was obtained from the bed of Ghagger river. Prior to liquefaction studies, coal ash (Trivedi et al. 1996) and sand Pathak [4] was characterized for its engineering properties, which are summarized in Table 1 and 2, respectively.

***Table 1:*** *Coal Ash Data.*

| S.No. | Property | Value |
|---|---|---|
| 1. | Sand size, % | 40 |
| 2. | Silt size, % | 58 |
| 3. | Clay size, % | 0.2 |
| 4. | Maximum dry unit weight, $kN/m^3$ | 10.6 |
| 5. | Optimum Moisture content, % | 37 |
| 6. | Specific gravity of solids | 1.90 |
| 7. | Angle of internal friction, $^o$ | 38 |

***Table 2:*** *Sand Data.*

| S.No. | Property | Value |
|---|---|---|
| 1. | Sand size, % | 96 |
| 2. | Silt size, % | 4 |
| 3. | Clay size, % | 0 |
| 4. | Specific gravity of solids | 2.55 |
| 5. | Uniformity Coefficient, $C_u$ | 1.73 |
| 6. | Coefficient of curvature, $C_c$ | 0.988 |
| 7. | Maximum void ratio | 0.710 |
| 8. | Minimum void ratio | 0.554 |
| 9. | Effective Size, mm | 1.3 |

### Experimental Set up and Testing Techniques

A vibrating table was employed to induce liquefaction in the sand and ash deposit. The test tank was 100 x 60 cm in plan and 60 cm high. This platform was driven to and fro in horizontal plane by a 3 phase, 3HP A.C. motor. The amplitude was set to a desired value independently. The number of cycles was recorded on a digital counter. A hand brake on flywheel was equipped to stop the table. For the purpose of pore pressure measurement three flexible piezometric tubes were attached at three different depths viz. 5, 15, and 25 cm from the top of saturated deposit (Table 3). The ash/sand was deposited in the tank in layers of 6 cm each and desired density was ensured. After deposition, the deposit was saturated with water. After saturation the amplitude was set to a stipulated value and number of cycles to cause liquefaction was noted. Liquefaction was assumed to be complete when a metal piece placed on top of sample in tank, sank and pore water pressure increased sharply [5].

## RESULTS AND DISCUSSION

From the review of investigations carried out on soils, it is understood that liquefaction may be quantified in terms of excess pore water pressure at a specified depth. This excess pore water pressure leads to complete loss of shear strength of a cohesionless mass. Figure 1 shows the variation of excess pore water pressure with relative density for amplitude of 5 mm at different depth of observations. As relative density increases, the pore water pressure at all the depths decreases. However, this decrease is very significant at 25 cm depth. Figure 2 shows the variation of relative density with acceleration at 5mm amplitude for coal ash and sand. It indicates that for coal ash and as well as sand requires higher amount of acceleration to liquefy if relative density of the deposit increases from 65 to 85%. Further it is observed that in all the cases of relative density coal ash liquefies at significantly lower acceleration than sand. At relative density of 65% the acceleration required to liquefy sand is as high as 5.5 times that of coal ash. It indicates that at higher relative density there is significant improvement in the behaviour of coal ash, but still it remains far more susceptible to liquefaction compared to sand. This phenomenon needs attention of engineers and planners of ash as a structural fill for rail embankments, as ash would be subjected to dynamic loads more frequently in these cases. Figure 3 shows the variation of settlement with relative density at amplitude of 5 mm. It may be observed that for coal ash there is significant settlement of surface of the ash deposit in the tank at lower relative density. However, settlement in the case of sand is not significant compared to coal ash. It is further observed that, with increase in relative density there is decrease in the settlement in coal ash but this decrease is not very significant in case of sand. This phenomenon may be explained in terms of greater reduction in voids of ash compared to sand under dynamic loading [6,7].

***Table 3:*** *Range of Parameters.*

| Parameter | Range | Remarks |
|---|---|---|
| Relative density (i) Sand (ii) Coal ash | 65–85% | Values taken from relative density experiment |
| Amplitude | 1 to 5 mm | |
| Pore water pressure at 5, 15, 25 cm depth | Varying depending upon density and amplitude | Values at liquefaction |
| Settlement | 5 to 20 mm | Values at liquefaction |
| Frequency | 1 to 10 Hz | Values at liquefaction |

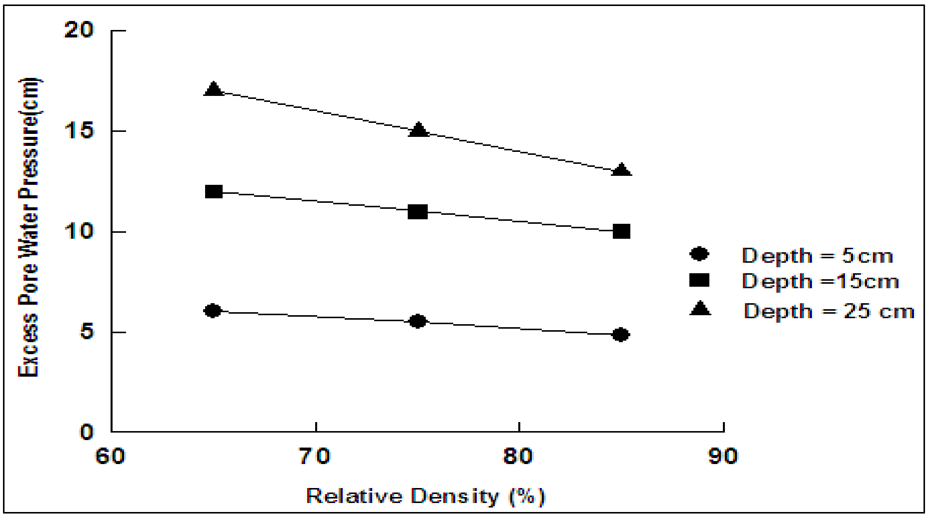


***Fig. 1***: *Variation of Excess Pore Water Pressure with Relative Density for Amplitude of 5 mm at different Depth of Observations.*

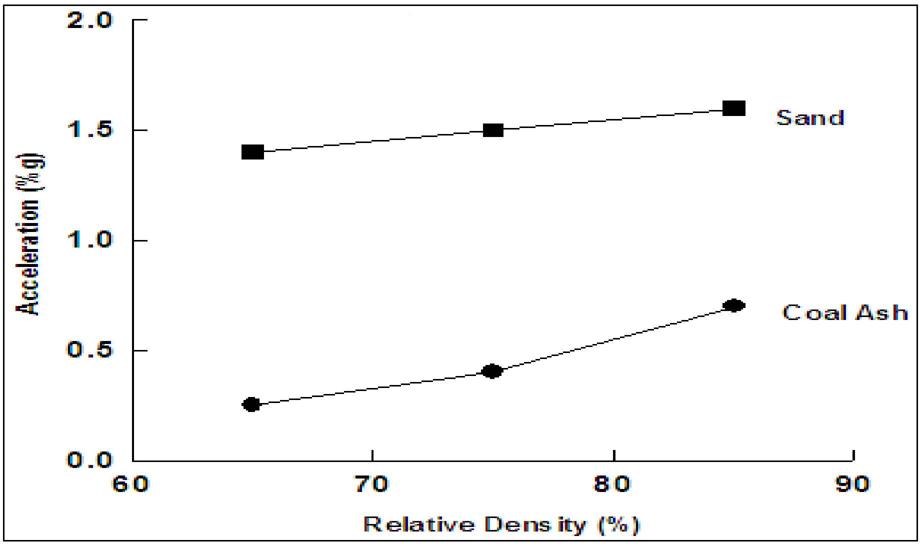


***Fig. 2:*** *Variation of Relative Density with Acceleration at 5mm Amplitude for Coal Ash and Sand.*

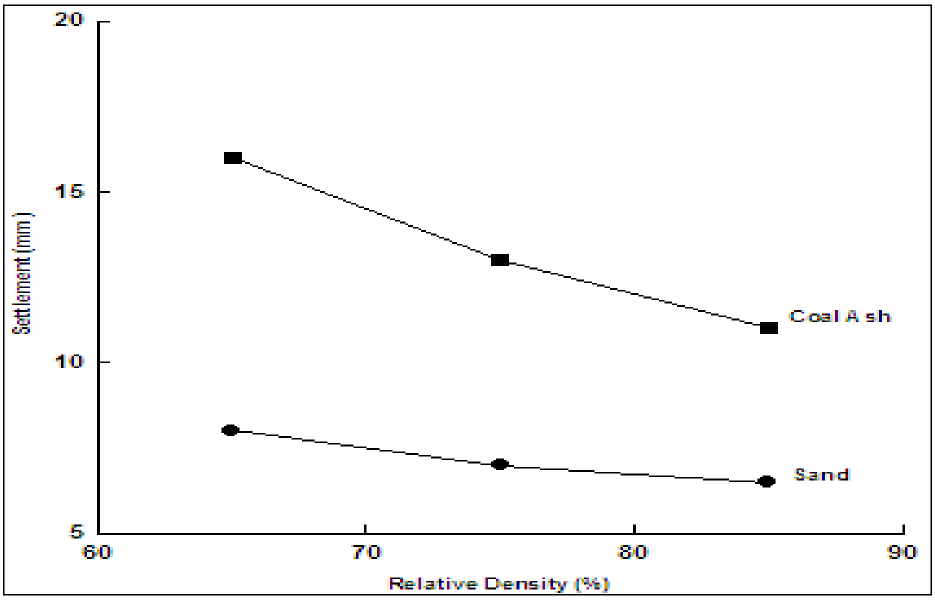


***Fig. 3***: *Variation of Settlement with Relative Density at Amplitude of 5 mm.*

  

## CONCLUSIONS

From the study of liquefaction behaviour of coal ash and sand the following conclusions may be drawn:

- The behavioral trends of coal ash and sand with reference to liquefaction are similar.
- There is a significant settlement of saturated ash deposit when dynamic disturbance is induced compared to Ghagger sand. This indicates that ash having higher percentage of voids is densified when dynamic disturbance is induced.
- Because of low dry unit weight of coal ash may liquefy at a lower acceleration compared to Ghagger sand.
- This study raises a needle of doubt on the potential coal ash as structural fill under dynamic loading.

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