On the Permanent Deformation Behavior of Rail Road Pond Ash Subgrade

Sur le comportement en déformation permanente d'une assise ferroviaire en cendres volantes de bassin

Mohanty B.
Dept. of Civil Engg., IISc Bangalore, India

Chandra S.
IIT Kanpur, Indian

ABSTRACT: In this study repeated load triaxial tests were conducted on reconstituted pond ash specimens and permanent deformation calculations have been made taking the stress history and number of passes of vehicular traffic loading into consideration. Tests were performed at different moisture content levels with varying dry unit weights, and at different stress levels simulating the environmental and traffic conditions. Specimens were prepared using moist tamping technique so as to obtain density closer to the field density. Test results were analyzed to study the effects of confining pressure, deviatoric stresses, and degree of saturation on the permanent deformation response of pond ash. Results show that both traffic and environmental condition play an important role in the permanent axial strain behavior of the material. Furthermore, the shakedown limit describing a critical stress level that exists between stable and unstable condition is also examined for the design purpose.

RÉSUMÉ : Dans cette étude des essais triaxiaux à charges répétées ont été effectués sur des échantillons reconstitués de cendre volante de bassin et des calculs de déformation permanente ont été effectués, prenant en compte l'historique de contraintes et le nombre de passages du chargement de circulation des véhicules. Des essais ont été réalisés à différents niveaux de teneur en eau et avec des densités sèches variables, et à différents niveaux de contrainte simulant les conditions environnementales et de trafic. Des échantillons ont été préparés utilisant la technique du compactage humide afin d'obtenir la densité la plus proche de la densité en place. Les résultats d'essai ont été analysés afin d'étudier les effets de la pression de confinement, des contraintes déviatoriques et du degré de saturation, sur la réponse en déformation permanente de la cendre. Les résultats prouvent que le trafic et l'état environnemental jouent tous deux un rôle important dans le comportement axial en déformation permanente du matériau. De plus, la limite de shakedown caractérisant un niveau de contrainte critique séparant l'état stable de l'état instable est également examinée vis-à-vis du dimensionnement.

KEYWORDS: Pond ash; Train loading; Triaxial tests; Permanent deformation.

1 INTRODUCTION

Pond ash is a by-product of coal-fired electric power plants found abundantly in India. In order to avoid environmental problem, it can be used in the construction of transportation facilities in bulk quanties. The use of pond ash containing a large fraction of bottom ash in rail road pavements or subgrade will experience repeated rail traffic loading while in-service. This material should be assessed for its suitable use by considering resistance to permanent deformation measured from repeated load triaxial tests. It has not been adequately researched in the past and is investigated in this study simulating the environmental and traffic conditions.

In laboratory, one-way cyclic triaxial tests are generally conducted to obtain the deformation characteristics of subsoils under repeated traffic loading simulating the in-service loading conditions induced by passing vehicles. Hence, one-way cyclic triaxial tests on remolded pond ash specimens were performed in this study under undrained conditions with a constant confining pressure and different cyclic applied compressive (non-reversal) deviatoric stresses for each test. In this case the axial deviatoric stress remains the major principal stress and shear reversal does not occur during the test. The permanent axial strain accumulated with respect to number of applied loading cycles were recorded for each test and analyzed to study the influence of different controlling parameters on the one-way cyclic behavior of pond ash.

2 TEST MATERIALS AND SAMPLE PREAPRATION

The pond ash used for preparation of remolded samples were sampled near the discharge point, near the margins of the wet disposal ash pond of a thermal power plant producing fly ash and bottom ash with a typical production ratio of approximately 80:20 by weight. The disturbed, completely saturated pond ash samples were oven-dried, and then thoroughly mixed to obtain the representative homogeneous samples. The specific gravity (G_s), optimum moisture content (w_{opt}), and maximum dry unit weight ($\gamma_{d\ max}$) of the pond ash were found to be 2.36, 33.6%, and 11.2 kN/m^3, respectively. From grain size distribution, it is observed that the dominant particle size is in the sand size range. It contains 77.81% sand, and 20.56% silt size particles. The coefficient of uniformity, C_u is obtained as 7.39, while the coefficient of curvature, C_c is 2.07. The ash was classified based on the classification system proposed by Prakash and Sridharan (2006). It is found to be *Non-plastic sand-silt size fractions* and is designated as *SMN*.

The samples were reconstituted at different initial dry unit weights [Relative Compaction: RC = 90%, 95%, 97%, and at standard proctor maximum dry unit weight (at MDD)] and at different water contents giving different degrees of saturation (S_r). The relative compaction, RC is defined as the percentage of desired dry unit weight (γ_d) to the maximum dry unit weight ($\gamma_{d\ max}$) that obtained from the standard proctor compaction curve. The specimen at 97% RC was reconstituted using water content value on the wet side of the standard proctor curve. The samples were prepared in accordance with the conventional moist-tamping technique, as it is a simple and easy method to provide good control over obtaining the wide range in target density (Ladd 1978). First, an appropriate quantity of oven-dried representative pond ash sample was calculated with respect to the desired dry unit weight. Then, de-aired water corresponding to desired moisture content was measured and mixed to form a mixture. Cylindrical split mold of 50 mm in diameter and 100 mm in height was selected for sample preparation. The prepared mix material (wet or moist ash mixture) was carefully placed and compacted inside the specimen mold in five identical layers, subdividing the total mass into five equal parts approximately. The specimen was prepared on a trial for at least three times to check the desired dry unit weight. Following compaction, the cylindrical specimens were subsequently removed from the split mold sampler, placed, isotropically consolidated and sheared in the cyclic triaxial apparatus.

2.1 *Testing Apparatus*

The one-way compressive cyclic triaxial device supplied by M/s. Geotechnical Instruments International Limited, Germany, was used in this research. The apparatus is computer controlled and has a provision for testing cylindrical soil specimens under both drained and un-drained conditions, with programmed deviatoric loading sequences and data acquisition rates at eight readings per applied loading or stress cycles. The system consists of a pneumatic stress-controlled actuator which is capable of generating reasonable representation of multiple cycles of compressive axial deviatoric stresses at multiple applied loading frequencies between 0.1 *Hz* and 10 *Hz* (cycles per second), with three types of built-in semi-sine, triangular, and square waveforms defined by means of external input. The vertical cyclic compressive deviatoric stresses could be applied to the specimen via the top specimen cap connected to the vertically movable frictionless shaft or loading piston going through the plexi-glass triaxial pressure cell. The loading ram or piston is directly connected to the actuator for application of one-way cyclic compressive loading. A load transducer with a capacity of 5 kN located below the bottom end platen, inside the plexi-glass triaxial pressure cell was used to monitor and measure the applied deviatoric stresses during testing. It is a constant confining pressure triaxial set-up applying the confining pressure with the use of pressurized air, which remains the same during consolidation and shearing. A sensitive Linear Variable Displacement Transducer (LVDT) of capacity 50 mm (resolution 0.01 mm) located outside of the triaxial pressure cell was used to monitor and measure the low-amplitude axial/vertical deformations of the specimen with high accuracy during testing. The applied initial effective confining pressure, back pressure, one-way compressive cyclic deviatoric/axial load, development of axial deformations etc. could be monitored using a built-in data acquisition system and recorded in a notepad file during testing with a computer connected to the device. The apparatus is supported by software which enables the user to perform stress-controlled testing only. A plexi-glass triaxial tank with full of de-aired water at the bottom of the one-way cyclic triaxial test set-up was used to fill the triaxial pressure cell when necessary and has the provision of draining the water from the triaxial pressure cell by gravitation after each testing

2.2 *Testing Procedure*

It was clear from the literature that, compositional and environmental factors primarily influence the permanent deformation characteristics of subgrade soil under one-way induced traffic loading. In the field, presence of moisture plays a vital role in either a road or railway pavement system and is one of the most important environmental considerations for strength and deformation behavior of material under cyclic loading. The moisture content may vary during the life time of the structure from the construction moisture content to full saturation with the ingress of moisture with seasonal changes or capillary action. Hence specimens were reconstituted to different moisture contents giving different initial degree of saturation. Three compaction moisture contents and dry density conditions were selected for the study.

The applied level of confining pressure and deviatoric stresses also affect the deformation characteristics of the material under traffic loading. Hence, tests were conducted under a range of initial effective confining pressure (σ'_{3c}) of 15, 25, and 35 kPa, which is the range of stresses for embankment of small height. All the remolded specimens were isotropically consolidated under an initial effective confining pressure. Following, samples were sheared cyclically under undrained condition. Tests were performed with different deviatoric stress levels. Fig. 1 shows the typical sinusoidal semi-sine wave cyclic load applied during the cyclic triaxial compression tests, with corresponding response recorded using data acquisition system during testing.

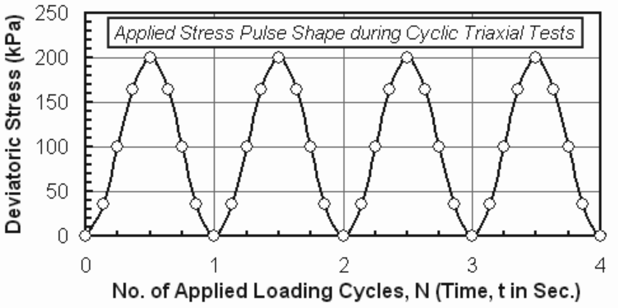

Figure 1. Typical sinusoidal semi-sine wave cyclic load form applied on the specimen and the response received using data acquisition system during the one-way cyclic triaxial compression tests

Each test was of constant-amplitude, consisted of cycling the stress pulse at only one level of cyclic deviatoric stress varying between zero and a preset value at a frequency of 1 *Hz*. During the tests, only a deviatoric stress (σ_d) is applied cyclically while the confining pressure (σ'_{3c}) remains constant. Tests were conducted on unsaturated or partially saturated specimens, i.e. the degree of saturation (S_r) employed during reconstitution of the sample was maintained same during the testing, without a back pressure saturation. Few samples were reconstituted at relative compaction dry unit weight equal to 95% giving degree of saturation of 52.70% and the samples were partially saturated by applying back pressure to obtain degree of saturation ranging between 65 and 95% before shearing, to study the effect of degree of saturation (post compaction) on the deformation response of the material. Since during the application of cyclic shear stress, the samples were not fully saturated, pore water pressure was not measured during shearing. During the test, the software presents the results in the form of a table in a note pad file. The raw data was then transferred to an excel sheet and plots of the desired quantities were obtained for the study.

The performance of road and railway pavements resting on compacted material primarily depends upon the stiffness or load-deformation characteristics of the material. Hence, in the present study, during each one-way cyclic triaxial test, the total and permanent deformations of the specimens were monitored and recorded to calculate the plastic or permanent (ε_p) and resilient axial strains (ε_a). The accumulation of permanent axial strain with load cycles is presented in this paper. As the development of permanent deformation in the specimen under repeated loading is a gradual process during which each load cycle contributes a small increment to the accumulation of strain, all the tests were conducted up to the development of sufficient permanent strain in each of the specimens tested. During the test, as the stiffness of the material gradually increases, causing a reduction in the development of permanent deformation under subsequent repetitive loading, tests were stopped after 10,000 applied load cycles.

3 TEST RESULTS AND DISCUSSION

Permanent axial strain mainly depends on the intensity of applied cyclic axial deviatoric stress and number of loading cycles and generally used to study the deformation characteristics of the compacted material. In this study, the effects of various factors such as applied cyclic deviatoric stress, initial effective confining pressure, and degree of saturation on the permanent axial strain response of pond ash are studied. In order to study the effect of applied cyclic deviatoric stress on the permanent axial strain response, results of tests performed at same initial effective confining pressure but different deviatoric stress for the specimen compaction dry unit weight, $\gamma_d = 10.64$ kN/m^3 (RC = 95%) are plotted in Fig. 2.

It is observed that at a constant initial effective confining pressure the applied cyclic deviatoric stress showed a considerable influence on the permanent axial strain. Higher the cyclic deviatoric stress higher is the permanent axial strain at the same initial effective confining pressure. With increase in applied cyclic deviatoric stress the variation in permanent axial strain is observed to be less for high initial effective confining pressure. For example, with increase in applied cyclic deviatoric stress from 71.27 to 203.64 kPa, the corresponding increase in permanent axial strain is approximately 85%, at initial effective confining pressure, $\sigma'_{3c} = 35$ kPa.

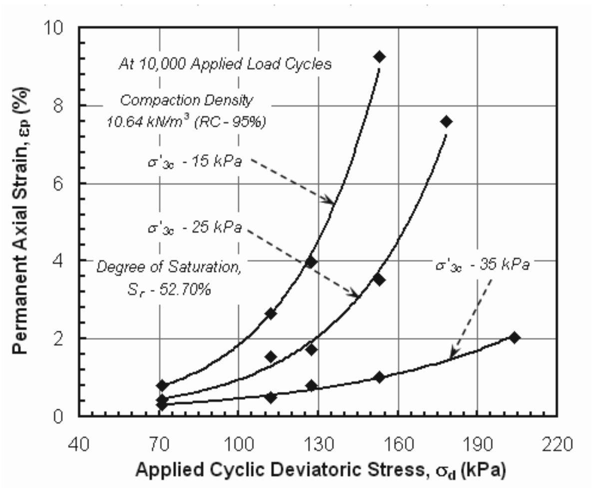

Figure 2. Relationships between permanent axial strains versus applied cyclic deviatoric stress

Fig. 3 shows the effect of initial effective confining pressure on the permanent axial strain response, at same applied cyclic deviatoric stress but different initial effective confining pressures for same reconstituted dry unit weight/density.

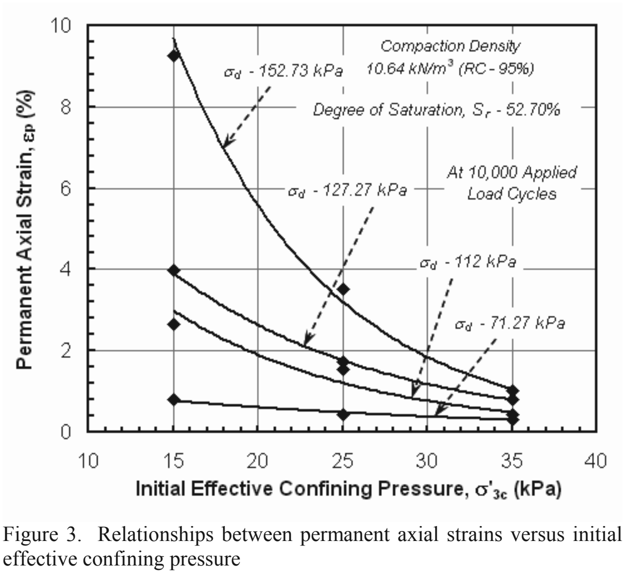

Figure 3. Relationships between permanent axial strains versus initial effective confining pressure

It may be observed from the figure that the applied cyclic deviatoric stress has a significant effect on permanent axial strain at low initial effective confining pressure. High value of permanent axial strain is observed at low initial effective confining pressure. The permanent axial strain decreases as the initial effective confining pressure increases and the decrease is more pronounced at high applied cyclic axial deviatoric stress. For example, with increase in initial effective confining pressure from 15 kPa to 35 kPa, the corresponding decrease in permanent axial strain value is approximately 89%, at an applied cyclic deviatoric stress, $\sigma_d = 152.73$ kPa.

The variation of permanent axial strain is plotted in Fig. 4 for three degrees of saturation, for initial effective confining pressure, $\sigma'_{3c} = 25$ kPa and applied cyclic deviatoric stress, $\sigma_d = 127.27$ kPa. The degree of saturation of the specimen during the test was kept same as the degree of saturation during compaction. It may be observed that with increase in degree of saturation, a significant increase in permanent axial strain values is obtained. The increase in permanent axial strain is gradual up to the degree of saturation corresponding to the MDD and is more rapid beyond this value. It is observed that the permanent axial strain increases by 57.80% as the degree of saturation increased from $S_r = 52.7\%$ to $S_r = 77.71\%$.

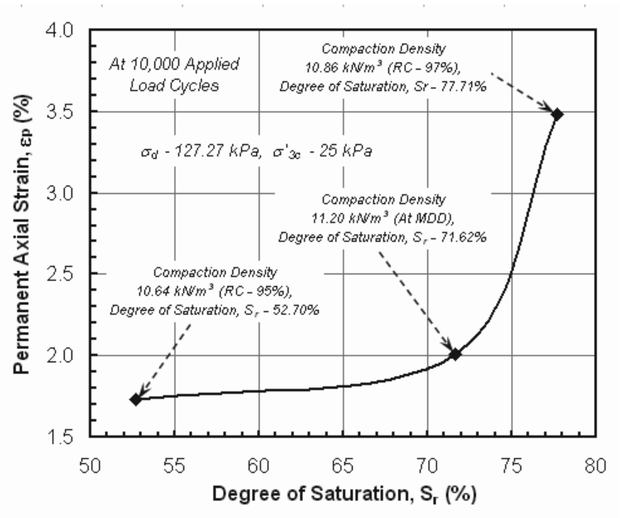

Figure 4. Relationships between permanent axial strains versus degree of saturation at compaction stage (without a back pressure saturation)

The effect of degree of saturation during shearing on permanent axial strain response of pond ash is shown in Fig. 5.

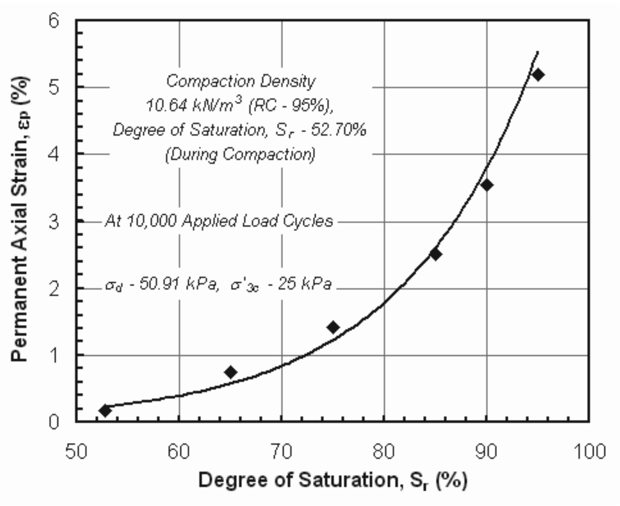

Figure 5. Relationships between permanent axial strains versus degree of saturation (with back pressure saturation)

Tests were conducted at the degree of saturation maintained during compaction stage ($S_r = 52.70\%$) and increased to $S_r = 65\%$, 75%, 85%, 90%, and 95% respectively, before shearing.

All the tests were conducted at initial effective confining pressure of 25 kPa and applied cyclic deviatoric stress of 50.91 kPa. It is observed from the figure that the degree of saturation during shearing has a significant effect on permanent axial strain response of pond ash specimen. With increase in degree of saturation the permanent axial strain values increase. A 110% increase in permanent axial strain is observed when the degree of saturation increases from 52.70% to 95%.

Fig. 6 shows the relationship between accumulation of permanent axial strain and number of applied loading cycles at a constant effective initial confining pressure of 15 kPa for a range of applied deviatoric stress levels. It can be clearly seen that with increasing deviator stress levels the magnitude of accumulated permanent strains increases with loading cycles. Depending on the level of applied stress, at small stress levels specimens experienced some value of permanent strain but at high stress levels test specimens have achieved failure after a finite number of applied load cycles.

Furthermore, as the stress level exceeds a specific value (critical stress), the permanent axial strain accumulates rapidly with the number of applied load cycles which exhibits the unstable conditions in terms of excessive permanent deformation in the test specimen. The test results reported here suggest that at stress levels greater than or equal to 91.64 kPa, permanent strain accumulates rapidly. Hence applied cyclic deviatoric stress should not exceed this value, so as to avoid the excessive plastic strain in the subgrade.

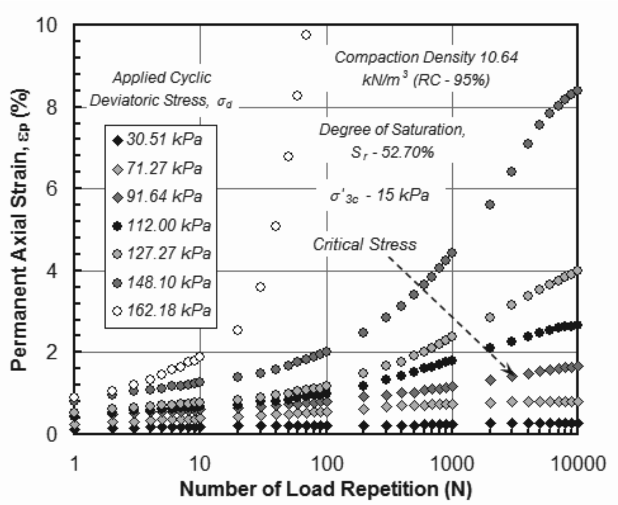

Figure 6. Relationship between permanent axial strain versus number of applied load cycles in undrained conditions

Fig. 7 shows the associated permanent strain rate during the one-way cyclic triaxial tests in undrained conditions. A total of seven tests with combination of various deviatoric stress and confining stress values have been presented. Two different cases viz. stable and unstable states are considered and labeled on the figure for the illustration of permanent deformation behaviour under repeated loading in this study.

As it is seen in the figure, in stable state, during the applied load cycles the permanent strain rate decreases gradually and reaches a constant value depending on the cyclic stress level applied to the specimen. Where ash material is in stable equilibrium and can be said to be in shake down range and would be permitted in the subgrade. In this case total accumulated strain is sufficiently small. In contrast, in unstable state the permanent strain rate decreases very slowly depending on the applied stress level than that observed in the stable state. It would result the failure in the subgrade and should be prevented.

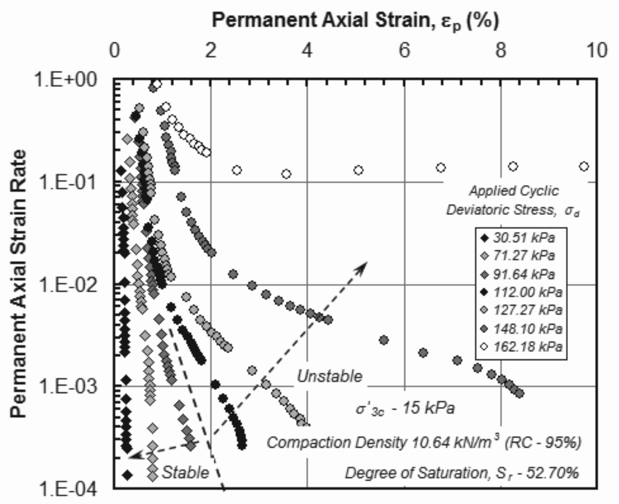

Figure 7. Relationship between permanent axial strain rates (log scale) versus permanent axial strain

4 CONCLUSIONS

This study aimed in understaing and characterising the developement of traffic load induced cumulative permanent axial strain in the compacted ash specimens in repated loading triaxial (RLT) tests. The investigation aimed specifically at evaluation of the magnitude of the permanent axial strain, with combination of various applied deviatoric stress and confining stress level, and the factors affecting it, as it has not been done before. The following conclusions are drawn from the investigation.

The occourance of permanent strain under traffic loading is controlled by several factors. It incresaes with increase in number of load cycles, applied cyclic deviatoric stress, and degree of saturation, and decreases with increase in initial effective confining pressures.

If the ash specimen is subjected to deveiatoric stress smaller than the critical stress, peramanent strain increases at the beginning of test, and reaches a peak value after a finite number of applied load cycles, and then remains constant till the end of test or practically unchanged, attributing to stable state. If cyclic deviatoric stress is higher than the critical stress then the strain will change permanently with number of applied loading cycles attributing to unstable state. Hence the amplitude of permanent strain represents a boundary between two fundamentally different kinds of one-way cyclic behavior in the compacted pond ash specimen under induced repeated traffic loading.

5 ACKNOWLEDGEMENTS

The experimental work presented in this paper was conducted at the Geotechnical Engineering Laboratory at the Indian Institute of Technology Kanpur, India. The first author gratefully acknowledges Indian Institute of Technology Kanpur for providing the one-way cyclic triaxial testing device for conducting the experiments successfully.

6 REFERENCES

Ladd R.S. 1978. Preparing test specimens using undercompaction. *Geotech. Testing J.* 1 (1), 16-23.

Prakash K. and Sridharan A. 2006. A geotechnical classification system for coal ashes. *Proc. Inst. Civ. Eng. Geotech. Eng. (UK)* 159 (GE2), 91-98.