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CBR Behaviour of Waste Plastic Strip-Reinforced Stone Dust/Fly Ash Overlying Saturated Clay

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Abstract

An experimental study was carried out to investigate the CBR behaviour of waste plastic strip reinforced-stone dust/fly ash overlying saturated clay. Three different sizes of waste plastic strips were used in this study. The effect of waste plastic strip content (0.25% to 4%) and length on the CBR and secant modulus of strip reinforced-stone dust/fly ash overlying saturated clay was investigated. The study reveals that addition of waste plastic strip in stone dust/fly ash overlying saturated clay resulted in an appreciable increase in the CBR and the secant modulus. The reinforcement benefit increased with an increase in waste plastic strip content and strip length. The benefit of adding waste plastic strips beyond 2% does not improve the CBR or secant modulus appreciably. Reinforced stone dust is more effective than reinforced fly ash overlying saturated clay in improving the behaviour of the system. The material can be used in base courses in constructing rural roads over saturated clay, thereby leading to safe disposal of these waste materials in an environmentally friendly manner. Further research is recommended to study the cost economics of the use of waste materials in base courses in rural roads.

Key words: CBR, Fly ash, Saturated clay, Secant modulus, Stone dust, Waste plastic strip.

Introduction

Most developed and developing countries all over the world have huge resources of waste materials such as fly ash, stone dust, and waste plastic. The quantities of wastes that are accumulating in developed and developing countries are causing disposal problems that are both financially and environmentally expensive. One method to reduce some portion of the waste disposal problem is by utilising these waste materials for engineering purposes. This paper examines the effect of waste plastic strip content and length on the CBR behaviour and secant modulus of stone dust/fly ash overlying saturated clay. A series of laboratory California Bearing Ratio (CBR) tests were carried out with varying strip content and lengths. The results obtained from the tests are presented and discussed in this paper.

Background

Several researchers have conducted investigations using different types of reinforcement and materials. Bauer and Oancea (1996), based on their triaxial test results, indicated that the secant modulus as an indicator of the stiffness within the initial vertical strain of 2% decreased with increasing polypropylene fibre contents up to 0.5%. They also reported that beyond this vertical strain the secant modulus remained fairly constant. Consoli et al. (1998), conducting triaxial compression tests, showed that fibre reinforcement decreased the stiffness. Gray and Ohashi (1983), based on direct shear test results, indicated that fibre reinforcement increased the peak shear strength and limited post-peak reductions in shear resistance. However, no increase in stiffness of the fibre-sand composite was observed. Freitag (1986) reported that randomly distributed fibres in a compacted fine-grained soil could result in greater stiffness. Gray and Al-Refeai (1986), conducted triaxial compression tests on sand and found that randomly distributed discrete fibres resulted in a loss of compressive stiffness at low strains (less than 1%). Benson and Khire (1994) used cut pieces of waste milk jugs and showed that there is an increase in CBR by a factor of 5. The secant modulus of the sand also improved with the addition of cut pieces of waste milk jugs into the sand. Michalowski and Zhao (1996), based on triaxial test results, indicated that the steel fibres led to an increase in the stiffness prior to reaching failure. Bueno (1997) conducted a laboratory study on mechanically stabilised soils with short thin plastic strips of different lengths and contents. They found an enhancement in load bearing capacity. Kumar et al. (1999), based on their laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibres, concluded that the fibres increased the CBR value and ductility of the specimens. They also reported that the optimum fibre content for both silty sand and pond ash was approximately 0.3%-0.4% of dry unit weight. Kaniraj and Havanagi (2001) conducted unconfined compression tests on cement-stabilised fibre-reinforced fly ash-soil mixtures and concluded that randomly oriented polyester fibre changed the brittle behaviour to ductile behaviour. Yetimoglu and Salbas (2003) indicated that initial stiffness of the sand was not affected significantly by the randomly distributed discrete fibres. Venkatappa Rao and Dutta (2004a) reported a theoretical analysis on the basis of triaxial results to assess the improvement in bearing capacity of a footing on a waste plastic strip reinforced sand bed resting on clay soil. Their analysis revealed that waste plastic strips in sand were found to improve only the bearing capacity. Venkatappa Rao and Dutta (2004b) reported a theoretical analysis on the basis of triaxial results to assess the overall influence of waste plastic strip reinforced sand on the bearing capacity improvement of a granular trench. Their analysis revealed that inclusion of waste plastic strips in sand improved the bearing capacity of the granular trench. Yetimoglu et al. (2005) conducted CBR tests on sand fills reinforced with randomly distributed discrete fibres overlying soft clay. Their study reveals that adding fibre to sand fill resulted in an appreciable increase in the peak piston load. However, the initial stiffness of the load-penetration curves was not significantly affected by fibre reinforcement. The test results further showed that increasing fibre reinforcement content could increase the brittleness of the fibre-reinforced sand fill-soft clay system. The disagreement among the reported results is attributed to the difference in the material properties and testing conditions.

The literature presented above clearly indicates that the influence of waste plastic strip reinforcement on the CBR behaviour of strip-reinforced stone dust/fly ash overlying saturated clay has not been investigated so far.

Experimental Work

A brief description of the material used in this investigation along with CBR tests conducted in the present study is as follows:

Stone dust

The investigation was carried out on locally available stone dust in Hamirpur, India. It contained a sand fraction of about 88.7%, and silt and clay content of about 11.3%. The particle size distribution curve of the stone dust is shown in Figure 1. It had a specific gravity of 2.65, mean particle diameter (D_{50}) of 0.40 mm, coefficient of uniformity (C_u) of 7.66, and coefficient of curvature (C_c) of 0.85. The stone dust was classified gap graded as per the Unified Classification System. The maximum dry unit weight and optimum water content obtained from a standard Proctor test for the stone dust were 18.64 kN/m^3 and 12%, respectively. The unsoaked CBR value of the stone dust was 8.0%. The secant modulus of stone dust at a penetration of 2.5 mm was 189.86 MPa. The load-penetration curve of the stone dust is shown in Figure 2.

Fly ash

The fly ash used in this study was procured from Ropar Thermal Power Plant (Punjab), India. It contained a sand fraction of about 15%, and silt and clay content of about 85%. It had a specific gravity of 2.07 and liquid limit of 50%. The maximum dry unit weight and optimum water content obtained from a standard Proctor test for the fly ash were 9.54 kN/m^3 and 27%, respectively. The unsoaked CBR value of the fly ash was 29.68%. The secant modulus of fly ash at a penetration of 2.5 mm was 705 MPa. The load-penetration curve of the stone dust is shown in Figure 3. The chemical analysis reported by Siddique et al. (2007) for Ropar Thermal Power Plant fly ash is shown in Table 1.

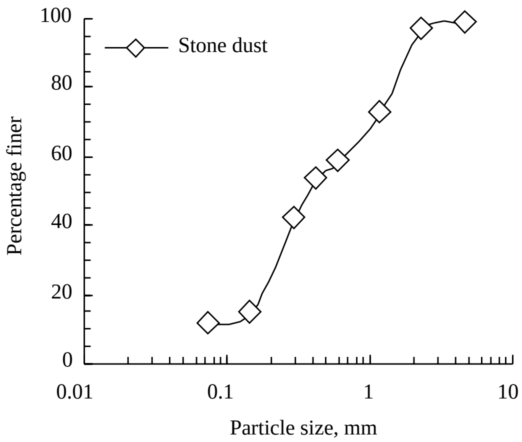

Figure 1. Particle size distribution of stone dust.

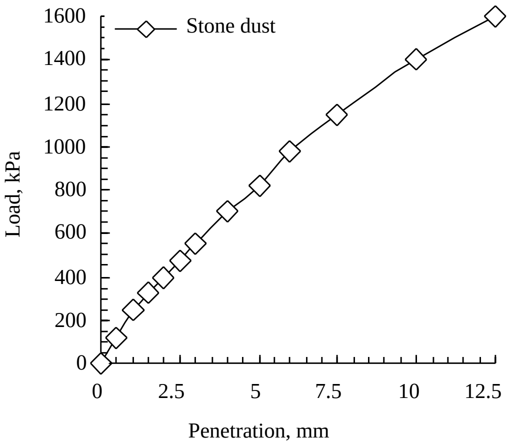

Figure 2. Load-penetration curve for stone dust.

Kaolinite

The kaolinite clay used in this study was of commercial grade. It contained a sand content of about 3.2%, silt content of about 12.2%, and clay content of about 84.6%. It had a specific gravity of 2.65, liquid limit of 61.8%, and plastic limit of 21.2%. The clay was classified as per the Unified Classification System as a high plasticity clay. The maximum dry unit weight and optimum water content obtained from a standard Proctor test for the kaolinite clay were 18 kN/m^3 and 22%, respectively. In the present study, the subgrade soil in the CBR mould was prepared at a water content of 36% (between plastic limit and liquid limit, the condition which can occur during the rainy season and to make a paste of workable consistency) and was made by hand kneading by pasting the kaolinite layer by layer in order to avoid the development of negative pore pressure (matric suction) or trapped air in the subgrade soil and hence soil is taken as being fully saturated. The placement dry unit weight of the clay in the CBR mould was 12.35 kN/m^3 at a water content of 36%. The CBR value of the saturated kaolinite clay was 0.32% at a water content of 36%. The secant modulus of kaolinite clay at a penetration of 2.5 mm was 8.80 MPa. The load-penetration curve of kaolinite is shown in Figure 4. The undrained shear strength and permeability coefficient for the kaolinite clay were 9.85 kPa and 4.17 x 10^{-9} m/s, respectively.

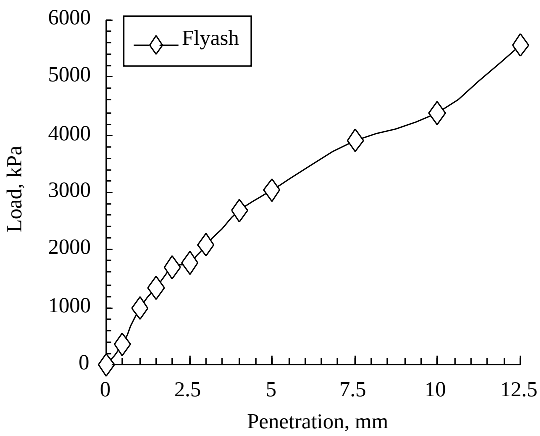

Figure 3. Load-penetration curve for fly ash.

Table 1. Chemical composition of Ropar Thermal Power Plant Fly Ash (after Siddique et al. (2007)).

Chemical analysis	Fly ash (%)
Silicon dioxide, SiO_2	56.8
Aluminium oxide, Al_2O_3	26.10
Ferric oxide, Fe_2O_3	5.0
Calcium oxide, CaO	3.8
Magnesium oxide, MgO	2.3
Titanium oxide, TiO_2	1.4
Potassium oxide, K_2O	0.6
Sodium oxide, Na_2O	0.4
Sulfur trioxide, SO_3	1.6
LOI (1000 °C),	1.9
Moisture	0.3

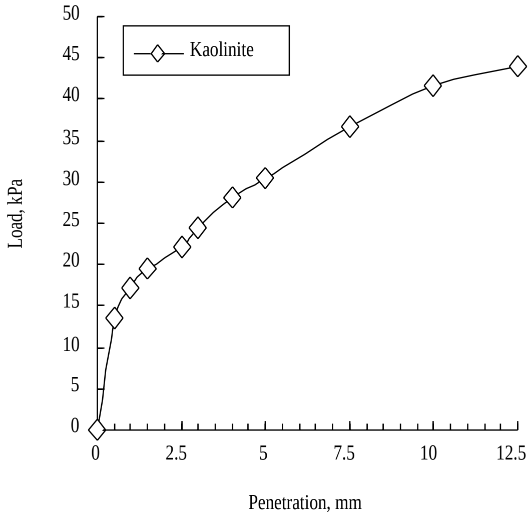

Figure 4. Load-penetration curve for kaolinite clay.

Waste plastic strip

The waste plastic strips used in the present study were purchased from a rag picker who collects recyclable material from the waste dumpsite in Hamirpur District, India, at a price of INR 90 per kg (approximately $2 per kg). They are made of HDPE having a width of 12 mm, and a thickness of 0.45 mm and a mass of 3.8 g/m. These were cut into lengths of 12 mm (designated as Type I, aspect ratio = 1), 24 mm (designated as Type II, aspect ratio = 2), and 36 mm (designated as Type III, aspect ratio = 3). In the absence of standards for testing strips, the standards used for wide width tensile strength test (ASTM D 4885) for geosynthetics were used. The tensile strength of 100-mm long waste plastic strip was determined at a deformation rate of 10 mm/min in a computer controlled Hounsfield machine. The average ultimate tensile strength of this strip was 0.32 kN and percent elongation at failure was 25%.

Parameters varied

The waste plastic strips to be added to the stone dust/fly ash were considered a part of the solids fraction in the void-solid matrix of the soil. The content of strips is defined herein as the ratio of weight of strips to weight of dry stone dust/fly ash. The tests were conducted at a strip content of 0.0%, 0.25%, 0.50%, 1.0%, 2.0%, and 4.0%, respectively.

CBR Tests

The experimental study involved a series of laboratory CBR tests on the unreinforced and randomly distributed strip-reinforced stone dust/fly ash overlying saturated clay. At the outset, a thin layer of grease was applied on the internal surfaces of the CBR mould in an attempt to minimise the side friction. A typical test model consisted of saturated clay subgrade overlain by a waste plastic strip-reinforced stone dust/fly ash, as the base course, was prepared as shown in Figure 5.

The stone dust/fly ash with and without strips was compacted in 2 layers of thickness 20 mm each on the top of the CBR mould (rigid metal cylinder with an inside diameter of 152 mm and a height of 178 mm) at optimum moisture contents of 12% and 27% by the standard procedure by giving 56 blows of a 25.5 N rammer dropped from a distance of 310 mm. Kaolinite clay as subgrade of thickness 88 mm at a moisture content 36% (previously prepared and kept for 24 h for obtaining moisture equilibrium) was placed in the CBR mould by hand kneading. The resulting dry unit weight of the kaolinite clay obtained was 12.35 kN/m^3. A manual loading machine equipped with a movable base that travelled at a uniform rate of 1.25 mm/min and a calibrated load-indicating device was used to force the penetration piston of diameter of 50 mm into the specimen. A surcharge plate of 2.44 kPa was placed on the specimen prior to testing. The loads were carefully recorded as a function of penetration up to a total penetration of 12.5 mm. The tests are carried out to simulate the worst field condition, which can occur during the rainy season.

Test Results and Discussion

Load Penetration Behaviour of Reinforced Stone Dust over Saturated Clay

The load-penetration curves obtained from the CBR tests for waste plastic strip (content varying from 0.25% to 4% of Type-I) reinforced stone dust overlying saturated clay is shown in Figure 6.

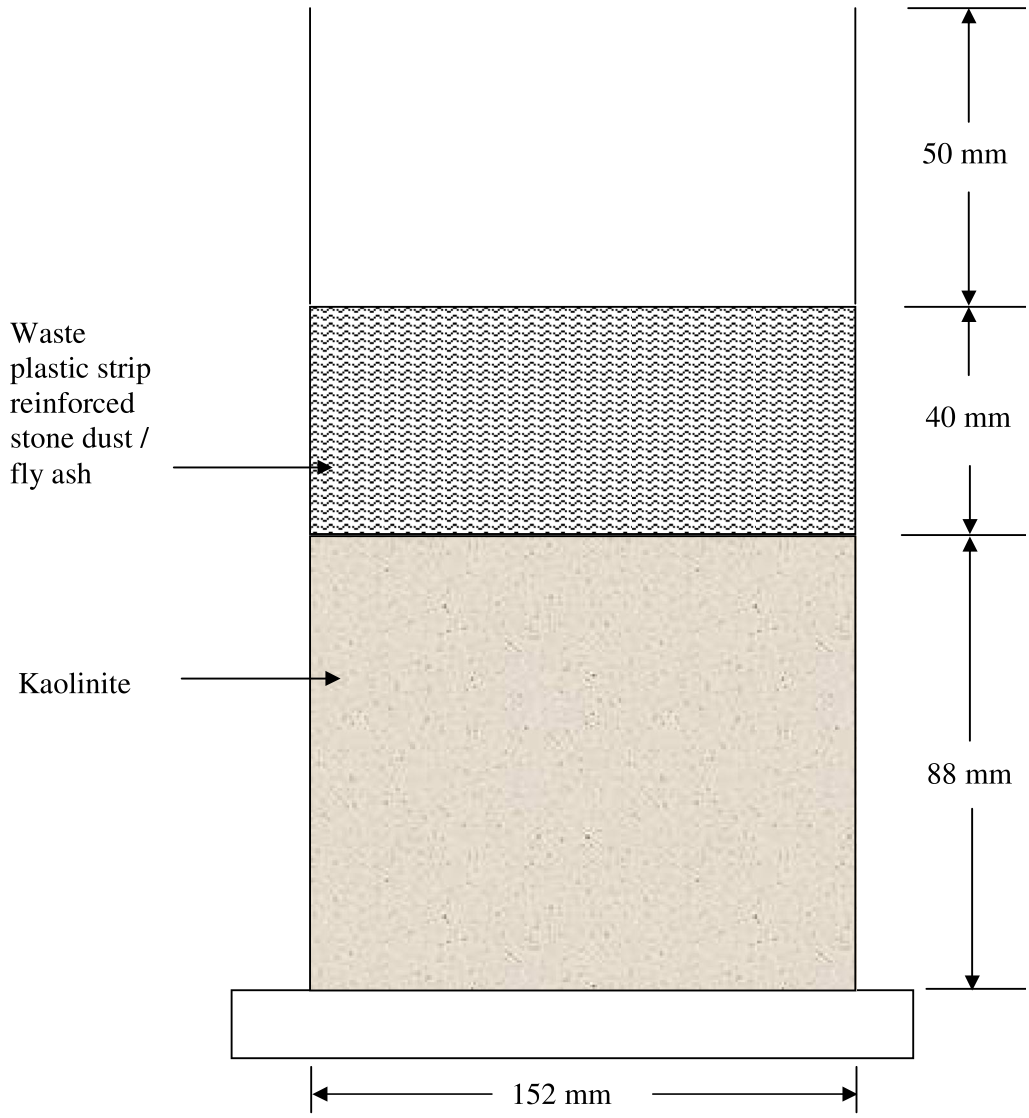

Figure 5. Test model of saturated clay as subgrade overlain by a waste plastic strip-reinforced stone dust/fly ash.

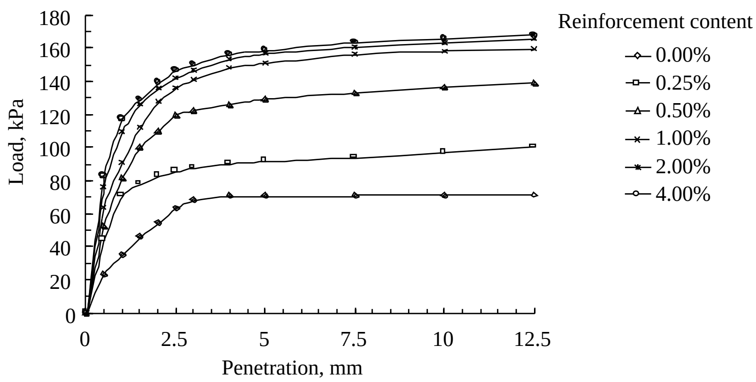

Figure 6. Load-penetration curves for waste plastic strip Type-I reinforced stone dust overlying saturated clay.

It is evident that waste plastic strip-reinforced stone dust overlying saturated clay increased the CBR significantly. For example, the CBR values of the unreinforced stone dust overlying saturated clay corresponding to 2.5 mm and 5.0 mm penetration were found to be 0.93% and 0.69%, respectively. These values of CBR for the stone dust reinforced with 0.25% waste plastic strips of Type-I overlying saturated clay increased to 1.25% and 0.89%, respectively, corresponding to the above penetrations. Further, for a stone dust with 2% waste plastic strips of Type-I overlying saturated clay, the CBR values increased to 2.07% and 1.52%, respectively, corresponding to 2.5 mm and 5.0 mm penetration. Similarly, for a stone dust with 4% waste plastic strips of Type-I overlying saturated clay, the CBR values increased to 2.14% and 1.54%, respectively, corresponding to 2.5 mm and 5.0 mm penetration. Figure 6 further reveals that the initial slope of the load-penetration curve is significantly improved by incorporation of strips in stone dust overlying saturated clay. A close examination of Figure 6 also reveals that the benefit of adding waste plastic strips beyond 2% does not improve the CBR value appreciably. Similar results have been found in respect of stone dust with strip Types II and III overlying saturated clay and the results are shown in Figures 7 and 8.

The variation in CBR of strips-reinforced stone dust overlying saturated clay with strip content and strip length is shown in Figure 9.

The increase in CBR is noticeably attributed to strip inclusion in the stone dust overlying saturated clay and strip length. For example, the CBR of the unreinforced stone dust overlying saturated clay was 0.93%. This value of CBR increased to 1.25% when 0.25% waste plastic strip of Type-I was added to stone dust. Further, for a stone dust with 2% waste plastic strips of Type-I overlying saturated clay, the CBR value increased to 2.07%. Similarly, for a stone dust with 4% waste plastic strips of Type-I overlying saturated clay, the CBR value increased to 2.14%. Figure 9 further reveals that for a stone dust with waste plastic strip content of 1% and strip length of 12 mm, the value of CBR is 1.98%. This value increased to 2.05% when the strip length was increased from 12 to 24 mm at the same strip content. A similar trend can be observed at other strip content also.

The variation in secant modulus (defined as the ratio of load in kPa at a penetration of 2.5 mm to the penetration of 0.0025 m) of strip-reinforced stone dust overlying saturated clay with waste plastic strip content and strip length is shown in Figure 10.

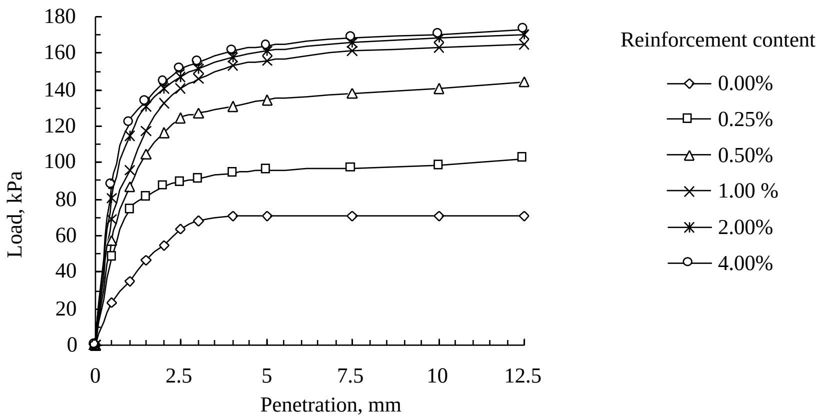

Figure 7. Load-penetration curves for waste plastic strip Type-II reinforced stone dust overlying saturated clay.

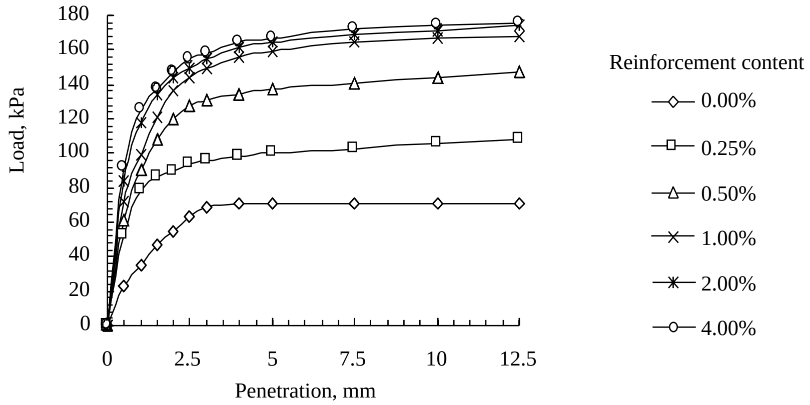

Figure 8. Load-penetration curves for waste plastic strip Type-III reinforced stone dust overlying saturated clay.

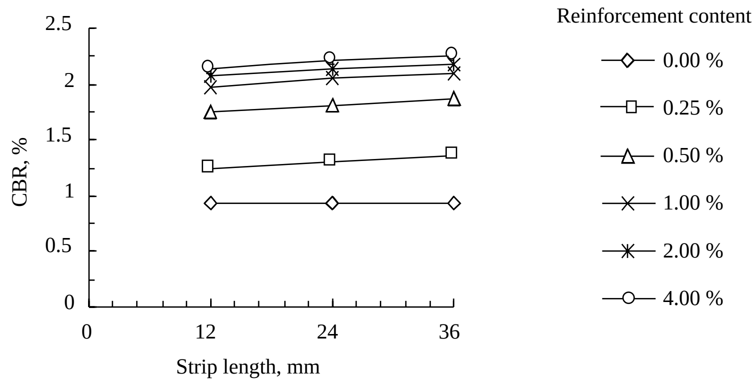

Figure 9. Variation in CBR of strip-reinforced stone dust overlying saturated clay with strip content and strip length.

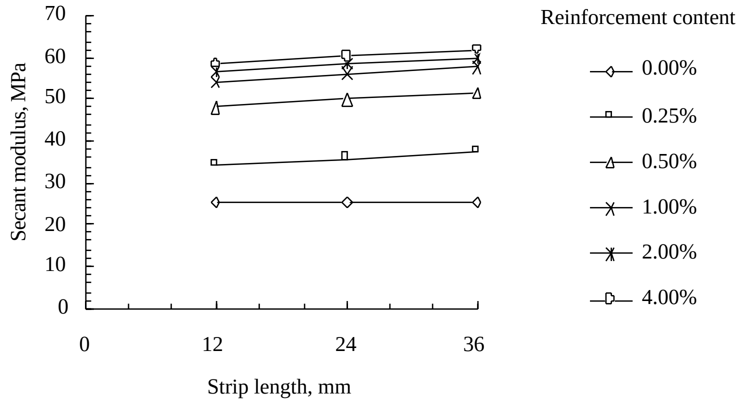

Figure 10. Variation in secant modulus of strip-reinforced stone dust overlying saturated clay with strip content and strip length.

As expected, the increase in secant modulus is again noticeably attributed to strip inclusion in the stone dust overlying saturated clay and strip length. For example, the secant modulus of the unreinforced stone dust overlying saturated clay was 25.44 MPa. This value of secant modulus increased to 34.2 MPa when 0.25% waste plastic strip of Type-I was added to stone dust. Further, for a stone dust with 2% waste plastic strips of Type-I overlying saturated clay, the secant modulus value increased to 56.74 MPa. Similarly, for a stone dust with 4% waste plastic strips of Type-I overlying saturated clay, the secant value increased to 58.7 MPa. Figure 10 further reveals that for a stone dust with waste plastic strip content of 1% and strip length of 12 mm the value of secant modulus was 54.48 MPa at a penetration of 2.5 mm. This value increased to 56.34 MPa when the strip length was increased from 12 to 24 mm at the same strip content. A similar trend can also be observed at other strip content.

Load penetration behaviour of reinforced fly ash over saturated clay

The load-penetration curves obtained from the CBR tests for waste plastic strip (content varying from 0.25% to 4% of Type-I) reinforced fly ash overlying saturated clay are shown in Figure 11.

It is seen that waste plastic strip-reinforced fly ash overlying saturated clay increased the CBR significantly. For example, the CBR values of the unreinforced fly ash overlying saturated clay corresponding to 2.5 mm and 5.0 mm penetration were found to be 1.08% and 0.83%, respectively. These values of CBR for the fly ash reinforced with 0.25% waste plastic strips of Type-I overlying saturated clay increased to 1.20% and 0.93%, respectively, corresponding to the above penetrations. Further, for a fly ash with 2% waste plastic strips of Type-I overlying saturated clay, the CBR values increased to 1.84% and 1.37%, respectively, corresponding to 2.5 mm and 5.0 mm penetration. Similarly, for a fly ash with 4% waste plastic strips of Type-I overlying saturated clay, the CBR values increased to 1.91% and 1.40%, respectively, corresponding to 2.5 mm and 5.0 mm penetration. Figure 11 reveals that the initial slope of the load-penetration curve is significantly improved by incorporation of strips in fly ash overlying saturated clay, which is in line with the results obtained in the case of stone dust as reported earlier. A close examination of Figure 11 further reveals that the benefit of adding waste plastic strips beyond 2% does not improve the CBR value appreciably. A similar study was carried out in respect of fly ash with strip Types II and III overlying saturated clay and the results are shown in Figures 12 and 13.

The variation in CBR of strip-reinforced fly ash overlying saturated clay with strip content and strip length is shown in Figure 14.

The increase in CBR can again be noticeably attributed to strip inclusion in the fly ash overlying saturated clay and strip length. For example, the CBR of the unreinforced fly ash overlying saturated clay was 1.08%. This value of CBR increased to 1.20% when 0.25% waste plastic strip of Type-I was added to fly ash. Further, for a fly ash with 2% waste plastic strips of Type-I overlying saturated clay, the CBR value increased to 1.84%. Similarly, for a fly ash with 4% waste plastic strips of Type-I overlying saturated clay, the CBR value increased to 1.91%. Figure 14 further reveals that for a fly ash with waste plastic strip content of 1% and strip length of 12 mm the value of CBR was 1.76%. This value increased to 1.86% when the strip length is increased from 12 to 24 mm at the same strip content. A similar trend can also be observed at other strip content.

The variation in secant modulus of strip-reinforced fly ash overlying saturated clay with waste plastic strip content and strip length is shown in Figure 15.

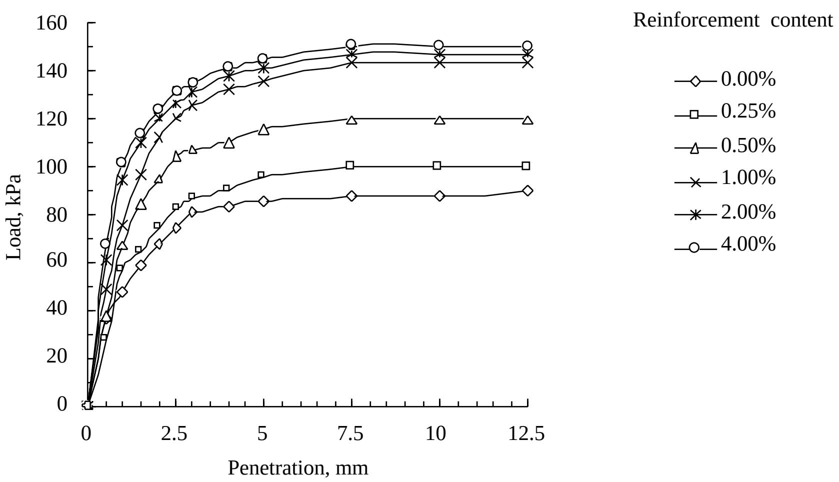

Figure 11. Load-penetration curves for waste plastic strip Type-I reinforced fly ash overlying saturated clay.

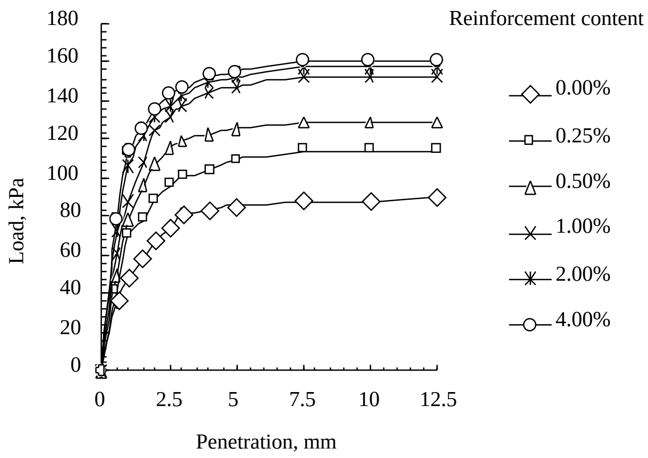

Figure 12. Load-penetration curves for waste plastic strip Type-II reinforced fly ash overlying saturated clay.

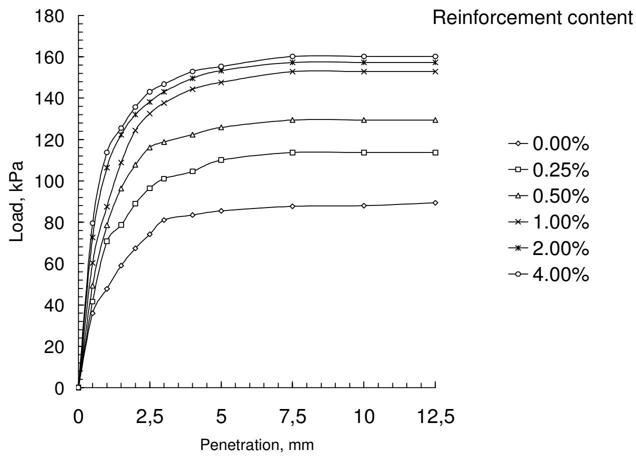

Figure 13. Load-penetration curves for waste plastic strip Type-III reinforced fly ash overlying saturated clay.

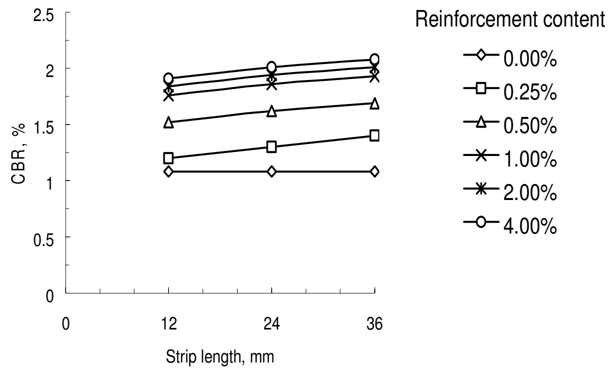

Figure 14. Variation in CBR of strip-reinforced fly ash overlying saturated clay with strip content and strip length.

As expected, the increase in secant modulus is again noticeably attributed to strip inclusion in the fly ash overlying saturated clay and strip length. For example, the secant modulus of the unreinforced fly ash overlying saturated clay was 29.66 MPa. This value of secant modulus increased to 32.96 MPa when 0.25% waste plastic strip of Type-I was added to fly ash. Further, for a fly ash with 2% waste plastic strips of Type-I overlying saturated clay, the secant modulus value increased to 50.56 MPa. Similarly, for a fly ash with 4% waste plastic strips of Type-I overlying saturated clay, the secant value increased to 52.52 MPa. Figure 15 further reveals that for a fly ash with waste plastic strip content of 1% and strip length of 12 mm the value of secant modulus was 48.30 MPa. This value increased to 50.94 MPa when the strip length was increased from 12 to 24 mm at the same strip content. A similar trend can also be observed at other strip content. The use of fly ash as base course material usually attracts the attention of the environmentalist. The inhibition of using this material as base or sub-base course material is due to the fact that it may interact with water during the rainy season and may generate leachate containing heavy metals, which can pollute the subsoil and subsequently the ground water table. In the present investigation the sub-base material used is kaolinite having a permeability coefficient of the order of 10^{-9} m/s, which is the requirement of the compacted clay liner in a landfill for not allowing the harmful leachate to pass deep into the sub-soil and ground water table. Hence the possibility of harmful leachate going into the sub-soil and ground water table is minimal in this case. The cost economics of using the waste materials in base or sub-base courses is beyond the scope of the present study, and requires a separate detailed investigation. However, the authors of this paper are of the opinion that the solution may be economical in those areas where the waste materials are available nearby.

Comparison of reinforced stone dust and fly ash

A comparison of the modulus ratio (ratio of secant modulus of strip reinforced stone dust/fly ash overlying saturated clay to the secant modulus of unreinforced stone dust/fly ash overlying saturated clay) is attempted. The results are shown in Figure 16, which reveals that the modulus ratio of strip reinforced stone dust overlying saturated clay is more than the modulus ratio of strip reinforced fly ash overlying saturated clay. Thus it can be concluded that reinforced stone dust is more effective than reinforced fly ash overlying saturated clay for improving the behaviour of the system.

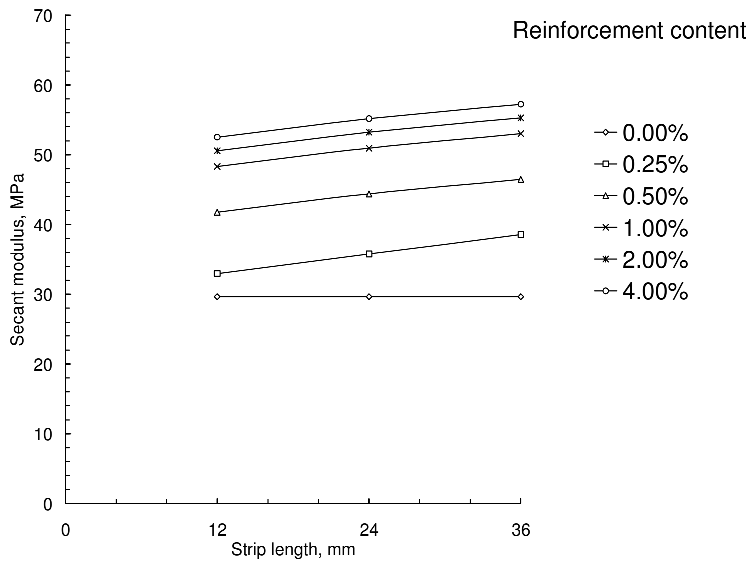

Figure 15. Variation in secant modulus of strip-reinforced fly ash overlying saturated clay with strip content and strip length.

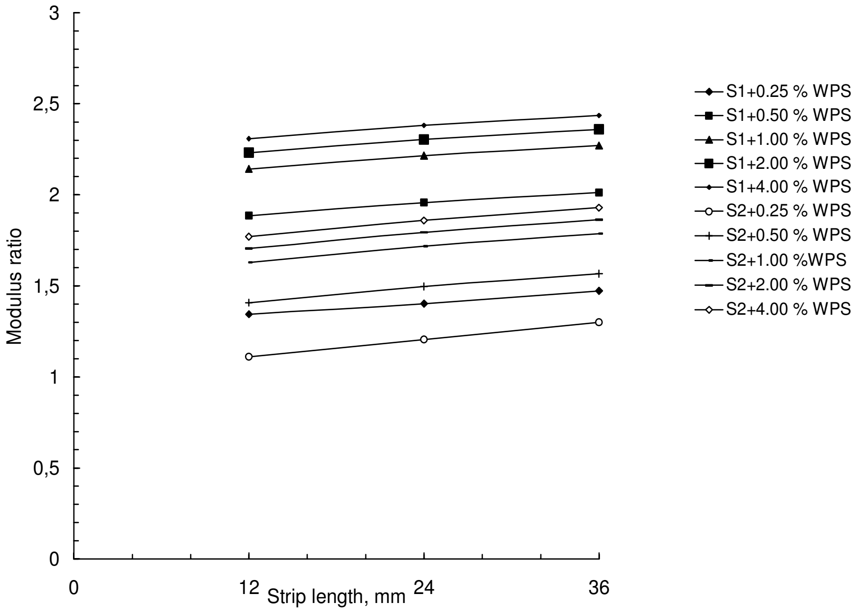

Figure 16. Comparison of the modulus ratio of strip reinforced stone dust/fly ash overlying saturated clay.

Conclusions

An experimental study was carried out to investigate the CBR behaviour of stone dust/fly ash reinforced with 3 different sizes of waste plastic strips overlying saturated clay. The effect of waste plastic strips content on CBR and secant modulus of strip reinforced-stone dust/fly ash overlying saturated clay was investigated. The study yielded the following conclusions.

1. Addition of waste plastic strip inclusions in stone dust/fly ash overlying saturated clay subgrade results in an appreciable increase in the CBR and the secant modulus.
2. The reinforcement benefits increase with an increase in waste plastic strip content and length.
3. The addition of waste plastic strips beyond 2% does not improve the CBR or secant modulus appreciably.
4. Reinforced stone dust is more effective than reinforced fly ash overlying saturated clay in improving the behaviour of the system.
5. Further research is recommended to study the cost economics of the use of waste materials in base courses in rural roads.

On the whole, this study has attempted to provide an insight into the CBR behaviour of stone dust/fly ash reinforced with different sizes of waste plastic strips overlying saturated clay for use in base course in constructing rural roads over saturated clay. Utilising some portion of the waste in this way will reduce the quantity of waste requiring disposal. More so the disposal in this way will be in an environmentally friendly manner.

Nomenclature

S1 : stone dust
S2 : fly ash
WPS: waste plastic strip

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