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Study of scale effect on strength characteristic of stabilised composite with sewage sludge – Part B: Critical investigation

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HIGHLIGHTS

- The strength characteristics of clay were improved in sludge-treated composites.
- The use of large direct shear data gave more reliable data to apply to in situ soil.
- The microstructure of the stabilised soil was more uniform than the pure clay.
- The addition of sludge led to a pozzolanic reaction by the polymerisation process.

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ABSTRACT

The preliminary study of the engineering properties of bentonite composites with and without added sludge by testing the pH, compaction, and consolidation has been discussed in part A. Further critical investigations were then performed to gain an understanding of the scale effect on soil strength characteristics and the microanalytical behaviour of soil composites. Research using two different sized direct shear boxes yielded more applicable data for applying to in situ soil. It was revealed that soil was slightly strengthened by the utilisation of sludge. Experimental data were then confirmed by further microstructural, chemical, elemental and mineralogical tests.

1. Introduction

Part A of the research paper reviewed the most common methods used in sludge application and presented some of the main issues with problematic soil. The initial study of stabilised soil revealed the effectiveness of sewage sludge in improving the compaction and consolidation properties of treated soil. In addition, the pH values and microstructural analysis suggested the potential for generation of a pozzolanic reaction due to the type of soil composite materials. The additional studies therefore had two main goals; to study the scale effect to achieve a more reliable result near to reality, and to carry out a microanalytical study on soil composites to record the chemical compounds created in soil composites.

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2. Experimental study

2.1. Direct shear test

In general, maximum shear strength is an important element in designing the geotechnical project [1,2]. As it is clear that the size of the shear box can affect the results of the direct shear test, valuable data on the shear strength parameters of soil will be obtained by using different shear box sizes. Thus, the study of the scale effect on the bentonite composite was carried out using both small direct shear and large direct shear devices. With regard to the large shear box, which could be considered similar to a real situation using in situ soil, the comparison between the obtained results of different scales and assessing the effect of several percentages of additives, can be suggested a reliable information about the effect of sludge addition on composite strength [1].

2.1.1. Small direct shear

Soil specimens with and without sludge mixtures of differing percentages were vertically loaded under 50, 100, and 200 kPa normal stress. The shear stress-horizontal displacement curves for the bentonite composites are illustrated in Figs. 1–3. It appears that initial stiffness at the same normal stress is similar for the bentonite mixtures. Overall, the results indicate the effect of the sludge mixture on the shear properties of bentonite for all vertical loads. A different effect can be seen for the optimum sludge dosage at each vertical load, however, the results show a regular correlation after increasing the normal stress. Fig. 1 illustrates that, with the addition of sludge, shear failure occurs at a higher horizontal load. The maximum amount was 98.59 kPa, with 2% added sludge, and it decreased with increased additive dosage. However, this tendency was gradual and was still higher than the pure bentonite failure point, which was 82.7 kPa.

Moreover, at the maximum shear stress for untreated soil, the displacement is about 0.601 mm. The addition of 2% sludge resulted in failure at 0.7 mm. Nevertheless it had the same behaviour with shear stress, when the additive dosage was increased.

By contrast, increasing the vertical load reversed this tendency. Fig. 2 shows a relationship between improved strength properties of bentonite and the amount of additive. Shear stress increased from 90.08 to 128.7 kPa, continuing with a minor increase to 136.8 kPa in the composite with 6% added sludge. However, the maximum improvement in shear strain occurred with the addition of 2% sludge. Horizontal failure mobilised from 0.4007 mm to a greater displacement of 0.8002 mm.

The shear stress-horizontal displacement results for bentonite mixtures at 200 kPa normal load are shown in Fig. 3. The results suggest that incremental increases in the dosage of sludge improve both the shear failure point and shear strain properties of bentonite. The maximum shear failure occurred in the sample with 6% added sludge, at 193.2 kPa and 0.9003 mm displacement.

2.1.2. Large direct shear

The shear stress-horizontal displacement curves achieved from the large direct shear tests for bentonite combinations are illustrated in Figs. 4–6. It is understandable that the initial slopes of the shear stress-horizontal displacement curves for all composites are similar. However, aside from a few differences, the large direct shear results generally confirmed the results of the small direct shear test.

Fig. 4 illustrates that the application of sludge leads to improvements in the strength properties of bentonite composites. The large direct shear results confirmed the small direct shear data. However, there was a higher shear stress value compared to the small direct shear test at 50 kPa vertical load. Addition of 2% sludge resulted in a maximum shear stress of 106.66 kPa. Further increases in additive led to a decrease in the shear stress, but this reversal of the trend was minor and the value was still greater than the pure bentonite shear stress of 96.88 kPa.

As can be seen from Fig. 4, the maximum shear strain occurred with the 2% sludge composite. The addition of 2% sludge resulted in failure occurring at 38.13 mm horizontal displacement, which is about 8 mm more than the failure point of pure bentonite. Not only the obtained data of shear strain tendency from the large direct shear test was similar to the small direct shear result, but also, it was more regular than the small box data.

Compared to the small scale data, the investigation of the effect of sludge addition under 100 kPa normal stress in large scale tests revealed different behaviour. The shear stress value showed an inverse correlation with the additive dosage, which is the opposite of the small direct shear results (Fig. 5).

However, the shear strength properties of bentonite composites in the large scale tests were similar to those at 50 kPa vertical load. Similarly to the small scale result, the maximum shear stress was obtained by the application of 2% sludge in bentonite stabilisation. Moreover, the shear strain results from the large device showed that failure occurred at 38.4 mm, nearly 19 mm more than the failure point of pure bentonite (Fig. 5).

Finally, the shear strength results for bentonite composites under 200 kPa normal stress are illustrated in Fig. 6. Although the results were similar to the shear stress results at 200 kPa, the value was almost 30 kPa less than the maximum shear stress yielded by the small direct shear device. The maximum shear stress observed for the sample with 6% added sludge was 165.88 kPa.

As with the small scale results, the maximum strain was associated with the bentonite composite containing the maximum dosage of additives. There was a notable improvement, with the failure point shifting from 15.85 to 42.12 mm horizontal displacement. In general, the large direct shear results illustrated a regular and predictable trend for shear stress and shear strain in the bentonite composites.

Thus, compression of the large direct shear and small direct shear data suggests a valid hypothesis about the effect of sludge on soft soil strength properties. Fig. 7 illustrates the maximum shear stress for each specimen at two different scales, and their responses under three normal stresses. As revealed in Fig. 7, compared to the

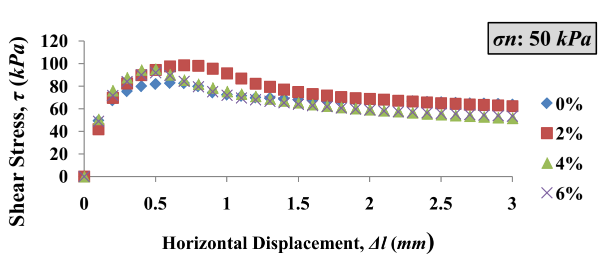

Fig. 1. Shear stress-horizontal displacement tests for the bentonite mixtures with different proportions of sludge added under vertical load at 50 kPa (small direct shear).

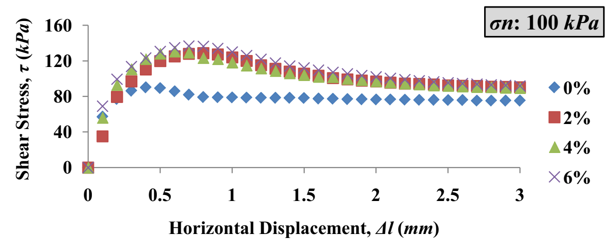

Fig. 2. Shear stress-horizontal displacement tests for the bentonite mixtures with different proportions of sludge added under vertical load at 100 kPa (small direct shear).

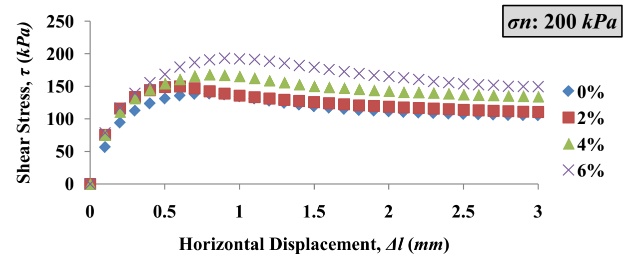

Fig. 3. Shear stress-horizontal displacement tests for the bentonite mixtures with different proportions of sludge added under vertical load at 200 kPa (small direct shear).

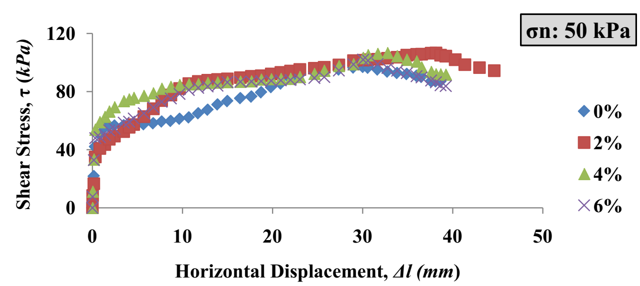

Fig. 4. Shear stress-horizontal displacement tests for the bentonite mixtures with different proportions of sludge added under vertical load at 50 kPa (large direct shear).

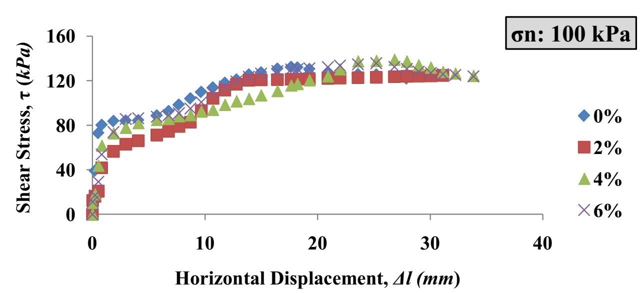

Fig. 5. Shear stress-horizontal displacement tests for the bentonite mixtures with different proportions of sludge added under vertical load at 100 kPa (large direct shear).

same samples in the small direct shear apparatus, the shear failure at a large scale (with the exception of the two final specimens with 4% sludge and 6% sludge, respectively) occurred after implementing a higher horizontal load.

However the difference in the failure point of each series of large direct shear samples for a constant dosage of additive was lower, and varied from 10 to 20 kPa, whereas the maximum shear stress in the small scale tests showed greater variation, with a range of 10 to 55 kPa (Fig. 7).

The addition of sludge also has a minor effect on the friction angle of bentonite composites (Fig. 8). The friction angles obtained from both small shear and large direct shear data demonstrated the same tendencies, with the maximum reduction