The effect of mechanical remoulding on the compression and strength characteristics of a Mercia Mudstone

L'effet de remaniement mécanique sur les caractéristiques de compression et la force d'un mudstone Mercia

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ABSTRACT

A series of laboratory tests have been undertaken as part of a larger study into the effect of continuous flight auger pile installation on the soil-pile interface in the Mercia Mudstone Group [1]. This paper reports the results of stress path triaxial tests on bulk samples of the mudstone which have been subjected to varying amounts of mechanical remoulding representing the remoulding that occurs due to the action of the auger. In addition, the water content at which remoulding takes place has been varied. The tests were undertaken to investigate whether the silt sized aggregates of clay particles that exist [2] within this soil could be broken up by the mechanical remoulding and whether this would affect the compression and strength properties of the mudstone. It was found that both mechanical remoulding and the water content at which this is carried out affect the subsequent response of the soil.

RÉSUMÉ

Une série de tests de laboratoire a été entreprise dans le cadre d'un plus grande étude sur l'effet de l'installation de pieux fores à la tarière sur l'interface sol-pieu dans le mudstone Mercia Group [1]. Cet article présente les résultats des tests de chemin de contrainte triaxiale sur des échantillons en vrac de la mudstone qui ont été soumis à des quantités variables de remaniement mécaniques représentant les remaniement qui se produisent en raison de l'action de la tarière. En outre, la teneur en eau au cours de laquelle a lieu remaniement a été modifiée. Les essais ont été entrepris afin de déterminer si les agrégats de particules de limon argileux qui existent [2], dans ce sol pourraiont être divisé par le remaniement mécanique et si cela affecterait les propriétés de compression et la force du mudstone. Il a été constaté que les deux remaniement mécanique et la teneur en eau au cours de laquelle ces opérations sont effectuées affectent la réponse du sol.

Keywords: Mudstone, stiff clay, strength, volumetric compression, remoulding, disaggregation

1 INTRODUCTION

In June 2007 a field trial was carried out at the Ibstock Brick Pit in Leicestershire. Four test piles were installed at a test site in the brick pit using a continuous flight auger piling rig. The aim of the trial was to study the effect of continuous flight auger pile installation on the soil-pile interface in the Mercia mudstone group [1]. About a week after installation the upper halves of all four piles were excavated in sections together with substantial samples of the surrounding soil. These sections and the soil surrounding them were transported back to City University London for examination and testing. In addition, a large bulk sample of the soil was also retrieved

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and it is this bulk sample which has been used for the tests reported in this paper.

It has been suggested [2] that the Mercia Mudstone has an aggregated structure, which means that clay minerals in the Mercia Mudstone are bonded together into silt size particles, such that a particle size distribution test will tend to greatly underestimate the proportion of clay minerals actually present in the mudstone. If these aggregations are broken up the clay minerals will be released and it is possible that this will affect the mechanical response of the mudstone.

The effect of breaking up aggregations of clay particles on index properties has been investigated for Mercia Mudstone for other sections of the stratigraphy [3] [4] and differing results have been obtained both in term of the energy required to disaggregate the particles and the effect on the index properties. It is likely that the later is strongly dependant on the clay minerals present, which varies significantly across the Mercia Mudstone group.

This study looked at the effect on strength and compressibility of subjecting samples of soil to varying amounts of mechanical remoulding and also of varying the water content at which remoulding takes place. The mechanical remoulding was undertaken to replicate the remoulding effect of the auger used in continuous flight auger piling and the water content was varied to investigate the effect of ground water entering the pile bore from more permeable water bearing layers. In the field trial water was added artificially during the excavation of two of the piles.

2 SOIL TESTED

Ibstock Brick Pit is in the Gunthorpe member of the Mercia Mudstone. The typical lithology of this member at Ibstock comprises red, and sometimes green and grey mudstones and siltstones ranging from finely laminated to structureless, with thin beds of coarse siltstone and very fine sandstone [5].

The stratigraphy logged at the site was consistent with this description with centimetre-scale laminated brick red/brown silty clay beds, interspersed with centimetre-scale red/purple hard beds. At certain depths these were interbedded with hard, olive green/grey sandy silt [1]. The bulk sample of soil which was obtained contained material from all three of the beds described above.

A mineralogical XRD analysis of soil from around the piles [1] showed that the clay fraction ranges from 0 – 28% with an average of 15% and that in most samples, illite is the most abundant mineral, making up to 98% of the clay fraction, and on average between 50-60%. Illite-smectite interlayers were present in approximately 50% of samples tested. The method used to test these samples requires the soil to be ground to a fine powder and it is thought that this would have caused any silt sized aggregates of clay particles to have been broken down. Consequently, the average values obtained from these mineralogical analyses should give a reasonably accurate picture of the clay fraction in the bulk soil sample used in these tests. It should noted that the bulk sample contains a representative amount of the sandy silt material which is unlikely to have a significant clay content.

Particle size distributions for this soil were obtained using wet sieving and sedimentation. Samples were prepared by soaking the soil and then by gentle agitation to separate uncemented aggregates. Typical particle size distribution curves are given in Figure 1. The distributions vary due to the variability of the bulk sample. This shows that in its natural state the mudstone appears to be sandy silt with a clay fraction of around 10%.

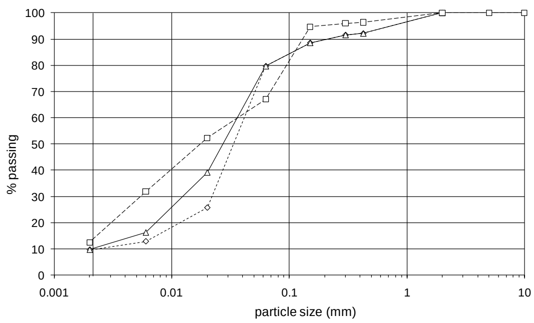

Figure 1. Typical particle size distribution curves for the un remoulded bulk sample

Comparing the clay fraction observed in Figure 1 with the average clay fraction of 15% observed from XRD analyses supports the suggestion that the Mercia Mudstone tested contains silt sized aggregations of clay particles [2], that can broken up under the action of mechanical remoulding, but is not conclusive due to the variability of the soil. Further evidence was obtained from particle size distribution tests carried out after the soil represented by the solid line in Figure 1 was remoulded, leading to a clay fraction of just over 20%.

The index properties of the bulk sample prior to remoulding were also obtained. The Liquid limit was 27.7%, and the plastic limit 10.0%, giving a plasticity index of 17.7% and an Activity of 1.42, which compares to the typical Activity for illite of 0.9.

3 EXPERIMENTAL METHOD

Two series of stress path triaxial tests have been carried out on samples of Mercia Mudstone taken from the bulk sample described in the previous section. In both series of tests an effort was made to start with a representative sample of the soil. In test series A the soil used in the test samples was mechanically remoulded, by passing through a meat mincer, at the average natural water content of 18%. In test series B the soil used in the test samples was mechanically remoulded at different water contents. Table 1 summarises the processes undergone by the soil used in the various tests.

Table 1. Summary of mechanical remoulding and water contents for soil samples tested.

Test ID	No of times soil remoulded by passing through meat mincer	Water content at which soil remoulded
Test A2	2	18%
Test A4	4	18%
Test A6	6	18%
Test B3L	3	19%
Test B3M	3	22%
Test B3H	3	26%

The use of a meat mincer to mechanically remould soil was proposed by Atkinson et al. [4] and was adopted for these tests. The aim was to simulate the same churning action that might occur in continuous flight auger pile construction. All the soil specimens tested were prepared using the same approach as described below.

3.1 Preparation of test specimens

A sub sample of soil from the bulk sample retrieved from site was prepared by soaking in distilled water for a few days and then being placed in a mixer. The sub sample used in the series A tests was mixed to a water content of 18%. The sub sample used in the series B tests was mixed to a water content of 19%. This soil was then divided into three batches and in two of these batches the water contents were increased to 22% and 26% respectively. All three batches were then mixed again before being passed through the meat mincer three times. The soil at 26% was at too high a water content to pass easily through the mincer and soil became stuck in the flights of the screw used in the mincer. All the soil used in the Series A tests was passed through the mincer twice. A third of the soil was set aside and the remainder was passed through the mincer a further two times. Another third was set aside and the final third was passed through the mincer two more times. This left six batches of soil as described in Table 1 and these were all separately mixed to a slurry with a water contents of 40-60%. The procedures outlined above were designed to ensure that the tests in each series are comparable despite the variability of the base bulk sample.

The 38mm diameter cylindrical specimens required for testing in the stress path triaxial apparatus were prepared from slurry using Perspex floating ring consolidation tubes. The specimens were consolidated under a maximum vertical stress of $60kN/m^2$. Because of the high silt and sand content in the Mercia Mudstone it was difficult to minimise friction between the pistons and the tube and consequently many of the specimens created did not have uniform water contents.

3.2 Testing procedure

The reconstituted specimens were carefully placed in computer controlled Bishop and Wesley [6] type stress path triaxial cells as described by Atkinson [7]. All specimens were compressed isotropically to the states given in Table 2 and then sheared under undrained conditions at a constant strain rate.

Water contents were obtained at the start of the tests from trimmings from the specimen and at the end of the test. Due to the problems in specimen preparation outlined above, the final water content was considered to be the most reliable and was used to calculate specific volumes.

Table 2. Test details

Test ID	p' after isotropic compression (kN/m^2)
Test A2	100
Test A4	180
Test A6	155
Test B3L	150
Test B3M	150
Test B3H	150

4 RESULTS

Because of the variability of the soil in the bulk sample each series of tests was effectively undertaken on a unique soil. The compression curves presented in Figure 2 should therefore be treated as two sets of data; Series A tests for which there are two reliable compression curves and Series B tests for which three compression curves are presented. The curve for Test B3H starts from a higher value of mean effective stress because the first stage of this test was a one step consolidation.

In all cases the soil was only lightly overconsolidated at the start of isotropic compression and all samples reached a normal compression line during the compression stage. As shown in Figure 1 the mudstone has a very high silt content and low clay fraction, so it is not surprising that the values of λ derived from the normal compression lines in Figure 2 are relatively low. They vary from 0.077 and 0.080 for Tests A4 and A6 respectively through 0.068 for Tests B3L and B3M to 0.046 for tests B3H.

The low compressibility of the soil means that the compression behaviour is very sensitive to the measurement of water contents in the sample. It was estimated that the final water content of the specimens may vary due to water entering the sample at the base of the specimen by as much as 0.5%. This gives a potential error in the specific volume which is indicated by the vertical line shown in Figure 2. This error will not only affect the position of the curves in terms of an offset to the specific volume but also to a lesser extent the gradient of the curves.

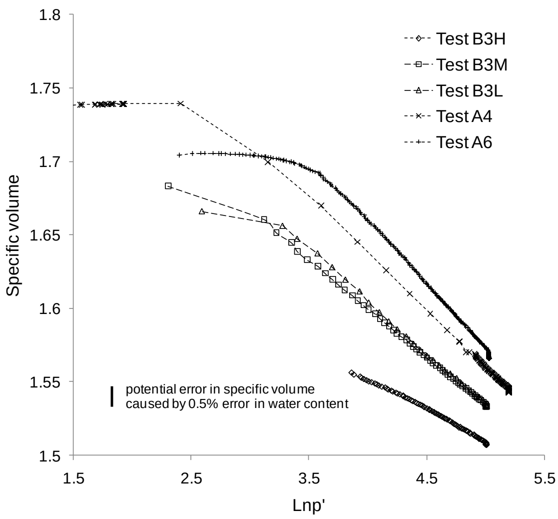

Figure 2. Compression data for Series A and Series B tests

Despite the potential inaccuracy in the specific volumes it is clear that the two Series B tests subjected to mechanical remoulding in the meat mincer at 19 and 22% water content have very similar normal compression lines whereas the normal compression line for the soil remoulded at a higher water content (26%) characterises a soil with a lower specific volume or more closely packed grains. It also has a lower value of λ, indicating the presence of a greater proportion of silt and sand sized particles. The gradients of the normal compression lines obtained in the Series A tests are similar, but for these tests it appears that the gradient and specific volume increase with greater mechanical remoulding in the meat mincer.

Data from the undrained shear stages are presented in Figures 3 and 4 as q/p' against axial strain. Figure 3 shows data for the Series A tests and in these the value of stress ratio at failure increases steadily with number of passes through the meat mincer from 1.11 through 1.22 to 1.43. In all cases the soil has reached a critical state and these values of the critical state friction coefficient are consistent with angles of friction of 27.9°, 30.5° and 35.3° respectively. Figure 4 shows stress ratio against axial strain for the Series B tests. The stress ratio against strain response is not affected by the water content at which remoulding takes place. All the data for the Series B tests are very consistent and give a value of stress ratio at failure of 1.31, equivalent to a critical state angle of friction of 32.5°.

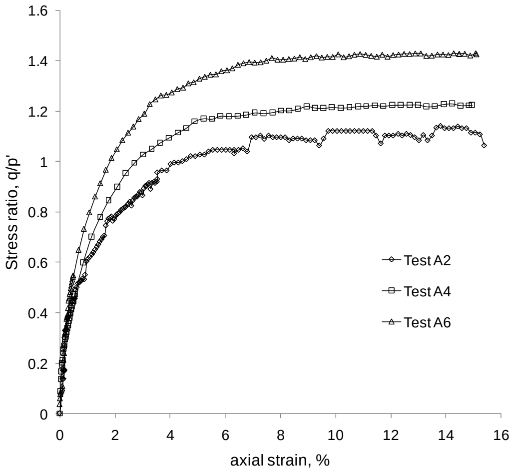

Figure 3. Stress ratio against axial strain for Series A tests

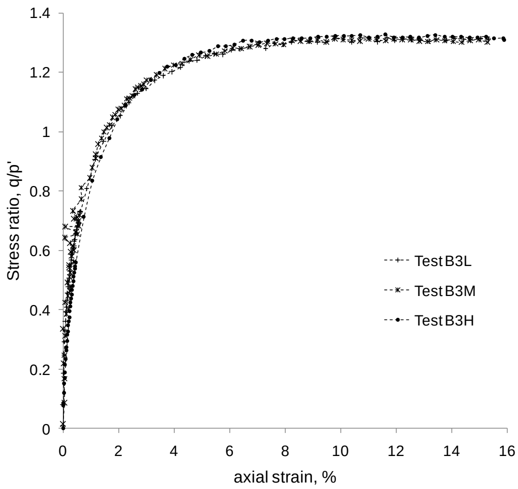

Figure 4. Stress ratio against axial strain for Series B tests

The results from the Series A tests are slightly counter intuitive as it might be expected that if the mechanical remoulding is causing particles to disaggregate from silt sized to clay, the stress ratio at failure should decrease from a value consistent with a silt, which would be greater than 1to a value consistent with a clay which would be 1 or less. This is in contrast to the values of q/p' at failure reported earlier. However, this may be explained with reference to the data from the Series B tests

The data from the Series B tests appear very consistent when plotted as normalised stress strain data as in Figure 4, they are less consistent when the stress paths followed during the tests are plotted in q:p' stress space as shown in Figure 5.

The stress path for Test B3H is characteristic of a soil where the dominant particle fraction is, sand or silt, whereas the stress paths for Tests B3M and B3L are characteristic of soils where the clay fraction is dominating.

This indicates that despite the consistent values of stress ratio at failure, in the sample remoulded at the highest water content there has been less disaggregation of particles. It is possible that in the other two samples the disaggregation of the silt into clay has not been sufficient to reduce the angle of friction at failure, but has affected the pre-failure deformation.

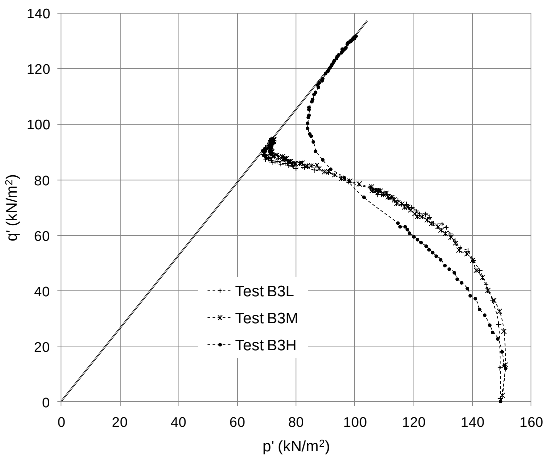

Figure 5. Stress paths for Series B tests

Stress paths for the three Series A tests are given in Figure 6. These tests were all compressed to different initial states before shearing. The curves are a little uneven due to lack of control of the stresses, but nevertheless are all essentially the same shape and similar to the stress paths in test Series B where it appeared that pre failure deformations were dominated by the clay fraction but failure was dominated by the sandy silt fraction. It may be that when the soil is mechanically remoulded to low levels, aggregations of clay particles are not split up but aggregations of silt particles are resulting in the higher angles of friction.

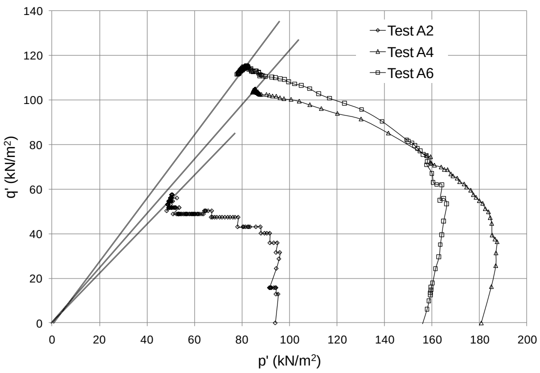

Figure 6. Stress paths for Series A tests

5 CONCLUSIONS

Two series of tests have been undertaken on Mercia Mudstone from a bulk sample retrieved from the Ibstock Brick pit. The data show that mechanical remoulding does affect the strength and compression characteristics of the soil, but not by solely breaking up aggregations of clay particles. The latter would result in a greater clay content and to the specimen behaving more like clay. The increase in the compressibility of the soil with increased mechanical remoulding (Series A tests), observed during isotropic compression is consistent with this hypothesis. However the increase in critical state friction coefficient with mechanical remoulding is not.

The Series B tests demonstrate that if the water content at which remoulding takes place is sufficiently high, remoulding is not efficient and the specimen retains the characteristics of the natural bulk sample. However, the other two specimens are not sufficiently affected by the remoulding for the critical state friction coefficient to change. Pre-failure deformations are altered by the remoulding resulting in stress paths which appear more typical of normally compressed clay.

Further testing is required to establish how sensitive the remoulding is to water content and whether prolonged mechanical remoulding would lead to a clay content that would start to affect the critical state friction coefficient.

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