Simple Shear Compaction of Basecourse Aggregates

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SUMMARY: This paper will report on a research project in which the densification and stiffness of basecourse aggregate were measured during cyclic simple shearing. Good quality greywacke and basalt aggregates and a lesser quality argillite aggregate from the Auckland region were tested. The intention of the simple shear compaction device is to provide a rapid means of categorising various basecourse aggregates. The differences between the good quality basecourse materials and the lesser quality argillite is readily apparent from the test results.

1. INTRODUCTION

Characterisation of basecourse aggregates is difficult in that the materials contain large particles so determination of mechanical properties requires large specimens and large pieces of apparatus. Earlier projects concerned with the characterisation of roading basecourse at the University of Auckland used a triaxial apparatus capable of accepting specimens 250mm in diameter and 625 mm high, Toan (1976). These specimens are difficult to handle and also difficult to prepare, requiring a separate compactor and about 1 man-day of effort just to prepare the specimen. The net effect of this is that the basecourse triaxial is a useful piece of research equipment but hardly likely to be used for routine evaluation of prospective basecourse materials. In this paper a method of characterisation of basecourse materials which uses a smaller quantity of material and has a very simple specimen preparation procedure is discussed. This is the so-called simple shear compactor originally developed at the University of Auckland following the ideas of Dr. G. R. Martin. The initial work was reported by Maurice (1977). This paper describes and summarises the results of an extensive series of tests on various aggregates from Auckland using an updated version of the machine having a more versatile control system than the original and also an automated data gathering system.

The data presented below provide a comparison between the stiffness properties of greywacke, basalt and argillite and the densification of the aggregate with increasing numbers of cycles. This data can be obtained relatively easily with the simple shear compactor and in particular it provides a ready means for comparing the likely performance of various aggregates. The apparatus could be used to gauge the performance of a hitherto unused aggregate by doing parallel tests on the new aggregate and comparing with the results of a similar suite of tests on an aggregate of known field performance.

2. APPARATUS

The objective was to develop a device that could subject a basecourse specimen to cyclic simple shear and monitor shear stiffness and change in volume as functions of shear strain amplitude and normal stress.

The simple shear compactor consists of an assembly of "floating" steel confining plates each 10mm thick. There are 10 of these giving a total specicmen thickness of 100mm The plan dimensions of the specimen are 250mm by 250mm. The top of the specimen is fixed in position whilst the shear force (or displacement) is applied to the base of the specimen. The shear force and displacement is applied through a servo controlled hydraulic system. Normal stress is also applied to the specimen through a servo controlled hydraulic system. Control of the servo systems and the recording of the deformation of the specimen is done by PC computer fitted with analogue to digital (for recording output from force and displacement transducers) and digital to analogue (for control of the servo valves) facilities. The system is able to apply several hundred thousand loading cycles unattended. Both shear strain and shear stress controlled testing is possible with the apparatus, however it was found that the system works better under strain control. The majority of the tests were done at 3 cycles per second, although some preliminary testing confirmed that the results were not affected by loading frequency.

Friction at the base and between the confining plates are important factors in the performance of the device. The roller bearings between hardened steel plates were shown to have negligible friction under the normal loads applied to the specimens under test. Friction between the confining rings was investigated and also found to have negligible effect on the measured basecourse properties. Initial tests revealed that as well as the simple shear deformation the specimen exhibited a rocking deformation which became more significant as the shear strain amplitude increased. This undesireable deformation was prevented by restraining vertical motion of the ends of the top platen, the additional component of vertical load was measured and included as part of the normal load on the specimen.

Specimen preparation involved removing the coarse fraction (> 25mm) from the basecourse and simply placing a weighed amount into the apparatus. Because of

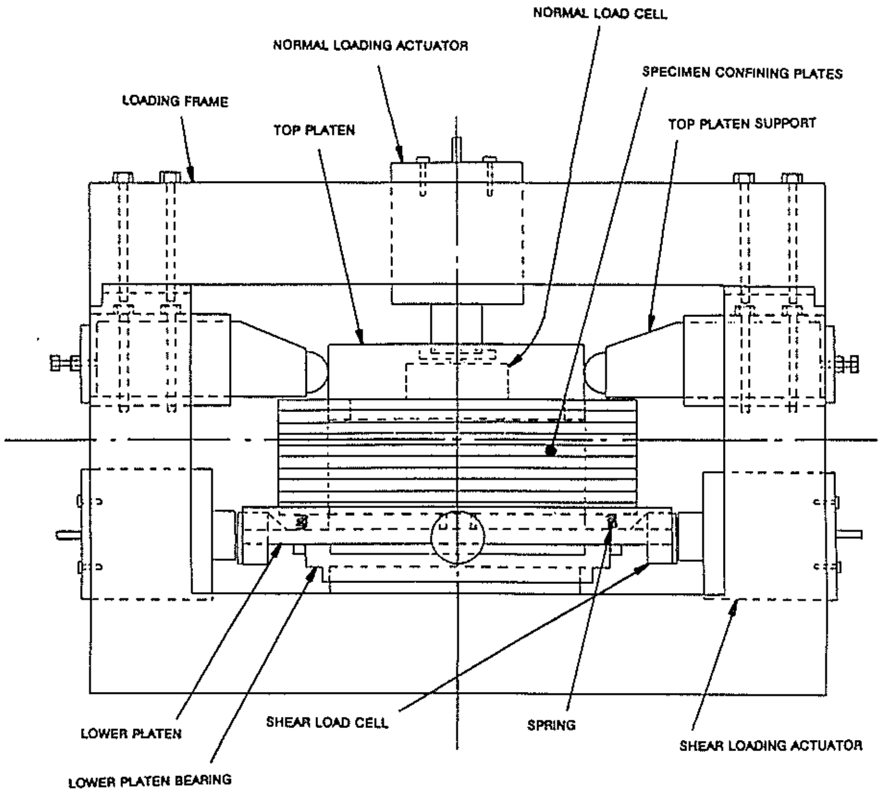

Figure 1 Simple shear compactor.

the design of the device there is no facility for saturating the material to be tested. The basalt and greywacke specimens were placed at a moisture content of 4%. The argillite showed a great affinity for water and was placed in the device at a water content of 10%.

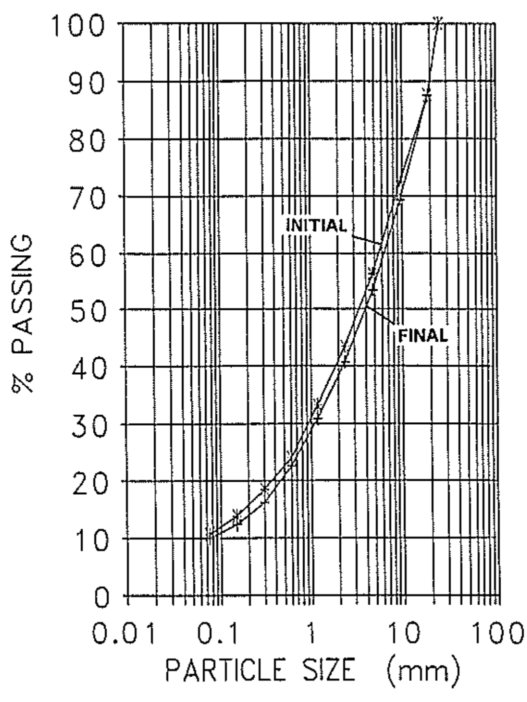

Figure 2 Particle size distribution for the argillite basecourse (before and after testing).

3. TEST RESULTS

Basecourse materials available in Auckland, greywacke, basalt and argillite, were tested. The grading curves for the greywacke and argillite complied with the M/4 specification. The grading for the argillite did not satisfy the M/4 curve, it is plotted on the curve marked "initial" in Fig. 2.

A range of tests at various confining pressures showed that the stiffness of the basecourse increased approximately linearly with normal pressure. This observation was not unexpected and will not be discussed further in this paper.

The change in density was characterised with the Dry Density Ratio, a parameter which reflects the increase in density during the cyclic loading. It is calculated by converting the settlement of the top platen to the current density of the specimen. The Dry Density Ratio is then the ratio of the current density to the initial density of the specimen. The shear modulus is the secant modulus calculated by taking the slope of the line joining the ends of each stress strain loop.

3.1 Strain controlled tests

Figure 3 shows the increase in density during strain controlled cyclic loading of the basalt, the shear strain amplitudes for the various tests are given in Table I. It is apparent that, for the range of shear strain amplitudes investigated, the density increases at a faster rate for the larger shear strain amplitudes. For the test with a shear strain amplitude of 0.27% there was still a noticeable increase in density after 500,000 cycles. The rate of density increase was much less, but still finite, for the 0.02% shear strain amplitude after 500,000 cycles.

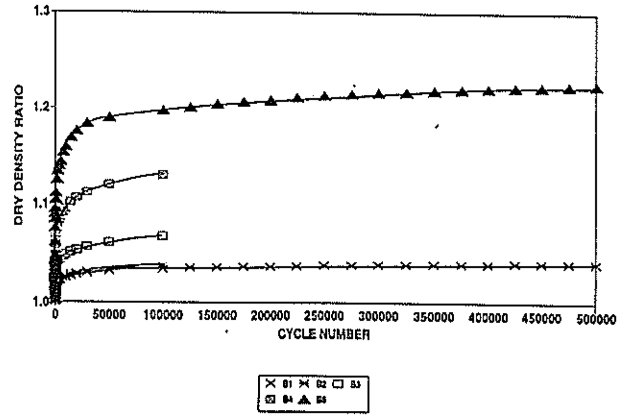

Figure 3 Increase in density of basalt as a function of shear strain amplitude.

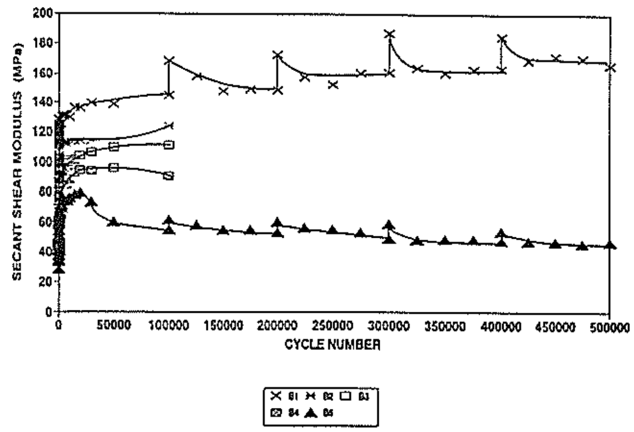

Figure 4 Effect of shear strain amplitude and number of cycles on basecourse shear stiffness.

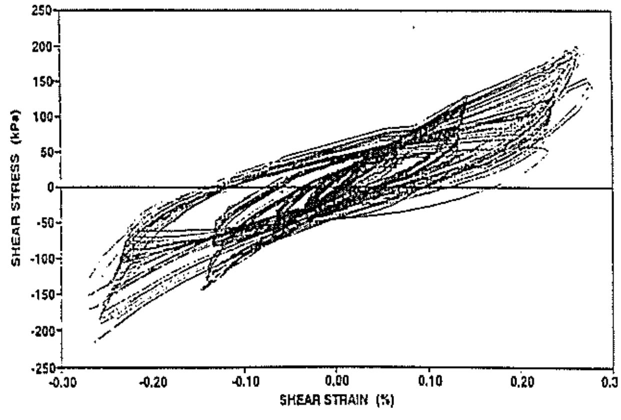

Figure 5 Shear stress shear strain loops for tests on the basalt.

Table I: Shear strain amplitudes for the tests on basalt in Figs. 3 - 5.

Test number	Shear strain amplitude %
B1	0.024
B2	0.033
B3	0.067
B4	0.145
B5	0.273

The effect of the 500,000 cycles on the secant shear modulus is shown in Fig. 4. The tests were done over a five day period with stages of 100,000 cycles each day. Between stages the specimens were rested overnight. It is clear from the figure that the stiffness is higher at the recommencement of cycling, this being more significant at small strain amplitudes. Also of significance, possibly greater, is the fact that for the higher shear strain amplitude, 0.273%, there is a decrease in the cyclic shear stiffness for cycle numbers in excess of about 20,000, this decrease occurs despite the fact that the density of the basecourse material is still increasing.

In Fig. 5 some stress strain loops for various cycles are presented. These show the hysteretic nature of the stress-strain loops and how the shape of the loop changes with cycle numbers.

In Figs. 6 and 7 the results for one specimen of basalt subject to stage loading for a total of 450,000 cycles is presented. Each stage consisted of 50,000 cycles at a set strain amplitude, the values for the various stages are set out Table II. In Fig. 6 the progressive increase in density with increasing cycle numbers is evident but with a marked decrease in the rate of increase between 300,000 and 400,000 cycles. The explanation for this is seen in Table II where there is a decrease in the strain amplitude, this appears to have an overconsolidation effect and virtually no increase in density is observed during this part of the test, once the previous maximum strain amplitude is exceeded the densification process continues. In Fig. 7 the effect is presented more clearly by plotting dry density ratio against shear strain amplitude.

3.2 Stress controlled tests

In Fig. 8 the results of stress controlled tests on argillite are presented. The diagram shows a fatigue phenomenon for the larger shear stress amplitudes with a progressive and quite rapid increase in the shear strain amplitude, i.e. a progressive decrease in the shear modulus of the basecourse specimen. On the other hand for the low levels of shear stress amplitude the argillite settles down to a stable stiffness with no apparent degradation after 50,000 cycles. Figure 9 plots data obtained from strain controlled tests on argillite. There are three different levels of cyclic shear stress as set out in Table III. The drop in the shear modulus after a small number of cycles at larger strain amplitudes is the strain controlled equivalent to the increase in shear strain amplitude in the stress controlled tests. This indicates deterioration or damage to the basecourse specimen. The curve labelled "final" in Fig. 2 is the particle size distribution of the argillite after the large strain tests, the initial distribution is also shown in Fig. 2. It is apparent that there has been slight particle breakdown. Similar comparisons attempted for the greywacke and basalt did not reveal any change in grading.

3.3 Comparative results for the three aggregates

Figures 10 and 11 present data after 100,000 cycles of strain controlled loading on the three aggregates, the dry density ratio and the shear modulus are plotted against the shear strain amplitude of the tests. Figure 10 shows that the greywacke is a little more resistant to densification

Table II: Shear stain amplitudes for the various stages of the test illustrated in Figs. 6 and 7.

Test number	Shear strain amplitude %
ST1#1	0.024
ST1#2	0.033
ST1#3	0.068
ST1#4	0.103
ST1#5	0.141
ST1#6	0.178
ST1#7	0.070
ST1#8	0.145
ST1#9	0.215

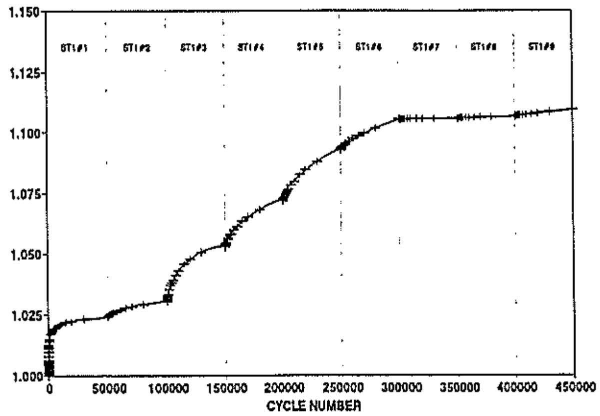

Figure 6 Dry density ratio for the stage testing on basalt.

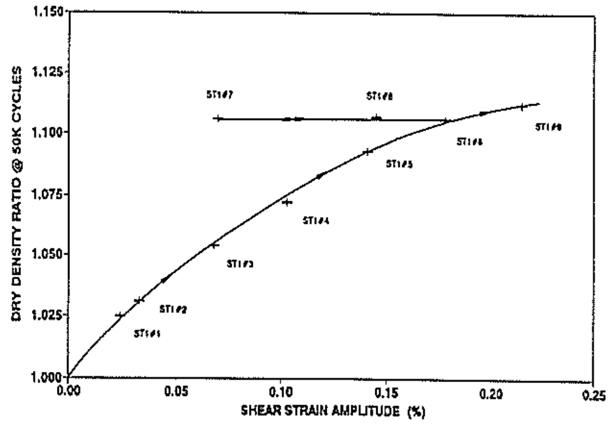

Figure 7 Effect of reduction of shear strain amplitude on dry density ratio.

Table III: Shear strain amplitude for the tests on argillite in Fig. 9

Test number	Shear strain amplitude %
A1	0.034
A2	0.148
A3	0.312

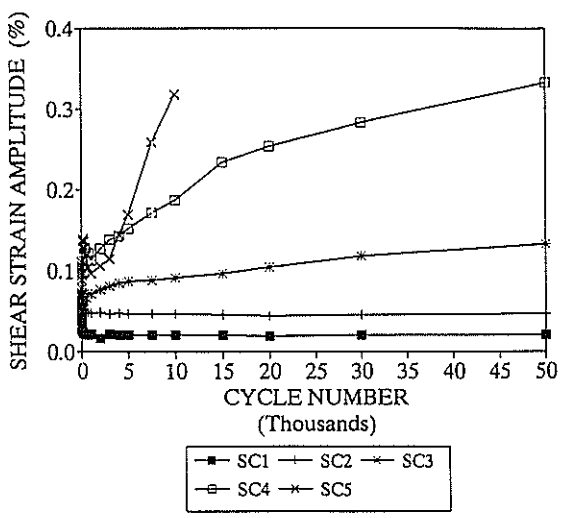

Figure 8 Stress controlled tests on argillite basecourse.

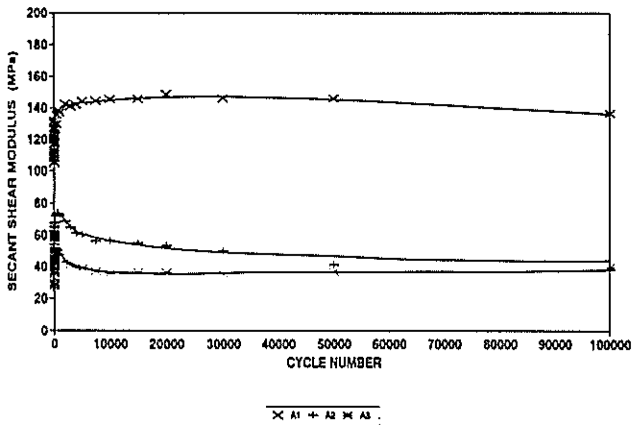

Figure 9 Strain controlled tests on argillite basecourse.

than the basalt and argillite. Figure 11 shows that the argillite has inferior shear stiffness behaviour with numbers of cycles in comparison to the basalt and greywacke.

4. DISCUSSION

Section 3 presents a representative sample from a large amount of data reported by Peploe (1991). The speed with which a basecourse specimen can be set up in the apparatus and tested makes the device attractive for comparing different aggregates.

Empirical observations of pavement performance usually relate deterioration to the presence of water in and perhaps saturation of the basecourse. It would be desirable to perform compaction tests on saturated specimens. The present design of the apparatus precludes this and installing and sealing a tough membrane between the specimen and the confining plates would require modification of the apparatus.

Figure 7 presents the most interesting data with respect to the construction of pavements. It suggests that if vigorous shear straining is applied to the basecourse during compaction and then the operational shear strains during the pavement life are less than those at compaction the basecourse will perform with a large value of the shear modulus. Figure 8 shows that if the cyclic shear stress is less than a threshold value the basecourse will deform in a stable manner with no, or very small, accumulation of

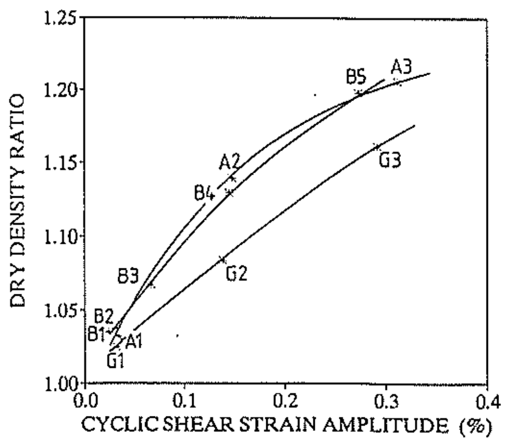

Figure 10 Comparison of the densification of the three types of aggregate at 100,000 cycles.

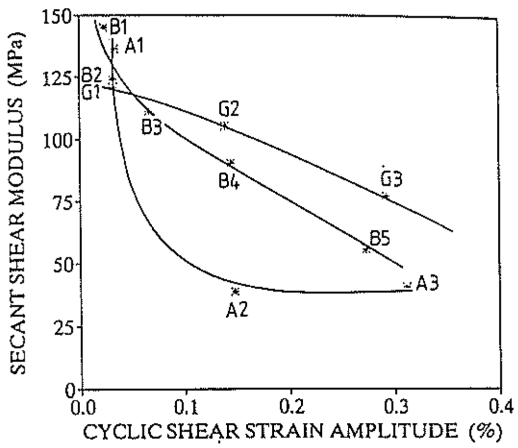

Figure 11 Comparison of the shear modulus of the three types of aggregate at 100,000 cycles.

strain. These two observations have the potential to lead to a pavement design method.

5. CONCLUSIONS

The simple shear compactor provides a means of categorising basecourse materials. In comparison with tests in the triaxial apparatus, which require a considerably larger specimen and much more time in preparation, the simple shear compaction test is attractive. At the present state of development the greatest limitation of the device is probably the lack of facility to test the basecourse specimen in a saturated condition.

The test results illustrate the effect of shear strain amplitude on density and shear modulus. They show that a threshold stress exists beneath which the basecourse shakes down to a fixed shear modulus. Further investigation of this concept might lead to developments in the design of pavements.

The tests confirm the well known fact that greywacke and basalt are superior aggregates to argillite. A small amount of particle breakdown was observed with the argillite but no perceptible change was found for the basalt and argillite.

6. ACKNOWLEDGEMENT

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