



DEVELOPMENT OF A FLOATING RING OEDOMETER FOR TESTING GEOMATERIALS

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Abstract

Evaluation of load-deformation characteristics of geomaterials is very essential and this is commonly obtained by conducting one-dimensional compression test using standard oedometer. However, only limited stress can be achieved using standard oedometer and many geomaterials particularly in the natural state require high stress. A floating ring oedometer has been designed, fabricated, assembled and used for testing clay for evaluation. This was achieved using steel and polymeric materials and fabrication tools. A vertical stresses of up to 20 MPa can be achieved in this new apparatus and can be used for both natural and reconstituted geomaterials. The new apparatus is comparable to standard oedometer based on evaluation.

Keywords: Floating ring oedometer, one-dimensional compression, natural and reconstituted geomaterials, specific volume

Introduction

The most common way of investigating engineering behaviour of geomaterials is by conducting mechanical test on the sample in the reconstituted and intact states. The mechanical tests are carried out using two basic forms of loading which are compression and shearing. Compression test can be divided into isotropic using triaxial apparatus (Bishop and Henkel, 1962) and one-dimensional using oedometer (Casagrande, 1936; Rowe and Barden, 1966). The behaviour of geomaterials in compression is very important in computation of settlements and numerical modelling (Baudet and Stallebrass, 2001; Liu *et al.*, 2011, 2013). Also many geotechnical and geological problems have been analysed using key data obtained from compression test and detailed understanding of compression behaviour is essential in geotechnical and geological engineering practice.

One-dimensional compression is most researched because it is the simplest form of compression that is likely to occur to geomaterials, for example, loading of geomaterials due to geological deposition. Conventional oedometers which allow load, deformation and drainage in vertical direction only are mostly used for one-dimensional compression tests. They are equipped with traditional fixed rings of 50mm diameter and 20mm height that permit limited stresses to be achieved in incremental loading (Rocchi and Coop, 2014; Okewale and Coop, 2017, 2018; Okewale, 2019). However, higher stresses are required for

geomaterials in the intact state and also for some reconstituted materials with high yield stress.

This work presents design, fabrication and assembly of floating ring oedometer for geomaterials in the intact and reconstituted states. This is very essential because it allows the attainments of higher stresses in the geomaterials and improve the local engineering practise. It also reduces wall friction. The design was tailored to optimise the accuracy in the measurements (specific volume, void ratio, porosity). These measurements are required to describe behaviour of geomaterials together with stress. In addition the floating ring was used to carry out tests on natural clay and the accuracy of the measured specific volumes is presented.

Materials Used

The materials used are basically steel and polymeric. High carbon steels are used due to their widespread applications. Increase in carbon in steels increase strength and hardness which are required for improved performances. The effect of high carbon in steel is the reduction in ductility and since the property can be tolerated in some of the parts, high carbon steel are used for them. Mild steel is also used due to its ductility property. The high carbon steel was used for the base, lower mount, upper mount, pin, screw and the top platen of the oedometer parts. Mild steel was used for the confining ring. Transparent polymeric material is used for cell in the oedometer and O-ring of rubber type was used for the seal.

The various parts were fabricated using rough and finishing turning tools. Lathe machine was used for shaping allowing the work piece to be held and rotated while bit is advancing in cutting action. Milling machine that used rotary cutters that remove materials from work piece was used. Cutting tools were used to remove materials from work piece through shear deformation. Tap and die were used to create threading. Also, facing tool, turning tool, centre drill cutter, end drill cutter, slot drill cutter, micrometer screw gauge and vernier caliper were used.

Components of the Apparatus

The apparatus consists of a base, a lower and upper mount, a confining ring, top platen, screw, pin, rubber seal and the transparent plastic used as oedometer cell. The base of the apparatus is most stable part and

provides support for the other components. The confining ring and sample are placed directly on it. It was fabricated from the steel as presented in schematic drawing of components presented in Figure. 1(a). The lower and upper mount provide radial support for confining ring and top platen respectively (Figure. 1(b)). The confining ring of 30mm diameter and 20mm height housed the sample to be tested (Figure. 1(b)). The lower and upper mount are connected by screws (Figure. 1(b)). The pins allow release of lower and upper mount thereby making sample to deform under the action of load (Figure. 1(a)). The plastic cell and O-ring were sourced from market. The plastic cell allows water for saturation of sample and O-ring keeps cell very firm. The assembly of the floating ring components are presented in Figure. 2. The 3D pictorial view of the apparatus is presented in Figure. 3.

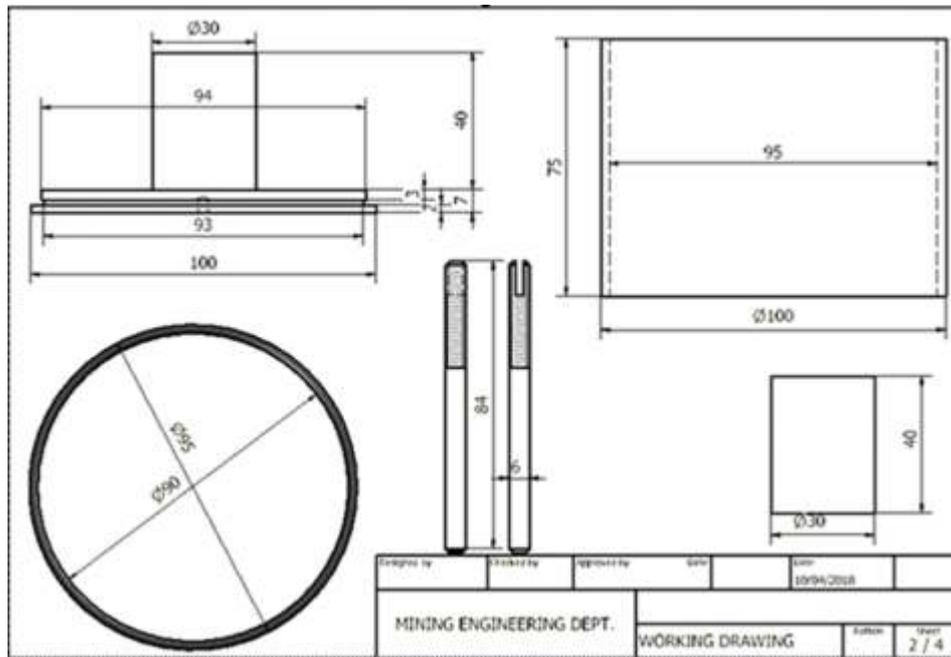


Figure 1. 2D orthographic plots of apparatus parts

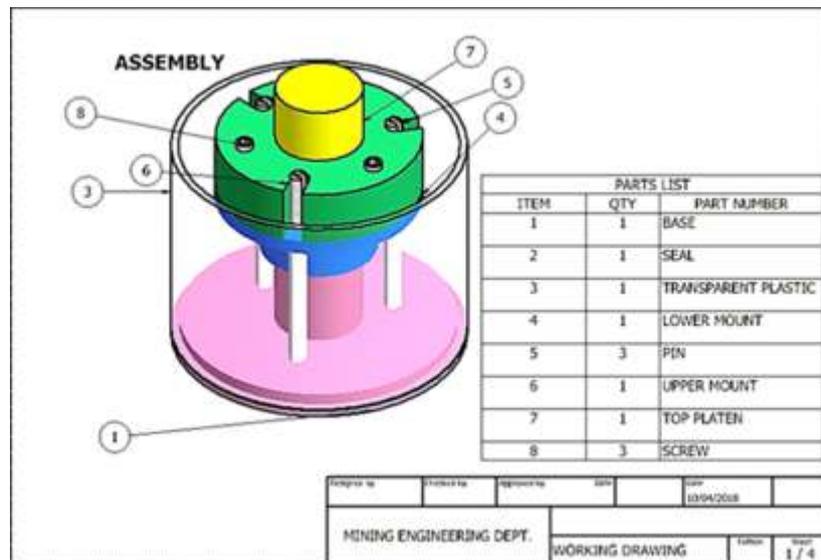


Figure 2. Assembly of new apparatus

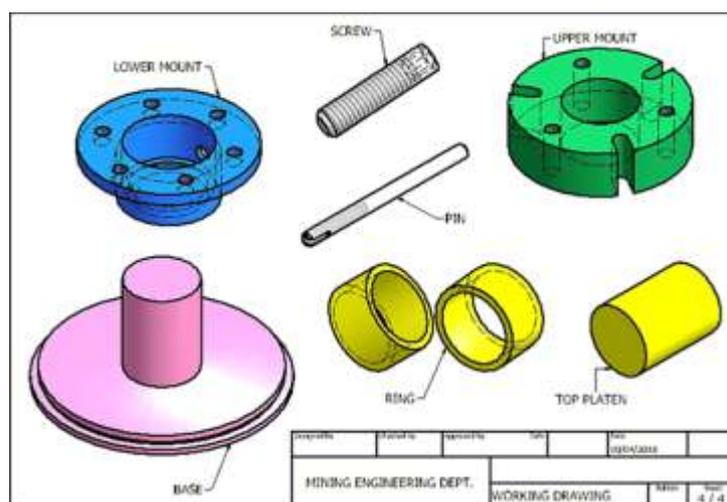


Figure 3. 3D pictorial view of the parts

Laboratory Test Using the Apparatus

The apparatus was used to carry out one-dimensional compression tests in conventional front loading frame. The tests were used to estimate specific volume ($v = 1 + e$, where e is void ratio) which is very important in fundamental critical state framework to describe the behaviour of geomaterials together with stress. Specific volume is the ratio of total volume of the sample to the volume of the solid. The accuracy of the specific volume is very crucial for proper description of true behaviour of geomaterials. The measured accuracy of v is used for performance evaluation of the apparatus because the v is estimated from initial and final measurements of the confining ring which housed the sample. Precision is related to accuracy in the sense that a measurement that is accurate should be precise.

Materials Tested

The material used in the tests is natural clay. The soil was collected in block at 2.06m depth from Ekiti State South-Western Nigeria. The grading curve of the soil obtained from wet sieving and sedimentation technique is presented in Figure. 4. The soil is well-graded with different fractions of clay, silt and sand. The demarcations show clay fraction (particles diameter less than 0.002 mm), silt fraction (particles diameter between 0.002 and 0.063 mm) and sand fraction (particle diameters greater than 0.063 mm). The index properties in terms of plasticity determined from Atterberg limit tests are 49.6%, 34% and 15.6% for liquid limit, plastic limit and plasticity index respectively. The clay fraction is 56%. The mineralogies of the soil as obtained from X-ray diffraction are quartz, feldspar and clay. The details of sample characteristics, index properties and mineralogy are given Table 1.

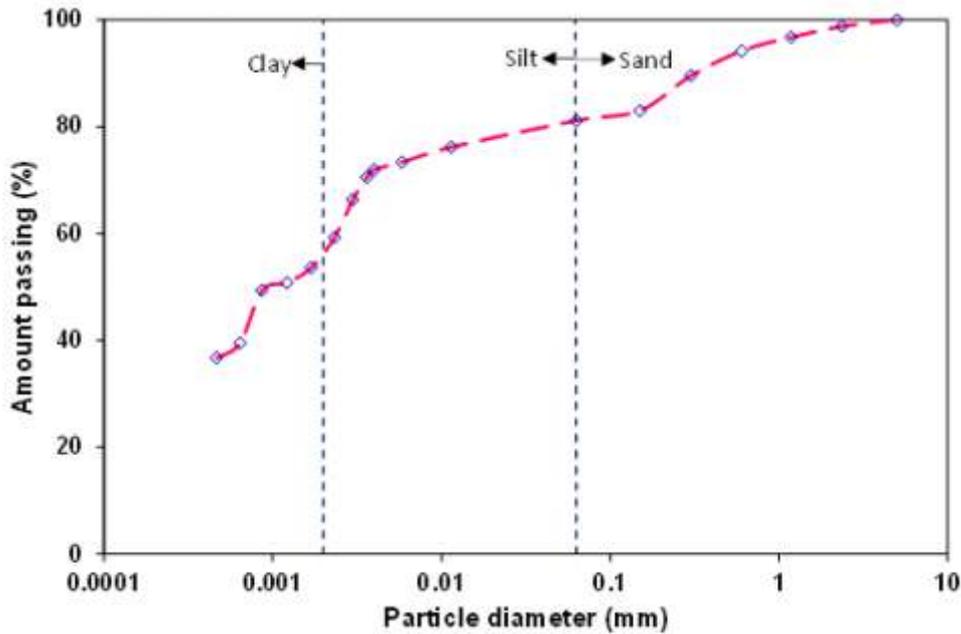


Figure 4. Grading curve of the sample tested

Table 1. Details of sample characteristics, index properties and mineralogy

Sample	Depth (m)	LL (%)	PL (%)	PI (%)	CF (%)	Quartz (%)	Feldspar (%)	Clay (%)
Clay	2.06	49.60	34.00	15.60	56	30.41	6.63	59.33

LL liquid limit, PL plastic limit, PI plasticity index, CF clay fraction

Sample Preparation

The natural oedometer samples were prepared by trimming the block samples very carefully thereby minimising the disturbance while excavating the sample slightly ahead of the ring that was advanced with little downward pressure. The sample was saturated in the oedometer cell under small nominal load to prevent destructuration resulting from swelling and collapse. The sample was then flooded and 12-24 hours was allowed for saturation before incremental loading to 4.6 MPa. The apparatus allows stresses up to 20 MPa to be achieved based on dimension but the test in this paper was terminated at 4.6 MPa because the samples had low yield stresses.

Calculation of Initial Specific Volume

The specific volume was determined using different methods in order to improve the confidence in the measurements. The initial v was derived from initial sample weight, initial height, initial diameter and initial water content. The final v was estimated from final weight, final height, final diameter and final water content and back-calculating the initial v using volumetric strain measured in the tests. This method is similar to those used by Rocchi and Coop (2014), Okewale and Coop (2017, 2018) and Okewale (2019). The equations used were made to be as independent as possible as presented in Equations 1-3.

$$v_i = w_i G_s + 1 \tag{1}$$

$$v_i = \frac{w_f G_s + 1}{(1 - \epsilon_{vol})} \tag{2}$$

$$v_i = \frac{\gamma_w (1 + w_i) G_s}{\gamma_{bi}} \tag{3}$$

where v_i is initial specific volume, G_s is specific gravity, w_i is initial water content, w_f is final water content, γ_w is unit weight of water, γ_{bi} initial bulk unit weight, γ_{bf} is final bulk unit weight and ϵ_{vol} is volumetric strain.

Estimation of Accuracy of v

The accuracy was estimated by evaluating values of v using different methods. The mean of the various initial values was taken and the largest difference between individual value and the mean was taking as the estimate of the accuracy of measurement of specific volume. This method is similar to what has been used by other researchers to estimate accuracy of specific volume (e.g., Jefferies and Been, 2000; Shipton and Coop, 2012; Rocchi and Coop, 2014).

Results and Discussions

The compression behaviour of sample in $v: \log \sigma'_v$ plane obtained from incremental loading oedometer is

presented in Figure. 5. The compression and recompression paths are for the tests using new and standard apparatuses. The demarcation in the figure shows the highest value of stress that can be achieved using the new apparatus. Apart from scatter in the measured initial specific volume which is a function of initial water content, the paths followed by the samples are comparable, similar to what has been found for large oedometer fabricated by Ng et al. (2006). This shows that the new apparatus can function in the same manner as standard oedometer type. The new apparatus can also measure other compressible parameters, for example, the coefficient of compressibility (m_v) as presented in Figure. 6. It is very interesting that this new apparatus can handle sample with different methods of preparation. For example, a reconstituted/remoulded or disturbed sample that require higher stress can easily be handled using this apparatus.

The details of few tests on the natural samples is presented in Table 2. In the test description, S stands for sample followed by the test number. The initial and final specific volumes as well as the accuracy of the measurement of specific volume are given in the table. The average accuracy of the very few tests is ± 0.016 , which is comparable with other standard oedometer type (Jefferies and Been, 2000; Shipton and Coop, 2012; Rocchi and Coop, 2014; Okewale and Coop, 2017, 2018; Okewale, 2019). However, this result is just for very few data but based on many tests that the new apparatus have been used for, the accuracy is high. As stated earlier, an accurate measurement will be precise therefore the precision of the new apparatus can be said to be high.

The disadvantage of the new apparatus is that just like standard oedometer, the effect of maximum particle size cannot be overcome due to small dimension.

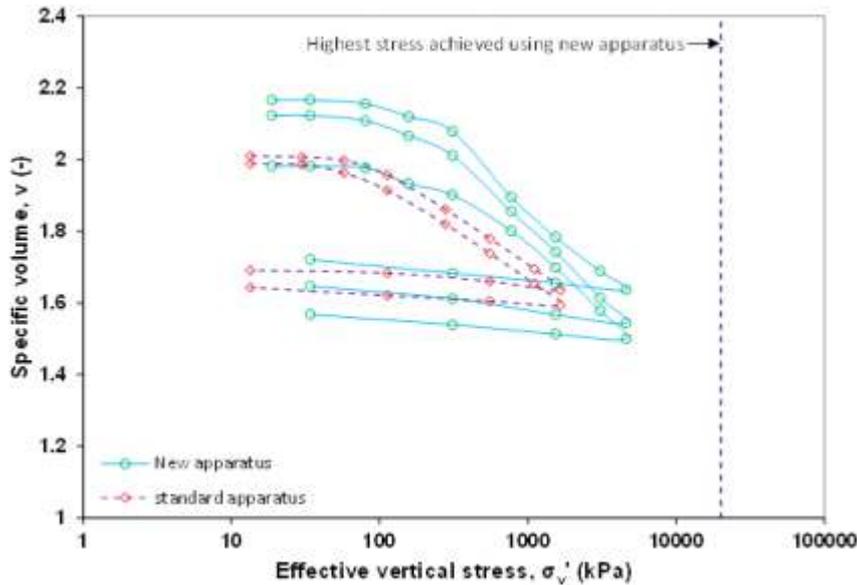


Figure 5. Compression behaviour using new apparatus

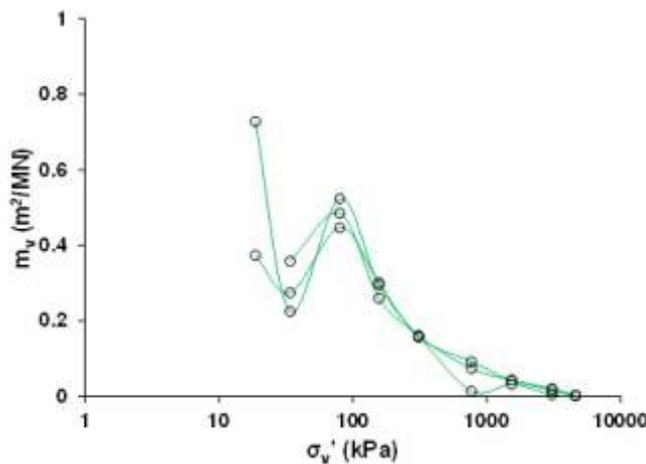


Figure 6. Coefficient of compressibility

Table 2. Details of few oedometer tests

Test Description	v_o	v_f	Accuracy of v (\pm)
S1	2.250	1.676	0.004
S2	2.414	1.706	0.007
S3	2.344	1.678	0.04

v_o initial specific volume, v_f final specific volume, v specific volume

Conclusion

A floating ring oedometer has been designed, fabricated and assembled for testing geomaterials in one-dimensional compression. The new apparatus was fabricated using steel and polymeric materials as well as fabrication tools. The new apparatus was used for testing materials using conventional front loading frame. The apparatus can take sample of 30mm diameter and 20mm height. The vertical stress that can be applied to sample can be as high as 20 MPa. It can be used for both natural and reconstituted samples. The new apparatus is comparable to standard oedometer based on the evaluation of results obtained from tests conducted.

References

- Baudet, B.A. and Stallebrass, S.E. (2001). Modelling the destructuring of soft natural clays. *Computer Methods and Advances in Geomechanics* 1(1), 297-302.
- Bishop, A.W. and Henkel, D.J. (1962). *The Measurement of Soil Properties in the Triaxial Test*. 2nd Ed., Edward Arnold: London.
- Casagrande, A. (1936). The Determination of Preconsolidation Load and its Practical Significance. *Proc., 1st International Conference on Soil Mechanics Foundation Engineering*, Cambridge, p 60-65.
- Jefferies, M.G. and Been, K. (2000). Implications for Critical State Theory from Isotropic Compression of Sand. *Geotechnique*, 50(4), 419-429.
- Liu, M.D., Carter, J.P. and Airey, D.W. (2011). Sydney Soil model: (I) theoretical formulation. *International J. of Geomechanics*, 11(3), 211-224.
- Liu, M.D., Zhuang, Z. and Horpibulsuk, S. (2013). Estimation of the compression behaviour of reconstituted clays. *Engineering Geology*, 167, 84-94.
- Ng, A.M.Y., Yeung, A.T., Lee, P.K.K. and Tham, L.G. (2006). Design, Fabrication, and Assembly of a Large Oedometer. *Geotech. Test. Journal*, 29(4), 1-8.
- Okewale, I.A. and Coop, M.R. (2017). A study of the effects of weathering on soils derived from decomposed volcanic rocks. *Engineering Geology*, 222, 53-71.
- Okewale, I.A. and Coop, M.R. (2018). Suitability of different approaches for analysing and predicting the behaviour of decomposed volcanic rocks. *J. Geotech Geoenviron Eng.*, 144(9), 1-14.
- Okewale, I.A. (2019). Influence of fines on the compression behaviour of decomposed volcanic rocks. *Int. J. of Geo-Engineering*, 10(1), 1-17.
- Rocchi, I. and Coop, M.R. (2014). Experimental accuracy of the initial specific volume. *Geotech. Test. J.*, Vol. 37(1), 1-13..
- Rowe, P.W. and Barden, E.M. (1966). A New Consolidation Cell. *Ondontol Bonaer*, 16(2), 162-170.
- Shipton, B. and Coop, M.R. (2012). On the Compression Behaviour of Reconstituted Soils. *Soils and Found.*, 52(4), 668-681.