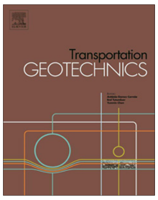
Transportation Geotechnics 5 (2015) 59–67

Contents lists available at ScienceDirect

Transportation Geotechnics

journal homepage: www.elsevier.com/locate/trgeo



California Bearing Ratio tests on a lateritic gravel from Kenya

D.G. Toll *

School of Engineering and Computing Sciences, Durham University, Durham DH1 3LE, UK

ARTICLE INFO

Article history:
Received 4 June 2015
Revised 19 September 2015
Accepted 20 September 2015
Available online 9 October 2015

Keywords:
Laterite
Road construction
California Bearing Ratio
Suction
Unsaturated soil
Compacted soil

ABSTRACT

A series of California Bearing Ratio (CBR) tests have been carried out on a lateritic gravel from Kiunyu Quarry in Kenya. Standard CBR tests were carried out at a range of water contents and using three different levels of compaction. These were supported by specialist CBR tests carried out in a CBR apparatus that provided measurement of matric suctions. Tests on the lateritic gravel showed that samples compacted at water contents near Proctor optimum had suctions near to zero, but suctions increased very rapidly in samples compacted dry of Proctor optimum, exceeding 500 kPa at water contents below 75% of Proctor optimum. The patterns of behaviour observed in the standard tests are explained using the concept of "suction stress". This unsaturated soil approach can explain why the samples show a loss of CBR value at the dry end of the water content spectrum (below 60% of Proctor optimum). Although suction continues to increase as the water content reduces, the degree of saturation is reducing, thereby reducing the "suction stress". The combined effect results in a loss in CBR value.

Introduction

California Bearing Ratio (CBR) tests have been carried out on a lateritic gravel. The gravel was used as roadbase material in the construction of a trial section of low-volume road constructed between Mataara and Gatura, about 60 km to the north-east of Nairobi, Kenya. As the material is a natural gravel, it contains a significant fine fraction, which means that the material is sensitive to water content changes. Toll (1991) has argued that the fine material (particularly clay) can be beneficial in allowing suctions to develop, thereby improving the strength and stiffness (in the right climatic and drainage conditions).

Although CBR tests can be carried out at different water contents in order to assess the degree of moisture sensitivity, this can only give a partial understanding of the material behaviour. The behaviour will be controlled by the matric suctions (negative pore water pressures) present within the soil. Since water content-suction relationships are not unique (due to hysteresis between wetting and drying conditions) (see e.g. Haines, 1930; Fredlund and Xing, 1994; Toll, 2012) it is not possible to identify the suction that may be present from the water content. Because of different wetting and drying histories, suctions may be very different for the same water content. Toll (1991) shows that suctions in a material used in roadbase construction can vary by hundreds of kilopascals at the same water content. This means that samples tested in the field can give significantly different results compared to tests on samples compacted in the laboratory at the same density and water content; strengths observed in the field can be 2–3 times those measured in the laboratory (Toll, 1991). Therefore, comparisons can only be made properly if the suctions are known in both sets of test.

This problem has been studied by Sánchez-Leal (2002) who used an unsaturated soil approach to interpret a set of CBR test data on a low plasticity "lean" clay from Vicksburg, Mississippi. However, the interpretation was only qualitative as no suction measurements or water retention

---

* Tel.: +44 0 191 334 2388.
E-mail address: d.g.toll@durham.ac.uk

http://dx.doi.org/10.1016/j.trgeo.2015.09.004
2214-3912/

behaviour was available for the soil. Ampadu (2007) did report CBR tests on a decomposed granite (sandy clay) where measurements of suction were obtained using the filter paper technique. He suggested CBR showed a log–log relationship to matric suction. Purwana and Nikraz (2013) have reported CBR test results on sand/clay mixtures, with measurements of suction using conventional tensiometers. However, their results are restricted to suction values of less than 70 kPa, so they were unable to comment on the behaviour at high suctions. They did observe in clean sand that CBR values increased for suctions up to about 7 kPa, but then fell as suctions increased to 40 kPa. However, for mixtures containing 5% or 10% of kaolin clay, they found the CBR values continued to increase with increasing suction, up to their measurement limit of 70 kPa.

To investigate the effect of water content and suction on CBR, a series of 28 standard CBR tests has been carried out on samples compacted at a range of water contents, using three different compaction levels. A further set of 9 CBR tests has been carried out using a specially designed CBR apparatus that allows measurement of suction in the CBR sample. Additional suction measurements from a separate series of 23 triaxial specimens are used to expand the data set on suction measurements for the same material. The CBR tests with suction measurements are used to interpret the behaviour observed in the standard tests, to understand the role of suction and degree of saturation in controlling the material behaviour.

The material

The lateritic gravel tested was used in the construction of a trial section of low-volume road constructed between Mataara and Gatura, about 60 km to the north-east of Nairobi, Kenya (Grace & Toll, 1987). The material was taken from Kiunyu Quarry, which is situated in a large open area of grassland in the base of a wide flat valley. The geology of the area comprises tuffs, agglomerates and basalts of Tertiary age belonging to the Laikipian Series.

The profile of the quarry is typical of a laterite profile. The top 1–1.3 m consisted of tropical red soil overlying a 150–200 mm thick layer of nodular lateritic gravel. This covered approximately 1 m of heavily indurated laterite cuirasse. Underlying the cuirasse, below the water table, was the pallid zone, identified by light yellow to white colouring.

On excavation, the laterite cuirasse broke down to a lateritic gravel but still containing some quite large weakly iron-cemented aggregations (larger than 100 mm). However, these were easily broken down by hand pressure. The remaining gravel sized fraction consisted predominantly of slightly stronger vesicular aggregations.

Since tropical soils are often sensitive to sample preparation procedures, such as oven drying and mixing (Fookes, 1997), the particle size distribution was obtained by wet sieving without any pre-drying. Prior to testing, aggregations were broken down using a rubber pestle until they could no longer be broken down by hand pressure. Sedimentation was carried out using standard Sodium hexametaphosphate and deflocculated in a mechanical shaker for several hours. The particle size distribution obtained is shown in Fig. 1. The clay fraction (<2 μm) was 8%, although it was found that this increased due to compaction to 16% as a result of the breakdown of iron cemented materials.

Atterberg limits were determined on material passing 425 μm (without pre-drying). Mineralogical determinations were made using X-ray diffraction (XRD) and geochemistry by bulk chemical analysis. The results are reported in Table 1. This shows that the gravel is made up of 55% of sesquioxides (Fe_2O_3 and Al_2O_3) with just 24% of quartz. The clay fraction is made up of a low activity kaolinite-type (1:1) clay mineral (from XRD it is not possible to identify whether the clay mineral is kaolinite, halloysite, nacrite or dickite). The particle density (specific gravity) exceeds 3 in the finer fractions (Table 1), due to the presence of iron minerals. It was found that a particle density of 3.2 Mg/m^3 best represented the bulk value, from

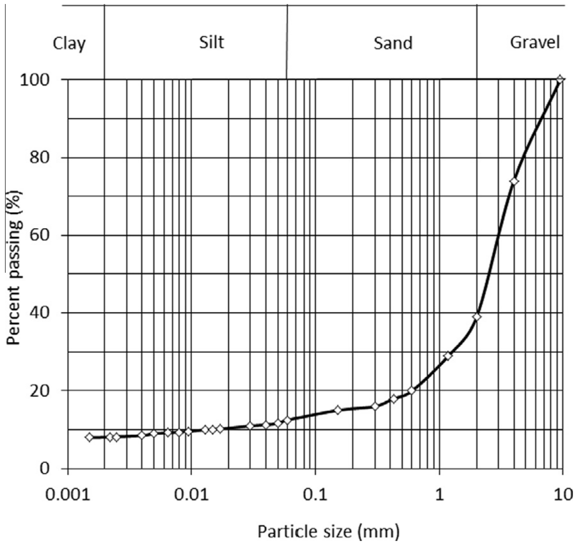


Fig. 1. Particle size distribution for Kiunyu lateritic gravel.

Table 1
Classification and mineralogy of Kiunyu lateritic gravel.

Property	Value
Liquid limit (%)	56
Plastic limit (%)	27
Plasticity index (%)	29
Clay fraction (%)	8
Activity	0.65
Shrinkage limit (%)	24
Particle density (Mg/m^3)	
<5 mm fraction	2.82
<425 μm fraction	3.00
<200 μm fraction	3.19
Mineralogy	Quartz, goethite, kaolinite
Geochemistry	
Fe_2O_3	40.0%
Al_2O_3	14.5%
SiO_2	23.8%