PREDICTING FOUR DAY SUB-GRADE CBR STRENGTH FROM UNSOAKED LABORATORY SPECIMENS

Muzi Bonginhlanhla Mndawe [a], Julius Ndambuki [b], Williams Kupolati [c]
[a, b, c] Department of Civil Engineering, Faculty of Engineering, Tshwane University of Technology, Pretoria, Republic of South Africa.
[a] Corresponding author: muzimndawe@vodamail.co.za

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Abstract: Most construction projects take place on soil and fewer projects are carried out on solid bedrock. Therefore the bearing capacity of any soil must be evaluated prior to the construction of any road. The bearing capacity or strength of granular materials for road construction is measured in terms of California Bearing Ratio (CBR). This test method has been used for the past seven decades with very limited improvements in its lifetime especially with regards to the time it takes to complete. It is considered one of the most fundamental tests of any granular material in road construction. It takes any soil laboratory a period of at least seven days to produce a comprehensive set of CBR and Indicator tests. The former is in essence a five day long test method. The waiting period means whatever progress that can be made with regards to construction on site will in the meantime be all based only on experience of site technical staff and very little scientific reliance. Therefore there is a need to make improvements on current test methods in order to expedite such a lengthy test procedure. The methodology followed in this research included extensive soil laboratory testing, particularly CBR tests on identical samples that are compacted at Optimum Moisture Content (OMC) and compressed after soaking at varying daily intervals. The results of such tests for all the specimen are then plotted on a graph to obtain a trend that will best represent the plotted data such that a formula can also be developed. An equation aimed at obtaining CBR strength of materials within a shorter timeframe than the current five day period it takes to soak and compress the soil specimen has been derived from the obtained data. Preliminary findings reveal that the equation is ideal for use on weaker gravels used as subgrade for road pavements as it has only been tested on such materials. These are materials that generally have a CBR strength ranging from 3% to 15%. Thus far, the formula has provided an impeccable correlation with the conventional four day CBR strength test method. The equation, similarly to other test methods such as DCP, provides a rapid and accurate way to determine the CBR of weaker materials. Ordinarily, the Maximum Dry Density (MDD) and CBR test alone would take five days to complete and the proposed formula shall drastically reduce that turnaround time as it manages to remove the entire four day soaking period. This means the CBR of such materials can be confirmed in two days, the same day as the actual MDD.

Keywords: cbr; soaking; maximum dry density; sub-grade; optimum moisture content

INTRODUCTION

The sub-grade is that portion of the earth roadbed which after having been constructed to reasonably close conformance with the lines, grades, and cross-sections indicated on the plans, receives the base or surface material. In a fill section, the sub-grade is the top of the embankment or the fill. In a cut section the sub-grade is the bottom of the cut. The sub-grade supports the sub-base and/or the pavement section. According to [6], the performance of a pavement depends on the quality of its sub-grade and sub-base layers. As the foundation for the pavement's upper layers, the sub-grade and sub-base help mitigate the detrimental effects of climate and the static and dynamic stresses generated by traffic.

Most construction projects take place on soil and fewer projects are carried out on solid bedrock. Therefore the bearing capacity of any soil must be evaluated prior to the construction of any road. The amount of weight a soil can hold without it giving way is called its bearing capacity. A soil's bearing capacity will vary depending on what type of soil it is and is affected by a number of environmental factors. According to [1], the strength of road sub-grade is commonly assessed in terms of the California Bearing Ratio (CBR) and this is dependent on the type of soil, its density, and its moisture content. Typical logistics and time constraints with the laboratory test resulted in the field CBR being more typically used by the military for design of contingency roads and airfields in the old days [2].

The laboratory test method has been used for the past seven decades with very limited improvements in its lifetime especially with regards to the time it takes to complete. It is considered one of the most fundamental tests of any granular material in road construction. It takes any soil laboratory a period of at least seven days to produce a comprehensive set of CBR and Indicator tests. The former is in essence a five day long test method. The waiting period means whatever progress that can be made with regards to construction on site will in the meantime be all based only on experience of site personnel and very little scientific reliance. Therefore there is a need to make improvements on current test methods in order to expedite such a lengthy test procedure.

Preliminary findings reveal that the equation is ideal for use on weaker gravels used as subgrade for road pavements as it has only been tested on such materials. These are materials that generally have a CBR strength ranging from 3% to 15%. Thus far, the formula has provided an impeccable correlation with the conventional four day CBR strength test method. The equation, similarly to other test methods such as DCP, provides a rapid and accurate way to determine the CBR of weaker materials. Ordinarily, the Maximum Dry Density (MDD) and CBR test alone would take five days to complete and the proposed formula shall drastically reduce that turnaround time as it manages to shave off the entire four day soaking period. This means the CBR of a material can be confirmed in two days, the same day as the actual MDD. This research investigated the development of a formula that can predict the four day sub-grade CBR strength from un-soaked laboratory specimen.

MATERIALS AND METHODS

The methodology followed in this research included extensive soil laboratory testing, particularly CBR tests on identical samples that are compacted at OMC and compressed after soaking at varying daily intervals. The results of such tests for all the specimen are then plotted on a graph to obtain a trend that will best represent the plotted data such that a formula can also be developed. An equation aimed at obtaining CBR strength of materials within a shorter timeframe than the current four day period it takes to soak and compress the soil specimen has been derived from the obtained data.

The procedure is described in detail in Method MC1 of TMH5 and was used for the sampling process. Six test samples were taken on already under construction sections of roads P443/1 and P435/1. The soil samples were taken from a minimum depth of over 0,44m below the surfacing. The number of samples was seen as adequate to provide data for the analysis considering it was sampled from a uniform section on the road. This was gathered from the soil profiling conducted during the design phase of the project. Every effort was made to collect all samples during one field mobilization, requiring approximately 2 days of sampling and drying by a team consisting of a soils laboratory manager, researcher and two laboratory assistants.

The investigations consisted of the following: (a) Visual inspection of the road condition and materials along the road. This was done to confirm the limits of uniform pavement sections as detailed in the soil profiles prior to the design stage. It was also conducted to identify localised areas of potential problem materials and areas with drainage problems, which could influence the performance of the pavement and consequently the research sampling. (b) Test pits were excavated at various pre-selected positions along the width of the existing road including some of the localised previously identified problem areas.

Field Visits

The research required that a few soil samples be collected out of a large number be dependable and its main characteristics be representative of the entire route or study area. The initial field visit on the actual study area was done in January 2012 and another by the Tshwane University of Technology co-authors took place on Friday 26 October 2012. This was to ascertain the sampling area, methods and other procedures that were necessary to be adhered to.

Figure 1: Jozini Locality Map [3]

Table 1: Laboratory and calculated CBR values

Time (Days)	Road P443/1 CBR (%)	Calculated CBR
0	24	25.9
2	21	22.0
3	20	20.0
5	18	16.1
6	17	14.1
7	13	12.2

Table 2: Laboratory and calculated CBR values

	Road P435/1	
Time (Days)	**CBR (%)**	**Calculated CBR**
0	22	25.0
2	21	20.6
3	19	18.5
5	17	14.1
6	13	11.9
7	12	9.8

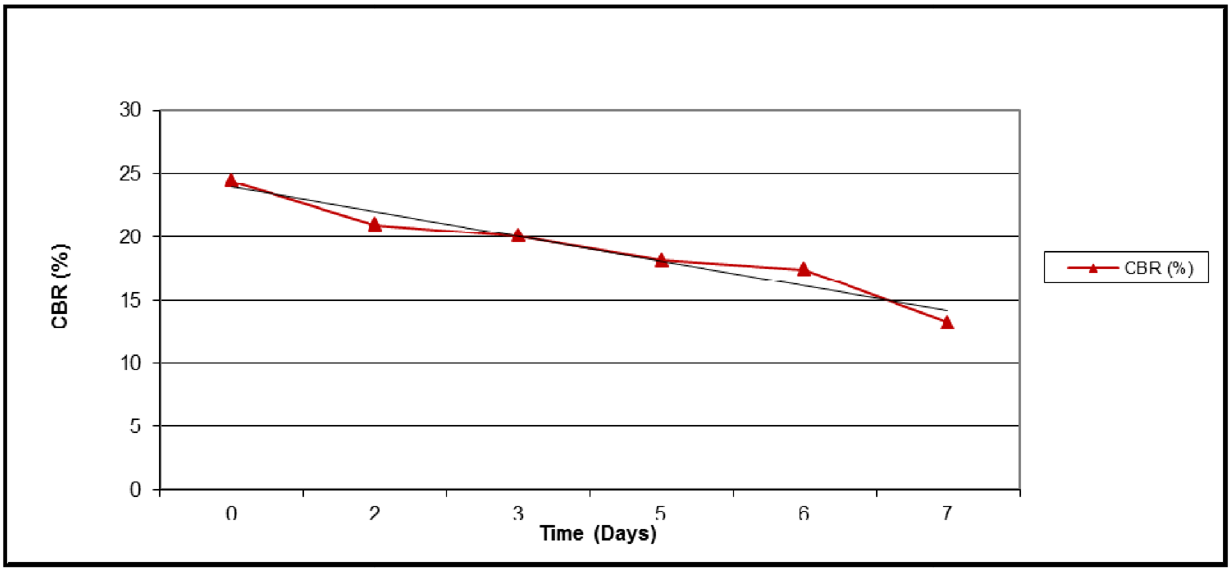

Figure 2: Variation of CBR with time of soaking (P443/1)

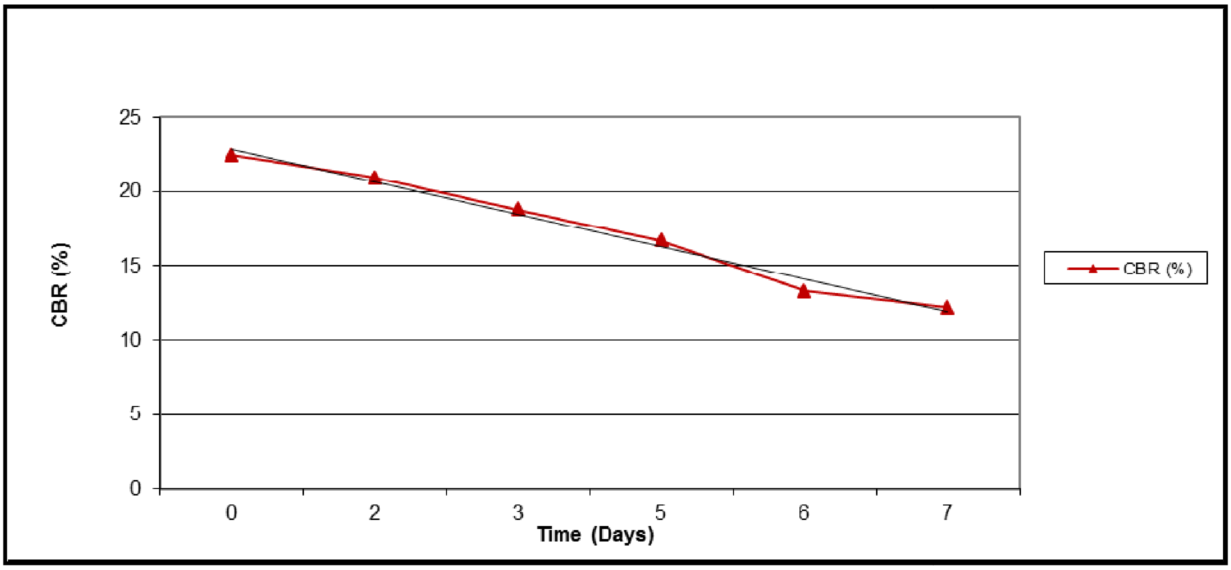

Figure 3: Variation of CBR with time of soaking (P435/1)

Study Area

The study was conducted in two areas adjacently located within uMkhanyakude District Municipality namely Jozini and Ndumo. They are located in Northern KwaZulu-Natal and borders Swaziland and Mozambique. The area is bound in the west by the Lubombo mountain range, which reaches an elevation of approximately 600m above sea level as shown in Figure 1. Jozini is characterized by seasonal dry winters and wet summers with periodic flooding. The summer temperature ranges from 23°C to 40°C, while winter temperatures range from 16°C to 25°C. Soil along the Lebombo Range consists mainly of shallow, stony soils of the Mispah and Glenrosa forms. The soils found along the floodplain and in particular along the west bank of the Pongola River, are derived alluvium, river terraces and the Cretaceous sediments.

Selection of sampling area

Several routes were identified for the study. These routes were P522, D9, P435 and P443/1 which are all within 50km from the study area's main town Jozini. Road D9 was reported to have been built on a calcrete sub-grade meaning that very little effect can be seen on this material as it is water resistant. Construction on road P522/2 was already complete together with asphalt paving and further exploration in terms of sampling would have required disturbance of the completed road pavement structure. With the bulk earthworks construction still underway on P435/1 and P443/1, these routes became the preferred choice as it would also eliminate further costs that would have been incurred on establishment for sampling and testing due to the currently constructed layer works and proximity of the site soil laboratory. Furthermore, the two routes were utilized due to construction and time constraints. P443/1 and P435/1 were selected as construction was currently underway on both routes. These routes also had the advantage of a soil laboratory which was situated at the midpoint of both projects and the availability of poor material suitable enough for subgrades.

The pavement and materials investigations were performed according to the methodology described in TMH5 document, Method MC1. Every effort was made to collect all samples during one field mobilization, requiring approximately 2 days of sampling and drying by a team consisting of a soils laboratory manager, researcher and two laboratory assistants.

Results And Discussion

Pavement investigation

The investigations consisted of the following: (a) Visual inspection of the road condition and materials along the road. This was done to confirm the limits of uniform pavement sections as detailed in the soil profiles prior to the design stage. It was also conducted to identify localized areas of potential problem materials and areas with drainage problems, which could influence the performance of the pavement and consequently the research sampling. (b) Test pits were excavated at various pre-selected positions along the width of the existing road including some of the localized previously identified problem areas.

Laboratory Tests

Laboratory tests were performed on a SOILCO Site Laboratory situated in the vicinity of the two routes P443/1 and P435/1. These tests were performed on two large portions of samples, each obtained from one of the roads and currently serving as the pavement sub-grade. Each sample was initially tested for MOD, CBR and Indicator tests in order to ascertain its classification and whether it falls within the range of subgrade material being G7 to G10. Thereafter, each the samples were quartered into six portions of three moulds that would be compacted and cured for 0, 2, 3, 5, 6 and 7 day periods. Swell readings were recorded, the specimen were removed from the water and compressed in triplicate as prepared.

Analysis of CBR Test Results

CBR values calculated upon compression were plotted on a graph against the varying number of days that each specimen was soaked in a curing bath. This was done for both samples taken from P443/1 and P435/1. A number of trendlines were then inserted where the plotted values resembled a linear trend for both routes. A fifth order polynomial trendline best represented the plotted data for both routes and have an R^2 value of 1, 0. Unfortunately the formulae derived were very extensive and hardly relevant to each other therefore attempting to merge them to best represent the data proved to be futile. A linear trendline on both graphs provided closely similar formulae with R^2 values of 0.945 and 0.985 for route P443/1 and P435/1 respectively. The formulae are for P443/1;

$$CBR_d = -1.9563 * d + 25.886 \quad (1)$$

And for route P435/1;

$$CBR_d = -2.1718 * d + 24.967 \quad (2)$$

Where;

CBR_d = CBR at day number d

d = day for which CBR is calculated

Tables 1 and 2 show the main CBR results plotted on Figure 2 and 3 as obtained from the compression of the specimen. Results of the CBR value calculated from the trendline formula are also shown in the tables. It should also be noted that when the wet days as obtained from Figure 2 and 3 are used, the formulae can give out the calculated subgrade strength for the said number of wet days.

Conclusions And Recommendations

The derivation of equation 3 is aimed at simplifying Eq. 1 and Eq. 2 thereby obtaining CBR strength of materials within a shorter time frame than the current four day period it takes to soak and compress the soil specimen. It is ideal for use on weaker gravels used as subgrade for road pavements. These are materials that generally have a CBR strength ranging from 3% to 15%. The formula may not always be practical especially when dealing with other gravels considered stronger than subgrade material. The equation, similarly to other test methods such as DCP, provides a rapid and accurate test to determine the CBR of subgrades. It is seen as ideal to review the conventional four day strength results for subgrades particularly where doubt exists.

Judging from the closeness of the equations derived from the test specimen, an observation was made and a single formula which combines both formulae has been proposed. The modified formula is expressed in Eq. (3) as;

$$CBR_d = -2 * d + 25 \quad (3)$$

Examples of the calculated values from the modified formula are shown in Table 1 and 2. Several trendlines were tested in order to identify one that is a close representation of the data. Since the data plotted best resemble a straight line, linear trendlines with R^2 values of as 0.9448 and 0.985 for route P443/1 and P435/1 respectively are shown on Figure 2 and Figure 3. The closeness of R^2 to 1.0 confirms a steady rate of decrease and that the trendline is a good fit to the results of CBR tests obtained under different times of soaking.

Certainly, this increases the confidence level in the use of such a formula for reducing the turnaround time for producing CBR results. Ordinarily it would take at least seven days to obtain a full comprehensive set of CBR results from any conventional laboratory. The formula developed here significantly reduces that turnaround time as it manages to shave off the entire four day soaking period. It follows that the usage of the formula should be considered not to be absolute, but rather comparative with the orthodox four day CBR method and should be used with care. [2] also found that the CBR value of the given soil sample decreases rapidly with time of soaking up to 24 hours and then decreases slowly which coincides with the observations of this study. The methodology used also takes into cognizance that significant variations can occur in CBR values due to differing properties in natural materials (grading, plasticity), even on a split sample and that the variation in quality of most natural gravels, the link between the 'G' designation and range of CBR values is quite broad [7].This study also established that the formula can be used with confidence to a certain number of days as accuracy cannot be guaranteed when time of soaking exceeds six days. Swell measurements however, cannot be recorded with this method as it does not allow for soaking of the specimen. Although these findings are based on subgrade soil, a suggestion for further study is to extend this methodology on other materials which are not of subgrade quality in an attempt to achieve the goal of a shorter timeframe for all laboratory soaked CBR's and hopefully materials classification. According to [5], a manual (Soils for Civil Engineering Purposes: Part 9), was developed for measuring the load bearing capacity of soils. This is also a test that has the advantage of being relatively quick and inexpensive and the results can be obtained the next working day. Similarly, the developed equations will serve as a way to obtain the CBR of a material within a shorter timeframe requiring the same apparatus as the conventional laboratory tested samples. It is current practice for the design parameter for subgrade to be the soaked California Bearing Ratio (CBR) for paved roads and it is recommended that unsoaked (field) CBR values should be used particularly in dry regions [4]. This recommendation is strongly opposed by the findings of this study as it requires no extended soaking for both wet and dry regions.

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ABOUT THE AUTHORS

Muzi Mndawe completed his Bachelor of Technology: Civil Engineering (Urban) in 2006. He is currently undergoing a Master of Technology program at the Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa under the supervision of Prof. J. M. Ndambuki and Dr W. K. Kupolati. He is currently employed by Royal Haskoning DHV as a Resident Engineer. Muzi is passionate about pavement design methods and their integration in future development of the transport sector. Most of his research is based on futuristic implications of current climatic influences and its impacts on road pavement designs. He is a Candidate Engineering Technologist eligible for professional registration with the Engineering Council of South Africa. (Corresponding author: mobile phone: +27721700277; fax: +27(0)866011127; email: muzimndawe@vodamail.co.za)

Prof. J. M. Ndambuki holds a B.Sc. (Hons), an M. Sc. and a Ph.D. in Civil Engineering. He is a rated researcher with extensive research experience in the area of water resources management. His research interests include: Stochastic Optimization, Multi-Objective Optimization, Groundwater Quality and Quantity modeling, Decision Support Systems as well as Generation of Green Energy through the use of agricultural and municipal solid waste. He is also the Head, Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa. (Mobile phone: +27836091607; fax: +27(0)123825226; e-mail: ndambukijm@tut.ac.za)

Dr. W. K. Kupolati holds a B.Sc. (Hons) and a Ph.D. in Civil Engineering. He also holds a M. Sc. in Construction Management. He is a Senior Lecturer at the Department of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa. He is involved with research on the sustainable and appropriate use of waste materials for civil engineering infrastructure, modeling and technopreneurship. (Corresponding author: mobile phone: +27733106085; fax: +27(0)123825226; email: kupolatiwk@tut.ac.za.)