COMPARING THE NEWLY IMPLEMENTED CBR TEST METHOD WITH ACTUAL FIELD CONSTRUCTION: SOUTH AFRICA

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ABSTRACT

The California Bearing Ratio test (CBR test) is a penetration test developed by the California State Highway Department (Caltrans) in early 1928/29 for evaluating the properties of construction materials. CBR testing is integrated in the design of flexible pavements and since its development. The CBR test has been adopted internationally. The South African road industry has implemented new CBR testing standards. The adaptation of the new standards has created questionable CBR results versus the actual material properties found in the field. Pavement design is based on the fact that the minimum structural quality will be achieved for each layer of material in the road prism. New construction techniques have allowed layers constructed previously in 150mm to be constructed in 300mm layers (especially for fill materials in the subgrade). This has shown a better structural quality as the top 150mm layer specification is achieved throughout the 300mm layer. This study, although not intensive, used a modified method of the CBR determination to approximate the classified material field conditions of the constructed layer. The modified method took into consideration a percentage (%) of the coarse material with the size greater than 37,5mm to be crushed through 37,5mm sieve. The modified method of the CBR indicated a substantial increase in the CBR values. The modified testing procedure for a specific case study increased the classification CBR value. These classified CBR values change from a minimum specified value of (G5 [CBR ≥ 45% at 95% MDD]) with an average reading of 46.7 at 95% MDD to a substantial improvement in the CBR value (G5) with an average reading of 60.8 at 95% MDD of the material. Although the gradings in the modified method is finer than the standard test, it's still followed the same curve. The other properties had a minimal effect on changes made. The Clegg Hammer Test was used to compare the strength of the constructed layer to the CBRs from the two test methods; it was found that the modified CBR testing method compared well with the Clegg hammer results. This confirms the importance of including to a certain extend of the coarse material (> 37,5mm) in the CBR testing regime.

Keywords: CBR, Modified Test Method, Natural uncrushed material, Clegg Hammer Test.

1. INTRODUCTION

The CBR was introduced between 1928 and 1930. This test was accepted worldwide and was accepted as being a cost effective and practical test to measure materials strength and stiffness properties. The test is a flexible test and can be conducted on all types of materials from silt to gravel. The CBR was established to measure the penetration resistance of an ideal crushed-rock base material as a standard reference, and this was used to compare against all other materials intended for construction. Existing field conditions is difficult to correlate with laboratory CBR values of the same material as the CBR samples are soaked at 100% while, the field materials are often ±2% of the optimum moisture content (OMC); therefore, field materials are effectively more resistant to penetration. The CBR penetration test measures the soil resistance to shear deformation.

Engineers have mostly based pavement designs on the assumption that minimum specified structural quality will be achieved for each layer of material found within the pavement system (Guyer, 2011). The design must ensure resistance to shearing, excessive deflections to counter fatigue cracking within the layer or in the overlying layers and to prevent permanent deformation through densification (Guyer, 2011).

New construction techniques and applications have changed the industry when compared to traditional road-building techniques. The traditional methods were constructing pavement layers in a thickness of 150mm while in today's newly applied methods, a stable stronger pavement layer can be constructed in a single layer of 300mm thickness. It should be noted that the thicker the layer the bigger the allowable aggregate size in the material. in general, the coarse aggregates are the strongest part of material and form it skeleton that bear the loading, thus, total exclusion of coarse material in the CBR testing regime might misrepresent the strength of this material.

Road formations, where subgrades act as pavement foundation, should be well designed. The evaluation of such road formations is a critical part of the design phase and construction. The CBR is commonly used to determine the suitability of a soil.

The Clegg Impact Hammer (CIH) was developed in Australia (Clegg, 1983) under the commercial name of “Clegg impact soil tester”. Studies have noted that this is an alternative method to the CBR test due to its practicality in both the field and laboratory testing regime. The hammer provides a quick overall measure of the stiffness of the material by giving the “Clegg Impact Value” (CIV) (Al-moudi et al., 2002). Studies have shown that with various adaptations to the CIV formulae and coefficients, a good correlation can be adapted between the CBR and field values.

1.1 Problem Statement

The CBR testing helps to classify the material and to quantify whether a specific material or possibly a treatment is suitable for a particular application. The test methods adapted comes into question as the industry grows in modern construction techniques, it is felt that the laboratory has been, in way, left behind to continue with the old, prescribed methods. The South African industry has since introduced new methods by adapting its standard to various worldwide techniques. The material standard documents, namely: SANS 1200, COLTO, TRH14 and COTO have shown that a contractor is allowed to construct fill and subgrade layers with maximum allowed oversize of 2/3 of the layer thickness. If a coarse material is used, this will influence the new standard of testing as also shown by Savage (2014), but the research was related to the old TMH1 CBR test methods. The question remains, how effective is the CBR test method in representing the actual constructed layer in the field. Standards in South Africa still allow for 2/3 (two-thirds) of rock size in a pavement layer when constructed but the new SANS test method does not cater for this type of construction method. This means that if a layer is constructed in 300mm thickness then a contractor is allowed rock sizes of up to 200mm in the layer. This will negatively affect the compaction of the layer and will reduce the workability during layer construction. Although, not formally indicate in the standard, some contracts specifications have been recommended the construction of 300mm layers. The new method discards the coarse material, and this will lead to results indicating that the layers were constructed with less superior quality materials. The coarse materials have been shown to be able to carry better load distribution throughout the layer and contribute to the structural quality of the pavement. However, this is not considered within the new methodology.

1.1.1 Aim of Paper

This paper will show a possible adaptation of the CBR method to indicate a more realistic results compare to the actual strength of layer constructed in the field. This is realised by the evaluation of fill and possible selected subgrades taking into consideration a calculated percentage (%) of the oversize material to be added to the CBR test method by crushing it through the 37,5mm sieve. The evaluation of the constructed layer will be completed by using the Clegg Hammer Test. The results can be compared to the modified and to the standard CBR testing regime to evaluate the effectiveness of the possible modified method. The main aim of the study was to suggest changes to the current test method by allowing consideration for a certain amount of coarse material.

1.1.2 Scope of Paper

The CBR test has been used worldwide since the 1930's. Although this test method has been adapted throughout the years, it is still a major talking point due to its reliability. South Africa has adapted new standards which raises few questions on the testing method especially if very coarse materials are used in the construction application. This paper has approached this by looking at possibilities of adapting the new test methods to try and incorporate what is been constructed in the field. This paper only reviews the test method for materials used from fill layers to selected subgrades. This research used the coarse materials for the modified method and the standard method. A clegg hammer is used for comparison between the insitu CBR and the test methods. This process will allow to verify if the new modified method can be adapted for the said layerworks and thus can be incorporated within the test method.

2. LITERATURE REVIEW

South Africa has a wide range of materials and the CBR testing is used to choose the most suitable type of material for the intended use. All parameters of the materials are studied to ensure that the materials used in the construction process conform to the design requirements. The design parameter used in South Africa is the soaked CBR reported at a representative density value. The classification of the CBR implies that not more than 10% of the reported values will fall below the CBR classification value (Guidelines for Human Settlement Planning and Design, 2018). There are limitations to design methods which the designers must bear in mind. Data is readily available showing further that empirical design methods were developed where the design bearing capacity did not exceed 10 to 12 million standard axles (Guidelines for Human Settlement Planning and Design, 2018). Various design methods need to be investigated in predicting a more suitable bearing capacity thus, creating a range of bearing capacity scenarios for the pavement design (Guidelines for Human Settlement Planning and Design, 2018). The AASHTO and various other documents such as the more comprehensive SAPEM guide was and is mostly used for the design of pavement structures as it had a set of comprehensive procedures for new and rehabilitation design and provides a good background to pavement design (AASHTO, 1993; SAPEM, 2014).

Breytenbach *et al.* (2010) noted that the strength of a soil material comprises of two components: The frictional component and the cohesion component:

The frictional component is based on the grading of the material that depends on the friction and interlock between the particles at various sieve sizes. This component is also affected by an applied stress normal to the shear plane. It is thus critical that this component also be considered once material is subdued to compaction/densification tests.

The second component which is noted as strength and cohesion is mainly influenced by the grain size distribution of the sample. The affinity of the particles to moisture (plasticity) and the moisture content. (Breytenbach *et al.*, 2010). Breytenbach *et al.* (2010) further noted that in the field, the particle interlock and particle packing is altered during compaction creating in a forced interlocking and denser packing material.

The soaked CBR symbolises the worst-case scenario, as the soaked CBR strength is lower than the strength at field moisture content. Designers complete an over-conservative approach in selection of materials creating a more expensive construction processes that is required as the soaked CBR simulates conditions that often do not or will never exist (Emery, 1985).

Savage (2014) noted that the variations in maximum density and CBR that oversize replacement effect for materials with oversize ranging from 20% to 40% are significant. Savage (2014) further reported that material sizes greater than the 19mm fraction should be treated in the manner of crushed stone materials by compacting to a specified solids ratio. It was further noted that it is essential that the laboratory material represents the field material and that the test procedure gives consistent and reliable results. Savage (2014) noted that for material above the 19mm sieve in excess of between 15 to 20%, the variation or errors in the determination of the maximum density and CBR become unacceptably large and increase successively as the oversized fraction increases.

Selected layers are usually compacted in layers of 150 to 300 mm thick, with the largest allowable oversize shown between 100 and 200 mm, in other words; two-thirds of layer thickness (SAPEM, 2014).

To date, although researchers feel that the CBR should be replaced, no effective alternative method has been developed except for the adaptation to the test method. It has been found that a large disadvantage is the poor repeatability of the CBR test (Breytenbach et al., 2010). South Africa do complete proficiency testing between accredited laboratories, but it requires substantial amount of material at a cost that only proves the accuracy of testing between the laboratories but not the actual concern over the effectiveness of the test.

The part of the new SANS 3001 is based on the South African TMH1 series used in the last 50 years. It is similar to ASTM and BS test methods apart from minor variations in the method (SANS 3001, 2014). The main difference between the TMH1 and the adapted SANS 3001 is that material is sieved through the 19mm sieve, and the oversize retained on the sieve is lightly crushed to pass the 19mm sieve. The latter uses the 37.5mm sieve and the oversize is discarded (SAPEM; 2014). SAPEM (2014) further stated that due to differing properties in natural materials including in split samples between laboratories, significant variations can occur in CBR values (SAPEM, 2014). The main part of the SANS 3001 is applied to check the quality of materials proposed for and used as subgrade and construction materials for roads (SANS 3001, 2014).

The CBR values of field tests are in-situ strengths of the material under existing field conditions and do not typically correlate with laboratory CBR values of the same material. The laboratory conditions are in controlled environment thus it is well known that it will be different from what was constructed in the field.

The Clegg hammer was developed to measure the stiffness of the field materials. Studies have shown that the readings stabilise after 5 blows. The higher the readings, the higher the field CBR value that is obtained. Al-Amoudi *et al* (2002), have noted that there is a desperate need to develop considerable data based on the correlation between Laboratory CBR values and Clegg Impact Hammer (CIH) results using several types of soils.

The Clegg Impact Value (CIV) has a direct application to the design and construction of pavements and the evaluation of strength characteristics of a wide range of materials (ASTM, 2016). ASTM (2016) further notes that the CIV responds to changes in the physical characteristics of the material properties that influence strength, thus it can be said that the CIV results provide a strength index value.

The CIV standard formula:

$$CBR = 0.07 \times CIV^2 \quad (1)$$

Al-Amoudi *et al* (2002) and Mathur et al (1987) have shown that an adaption of this formula should be applied to various materials. Mathur et al (1987) have developed the coefficient of K value showing that materials based on USCS classification system, materials Gw-Gm, GP – GM and SM have different K values as shown in Table 1. Al-Amoudi et al (2002) developed two formulae adapted for GM and SM soil respectively as best-fit models.

The two adapted formulae are as follows:

$$\text{GM Soil: } CBR = 0861\,(CIV)^{1.136} \quad (2)$$

$$\text{SM Soil: } CBR = 1.3577\,(CIV)^{1.011} \quad (3)$$

Al-Amoudi *et al* (2002) showed a summary of correlations for field and laboratory CBR/CIV relationships based on the two adapted formulae. In addition to the literature studies, a generalized model was developed to be viewed as a best-fit model and has shown that the coefficient of determination (R^2) for this model is 0.85. It is known that if the coefficient of determination is above 0.8, then the model can thus be considered dependable (Montgomery, 1984).

$$CBR = 0.1691(CIV)^{1.695} \quad (4)$$

The formula (3) was adopted by the civil engineering community to estimate the CBR values using the Clegg Hammer, but the general civil engineering community preferred the formula for correlation as found in 2 and 3 developed by Al-Amoudi *et al.* (2002).

Table 1: K values according to USCS soil classifications

Material	K
GW-GM	0,062
GP-GM	0,062
SM	0,07
SW	0,07
CL	0,08

3. MATERIALS AND METHODOLOGY

To evaluate the effectiveness of the newly adapted SANS methods, formulae need to be developed to simulate the corelation between the test results and the actual strength of constructed field material. The material used for this research is Dolomite which is abundantly found in the Gauteng Region in South Africa. The material was taken from a quarry in an in-situ state and not crushed. The material delivered showed a major amount in over size which the contractor used to successfully construct a subgrade layer to the requirement. The grading analysis showed material oversize between 80mm and 100mm.

To evaluate the accuracy of the current CBR values, the following methods are evaluated:

- Complete a CBR by applying the standard method according to SANS 3001.
- Weigh the total sample needed for the CBR test. Weigh the material passing the 37.5mm sieve and calculate the % passed. The difference will then be the oversize. The % required oversize will then be crushed to pass the 37.5mm sieve. The rest will be discarded.
- Evaluation of the field-constructed platform by completing the Clegg Hammer Test.

3.1 CBR

The standard CBR test is completed by following the steps as shown in SANS 3001 – GR40 (2013). The basic procedure followed:

- The samples are prepared according to SANS 3001 – GR30 (2013).
- The samples are then sealed in containers while the Maximum Dry Density (MDD) is prepared.
- Moistures are then taken from the containers to determine what % moisture must be added to the containers to bring the sample to the Optimum Moisture Content (OMC).
- Three (3) moulds are prepared, and material compacted as per SANS 3001 – GR40.
- Material is placed in a soaking bath for swell measurements.
- Material is then removed after 4 days, and the bearing test is completed.
- The material is classified according to the specifications and report issued.

3.2 Modified CBR

Modified CBR is completed by the following steps:

- As per SANS 3001 – GR30, the preparation of the samples is modified/adapted for the samples seen and applied for 300mm layer containing oversize materials.
- Modified preparation calculation steps are shown in Table 2.

- Total weight of sample is calculated (a).
- Total weight of sample passing the 37.5mm sieve is calculated (b).
- The percentage (%) of the whole sample is calculated passing the 37,5m sieve (c).
- The weight of the material (Oversize) scalped on the 37,5mm sieve is calculated (d).
- The percentage of the oversize material is calculated.
- The % material scalped on the 37,5mm is used to weigh out the required oversize to be crushed (d).
- The material is then mixed again with new indicators completed as this will show that there is still oversize above the 37,5mm sieve.
- The samples are then processed with the testing procedure according to SANS 3001 – GR40.

Table 2: Modified CBR Testing Method

Total Weight of sample (a)	Kg
Total weight passing 37,5mm Sieve (b)	Kg
% of sample passing the 37,5mm Sieve (c)= ((b)/(a)) *100	%
Weight of sample scalped on 37,5mm Sieve (d)	Kg
% of oversize to be crushed through the 37,5mm Sieve (e) = (100- (c))	%
Weight of oversize to be crushed (e/100) x (d)	Kg


Figure 1 and 2: Coarse material being mixed thoroughly

Figure 3: Layer completed after compaction

3.3 Clegg Hammer Test

Clegg Hammer testing was applied to various sections of the subgrade material. Figures 4 to 6 shows the Clegg hammer and some of the readings taken. Density testing was completed to indicate the CBR value of the in-situ at the compacted densities. Readings were taken after the five blows. Table 4 shows the CBR readings of the Clegg hammer using all three formulae as stated in the document (2, 3 & 4). This will also show which formulae are more suited for this type of material.

The density compaction was taken using a nuclear gauge. The required maximum dry density samples were taken to determine the compaction of the material including moisture samples to be able to complete correction to the nuclear gauge moisture readings. The compaction density results were used to compare the Clegg hammer readings and CBR value at that specific compaction.

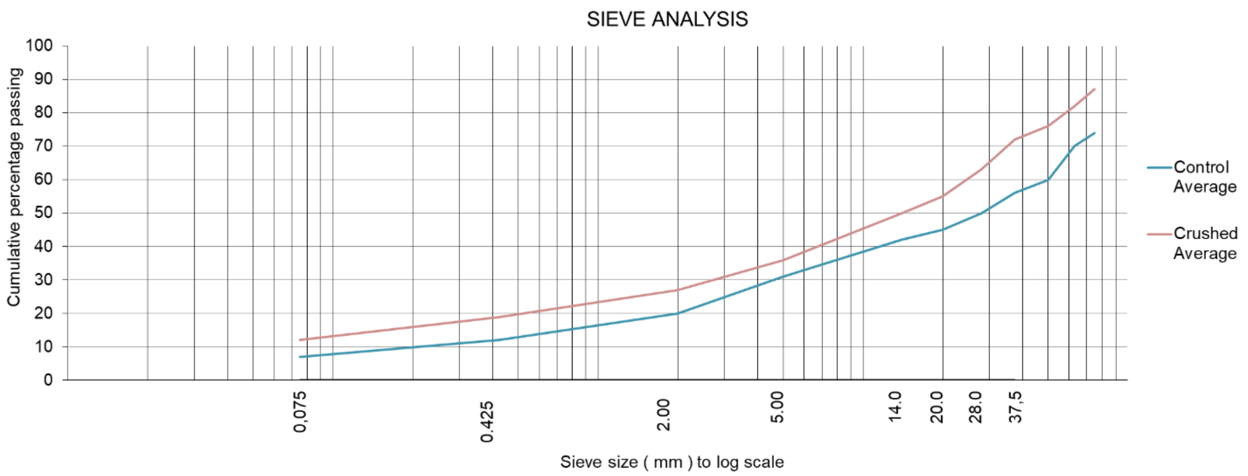
Figure 4 and 5: Clegg Hammer apparatus and operation

Figure 6: Clegg hammer reading after 5 blows

4. RESULTS AND DISCUSSION

4.1 Gradings

As noted in this study, the CBR has become quite a topic of discussion when it involves testing procedures and the correlation with the actual field material. The modified method was used to complete the testing as noted and can be seen in graph 1 for the gradings and table 5 for the CBR values, including the standard method of testing results. Oversize still shows on the crushed material and can be seen in the field. It must also be noted that the gradings of the crushed material will differ and will not be consistent as the material spreading and compaction plays an important role. The results found in graph 1 are the averages of all the samples taken for the purpose of this paper. The modified method average grading shows a finer material, but it follows the same flow trend as the standard CBR method.



Graph 1: Correlation Gradings between Standard CBR method and Modified Method

4.2 Clegg Hammer

The Clegg Hammer test results can be viewed in table 5. All three formulas (2, 3 & 4) were used to complete the comparisons. Using the comparisons, it was found that 2 is the formula to be used and thus showing that 2 is the more accepted formula according to Al-moudi et al. (2002) research work.

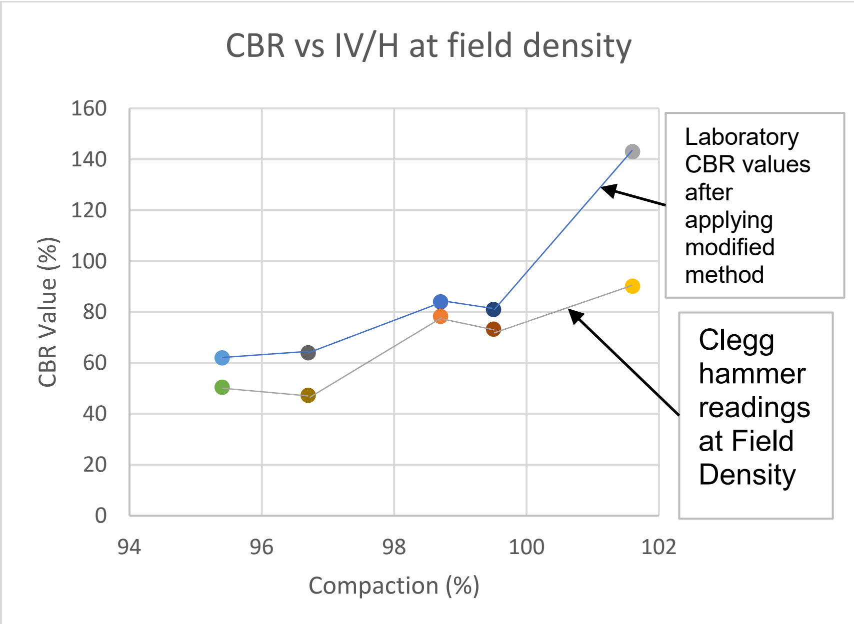
The results were plotted in graph 1 and show a close acceptance of the use of the modified CBR method than to the standard CBR method.

With further mathematical interpolation, the clegg hammer results lie between modified CBR and std CBR but one can conclude that the results are more favourable to the modified CBR results as shown in graph 2.

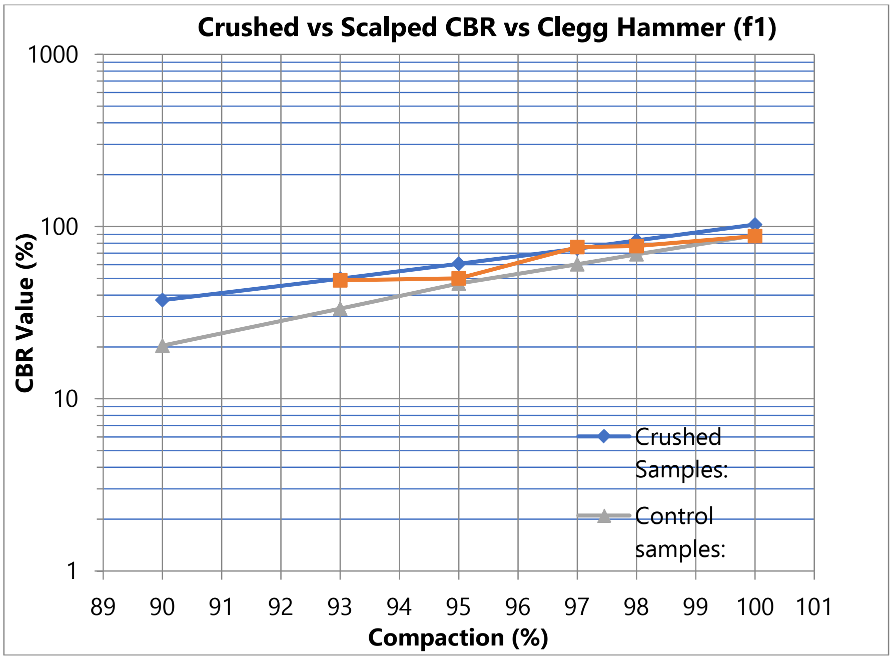
The density moistures are close to the OMC of the material. Using the requirements of ±2% of OMC, the clegg results can be evaluated as in place although one sample is below the requirements of 2% but can be considered as an outlier or the laboratory needs to repeat the test of the specific material. The Clegg Hammer test results tends to be more of a repeatable test considering that all the results are close to 8%OMC shown in Table 5.

Table 5: Clegg Hammer results

Clegg Hammer						
	CIV	Moisture Content (%)	Density (%)	Correlated CBR		
Chainage				Formula		
				2	3	4
CH120	53	6,6	98,7	78	75	142
CH110	60	6,9	101,6	90	85	175
CH100	36	9	95,4	50	51	73
CH90	50	7,3	99,5	73	71	128
CH80	34	7,3	96,7	47	48	67



Graph 2: Correlation between Clegg Hammer (2) and Laboratory CBR



Graph 3: Modified CBR vs Std CBR vs Clegg Hammer (2)

4.3 CBR

As per table 6 the modified CBR results show an increase in CBR values compared to the standard CBR. The average difference in the CBR values between the modified and standard from 100 to 95 compaction is 14 and from 93 to 90 is 17. This shows a substantial difference between the methods and can lead to a better understanding of the material properties currently found in the field. Both controlled and modified CBR values show a G5 classification but the modified indicates a substantial difference in readings from 90 to 97 in the CBR values.

These result differences show that the oversized materials need to be considered in the test results so that a better understanding of the material can be evaluated thoroughly.

Table 6: Modified CBR vs Std CBR results

	Atterberg Limits							CBR Values					
	L.L	P.I.	L.S.	GM	MDD	OMC	Swell	100	98	97	95	93	90
							Modified CBR						
	16	2	1	2,54	2176	7,7	0,06	119	84	70	50	35	21
	17	2	1	2,42	2145	10,6	0,06	143	117	106	86	70	52
	16	2	1	2,38	2198	7,5	0,06	81	73	69	62	56	48
	17	2	1	2,37	2158	7,7	0,06	81	69	63	54	46	36
	16	2	1	2,3	2209	8,2	0,06	89	72	64	52	42	30
Average	16,4	2	1	2,4	2177,2	8,3	0,06	102,6	83,0	74,4	**60,8**	49,8	37,4
							Std CBR						
	21	2	1	2,35	2103	8,2	0,06	76	65	59	48	36	17
	21	2	1	2,28	2124	7,8	0,06	98	72	61	45	33	20
	20	6	3	2,13	2173	7,2	0,07	93	70	61	47	31	24
Average	20,7	3,3	1,7	2,3	2133,3	7,7	0,06	89	69	60,3	**46,7**	33,3	20,3

5. CONCLUSIONS

The CBR test in South Africa has always been a continuous subject on what is been constructed. With innovative technologies, the testing methods have been adapted. Still, there is a question regarding the new method for the CBR for classification of materials used as Fills, Subgrades and Selected Layers. The specifications show that the maximum size that can be used in these types of layers is 2/3 and this is not then considered in the new updated CBR test methods. The new method discards this material, and this will lead to results showing that the layers were constructed with less superior standard. The coarse materials can carry better load distribution throughout the layer and contribute to the structural quality of structure and this is not considered with the new methods. The main aim of the study was to suggest changes and to modify the current test method by allowing consideration for a certain amount of coarse material. The results have shown an improvement in the quality which is much closer to what is in the field when compared to the standard method. The clegg hammer showed that the modified CBR could work as the results correlated well. This study has shown that coarse materials and the 2/3 layers specification need to be considered in a CBR test. Further investigation needs to be undertaken to give engineers a guide on when this type of modified test should be completed. The new method does have an impact on the cost of materials during construction and this must be considered.

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