Journal of Geoscience and Environment Protection, 2022, 10, 12-25
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

California Bearing Ratio Test on the Bearing Capacity of a Foundation in Unsaturated Soil

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How to cite this paper: Eboukou, R. C. D., & Manguet, D. E. N. (2022). California Bearing Ratio Test on the Bearing Capacity of a Foundation in Unsaturated Soil. *Journal of Geoscience and Environment Protection, 10,* 12-25.
https://doi.org/10.4236/gep.2022.106002

Received: May 10, 2022
Accepted: June 19, 2022
Published: June 22, 2022

Abstract

The value of the California bearing ratio (CBR) test is an index making it possible to evaluate the load of the foundation soil and the resistance of the pavement materials. The California Bearing Ratio (CBR) of unsaturated soils is particularly related to their quality. The mechanism affecting the bearing capacity, in the case of California Bearing Ratio (CBR), has been studied as a transformation of red clay for the backfill. In this study, the effect of compaction energy on compaction characteristics and California Bearing Ratio (CBR) values was investigated. The relationship between the CBR value (California Ratio Ratio) and the degree of compaction is characterized by a gradual evolution of unsaturated soils with different water contents. The results show that the compaction degree and California Bearing Ratio (CBR) value of the soil in the cold region are insufficient, but the bearing capacity of the compacted soil after immersion under the maximum dry density can still meet the filling requirements. The red clays tested are considered useful as bedding in areas of unsaturated soils.

Keywords

Compacted Soil, CBR Testing, Bearing Capacity, Colonies

1. Introduction

Compaction puts the material in a tight enough condition that further settlement is impossible or insignificant. Relative moves are reduced or removed, thus decreasing attrition. By reducing the volume of the voids, compaction increases the dry bulk density and decreases the permeability which is a function of the void index. Compaction leads to an increase in mechanical characteristics. Indeed, the tightening of the grains increases the number of contacts between them and consequently their friction. The angle of internal friction and the cohesion are increased. There is also a considerable increase in the modulus of deformation. The California Bearing Ratio (CBR) is a key geotechnical parameter used to determine the proper thickness of a flexible pavement made up of subgrades. The California Bearing Ratio CBR test is the most commonly used method in developing countries for pavement design (Ampadu, 2007). Compaction characteristics and California Bearing Ratio CBR are important because they impact transport construction. Under a given compaction energy, the relation between the water content and the dry density gives a bell curve which presents a maximum called Optimum Proctor separating from left to right the dry branch and the wet branch. In 1933, the American engineer Proctor proved the influence of humidity and compaction energy on the dry density of materials (Tchouani et al., 2004). Indeed, for a given compaction energy, if the water content changes, and the evolution of the dry density is represented graphically as a function of the water content, a bell curve is obtained, which has a maximum called Optimum Proctor, separating dry and wet branches from left to right. When the water content is reasonable, the water acts as a lubricant and the dry density increases as the water content increases (dry branch). On the other hand, when the water content is high (wet branch), the water absorbs a large part of the compaction energy. It occupies the place of solid particles, and no settling is possible. The behavior and stresses produced by a material are more or less a function of its properties. Generally speaking, the Proctor curve of sand is very flat, while on the other hand, the maximum value of plastic clay is very large (Tchouani et al., 2004). For materials with flat Proctor curves, compaction is virtually unaffected by water content. These materials are not very sensitive to water, but it is generally difficult to improve their properties (provide greater compaction energy). For a given material, if the compaction energy increases, the maximum density increases and the curve become sharper. Kay, Scimitar, Morel (1979) in (Gaye, 1995) points out that the dry density after compaction increases with increasing wheel load and inflation pressure. Martinez (1980) in (Gaye, 1995) points out that the response of granular materials to cyclic stresses before failure load can be divided into three types: adaptation; residence; ratchet.

The study of the geotechnical behavior of soils has been developed considering whether the soils are saturated or unsaturated. However, there are important geotechnical problems where the study of the establishment is essential, because a large part of the geological formations in the world are mostly unsaturated soils (Fredlund & Rahardjo, 1993; Barrera & Garnica, 2002). Unsaturated soil is the area of the subsoil between the ground surface and the surface of a free water table. Unsaturated soil is composed of three bulk phases (solid, liquid, and gas) and three interfaces (solid-liquid, liquid-gas, and gas-solid). Among the three interfaces, the liquid-gas interface plays a critical role in the mechanical behavior of unsaturated soils (Barrera & Garnica, 2002; Sheng, 2011; Fredlund & Morgenstern, 1977). During the compaction process, the gas and free water in the soil are driven out by an external force and the soil particles are rearranged to achieve the purpose of compaction. The composition of the ratio affects the compaction effect of the subgrade within a certain range. When using red clay to fill the platform, it mainly manifests as follows: when the water content is high, the liquid inside the red clay is difficult to drain out in the process of compaction, which compresses the volume occupied by the gas phase. After the compaction is completed, the gas volume gradually recovers and the spring soil phenomenon occurs; when the water content is low, the overall strength of red clay is very high, and it is difficult to rearrange the soil particles by the road roller, and the compaction effect is difficult to guarantee; high or low water volume, filling the platform with red clay can cause severe damage to the platform. If the red clay is not used to fill the platform, the land area for the project will be increased, the number of spoil areas will greatly increase, and the ecological environment will also be damaged. Improvement measures often used in the construction process are not perfect, and research on red clay with different soil qualities and conditions needs further investigation.

At the end of 2018, the mileage of the Hunan highway open to traffic reached 6725 kilometers. Hunan Province has heavy rainfall, long-lasting high temperatures, and large temperature differences. It belongs to the continental climate of humid monsoon to semi-subtropical. This kind of climatic condition makes the Hunan region distribute a wide range of red clay, its distribution area reaches 58,000 square kilometers, accounting for about 27.4% of the province's area (Hunan Provincial Department of Transportation, 2019). During the construction of Shi-Ning Expressway, Chang-Ji Expressway, Chang-Zhang Expressway and Dongxin Expressway, a large amount of red clay was discovered. Because red clay has a high liquid plastic limit, expansion and contraction, it is filled with red during backfilling, serious cracks and lattice cracks occur in the backfilling, associated with the influence of natural factors, promote more serious damage to the slope of the foundation, and at the same time, it is easy to cause various diseases such as cracks in the semi-rigid base layer and surface layer. If the red clay is replaced and filled, due to the huge amount of soil and rubble, it will cause great damage to the ecological environment, greatly increase the cost, and pose complex challenges for the safe use of the project. The choice of subgrade materials greatly affects the long-term performance of the road; only when the stability of the platform is ensured can the safe operation of the highway be ensured. Due to the vast distribution of red clay in the provinces of China, especially Hunan province, highways under construction have a large amount of red clay distributed on the route, and in the road network which must be continuously improved in the future, the construction of highways in the province will also challenge the red clay complex. Therefore, from the actual engineering, this article investigated the applicability of red clay in foundation bearing capacity on unsaturated soil through CBR test. More importantly, the study was aimed at analyzing the basic physical indicators of the red clay sample: including moisture content, analysis of particle density test, liquid limit, limit of plastic, and the characteristics of compaction; influence of sample preparation method on CBR value from red clay: compaction; influence of test method on CBR value of red clay: effect of immersion method, immersion time.

Indeed, this article was carried out as follows: the analysis of the mechanical and physical properties of natural soils, compacted soils in embankments, sub-layers, foundations and sub-foundations of roads and airports. It is therefore a test which aims to determine: establish a soil classification (GTR) "guide to road earthworks"; evaluate the traffic capacity of earth-moving machinery (IPI) "immediate lift index"; determining CBR (Californian-Bearing-Radio) pavement thickness increases thickness decreases tracking methodology and results.

2. Equipment and Test Program

The test method was used to determine the compaction test and CBR test values.

2.1. Equipment

The red clay soil sample was collected in Hunan province in China. Before making the load report of the soil samples, the preparation equipment should be prepared through a cylindrical mold with a diameter of 152 mm with a height of 120 mm, a perimeter bottom plate with a device for over-tightening the compaction cylinder, 8 pieces with a mass of 1.25 kg semicircular load block, filter paper, plastic wrap, electric wire stripper, scraper, and other round-hole sieve instruments.

2.2. Compaction Test

Air-dried soil was used to prepare the compaction samples. The main preparation processes were as follows:

- We took 5 samples, each mass of which is equal to 6 kg. To prepare for the compaction process: first we air-dried the soil using a 20 mm sieve, after pulverizing with a hammer. These 5 samples were put in the plastic bags for 1 day to have a homogeneous mixture.
- Water content of dry moisture has been determined, condensed water has been determined. The condensed water was spread on the clay using a spray bottle while mixing with a shovel to get a good clay texture. Then the samples were put in the plastic bags for a period of two days to have a homogeneous mixture.

The preparation of the samples were spread in three layers in a mould, with height of 40 mm each layer. Compaction tests were carried out in accordance with the Standard for Soil Test Method (JTG E40-2007).

2.3. CBR Test for Compacted Soil

The samples used in the CBR test were the compaction samples obtained from the compaction test. CBR tests were carried out in accordance with the Standard for the Test Method of Soil (JTG E40-2007). In this study, CBR values were obtained by driving a cylindrical piston into the ground. Before pressing the plunger, the samples were soaked in the water containers for 96 h. First, the samples on the mold were placed on a rigid porous plastic square board, and the mold and the board were tightly bonded. We then placed the samples in the container filled with water at the height of 25 mm from the top surface of the sample. It should be noted that there was a mass of 50 N of CBR test split overload rings on the samples during the soaking period. Additionally, a dial indicator was used to monitor the expansion of the compaction soils during soaking, as shown in **Figure 1**. The cylindrical plunger was driven into the soaked soil at a rate of 1 mm per minute up to at a maximum penetration of 12.5 mm (Ghorbani et al., 2015). **Figure 2** shows the mold after immersion. **Figure 3** shows the CBR test fixtures. The CBR value (%) of each soil sample was calculated at 2.5 mm and 5 mm penetrations by dividing the corrected load by the standard stress. Each experiment was performed once. The prepared samples are shown in **Table 1**. As the samples compacted after the compaction test could be directly used for the CBR test, there were 60 samples in total (see **Table 2**).

Figure 1. The preparation of the soil sample in immersion for 4 days.

Figure 2. After immersion.

Figure 3. During the CBR test.

Table 1. Basic physical parameters of tested soils.

Properties	
Liquid limit (%)	42.87
Plastic limit (%)	25.56
Particle density ($g \cdot cm^{-3}$)	2.73
Silt	22.01

Table 2. Statically compacted red clay CBR test data table.

Water content (%)	Specimen Numbering	Moisture content measured	Expansion (%)	Average Expansion (%)	CBR Value % 2.5mm	Average CBR Value %
	1		0.61		3.31	
36	2	25.04%	0.90	0.74	3.48	3.48
	3		0.72		3.66	
	1		0.63		6.97	
28	2	12.49%	9.35	3.6	4.01	6.39
	3		0.80		8.20	
	1		0.63		4.07	
24	2	16.19%	2.54	1.61	17.09	10.82
	3		1.66		11.34	
	1		0.55		3.31	
20	2	12.10%	11.72	4.97	3.14	3.19
	3		2.66		3.14	
	1		0.55		3.66	
16	2	13.88%	5.08	2.2	4.36	3.77
	3		0.96		3.31	

3. Result and Analysis

3.1. Compaction Characteristics

The samples were made using an analysis session to determine the index properties. In this investigation, the liquid limit of the samples is determined using the Casa grande apparatus according to IS: 2720 (Part 5) (IS: 2720 (Part 5), 1985), the plastic limit of the soil according to IS: 2720 (Part 5) - 1985 and the specific gravity according to IS: 2720 (Part 4) - 1985 (IS: 2720 (Part 5), 1985; IS: 2720 (Part 2), 1973). The results of all the properties of the index are represented by means of the curves of each water content which are each composed of three densities.

In the following figure, the static compaction method has a low moisture content of 16%, an optimal humidity content of 22.09%, of a content in High moisture of 24% and a high density of 1.5. The CBR value of the red clay floor samples showed the following changes (see **Figure 4** and **Figure 5**).

3.2. CBR Test Result for Compacted Soil

In **Tables 3-5**, we find that compared to the dry density 1.3, 1.4 and 1.5 the % CBR values of (2.5 mm) are higher than the % CBR values of (5 mm). The average % CBR value in dry density of 1.3 is 6.21% in water content 36%; in density 1.4 the average % CBR value is 15.05% in water content 24%; in dry density of 1.5 the % CBR value is 10.84% in water content 24%.

Figure 6 the relationship between penetration and load of clay with a content of 16%.

Figure 7 the relationship between penetration and load of clay with a content of 20%.

Curves 7 and 8 increasingly show slowing in pressure, curve deformation and

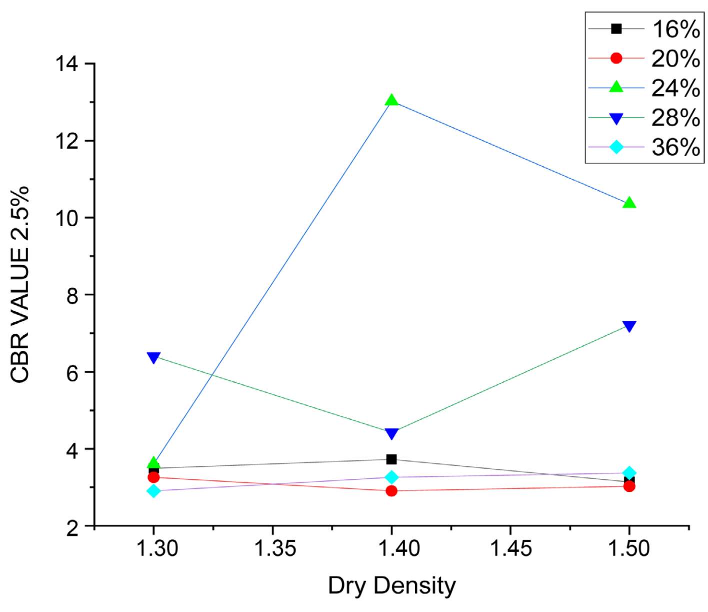

Figure 4. Testing the CBR value 2.5% mm in dry density.

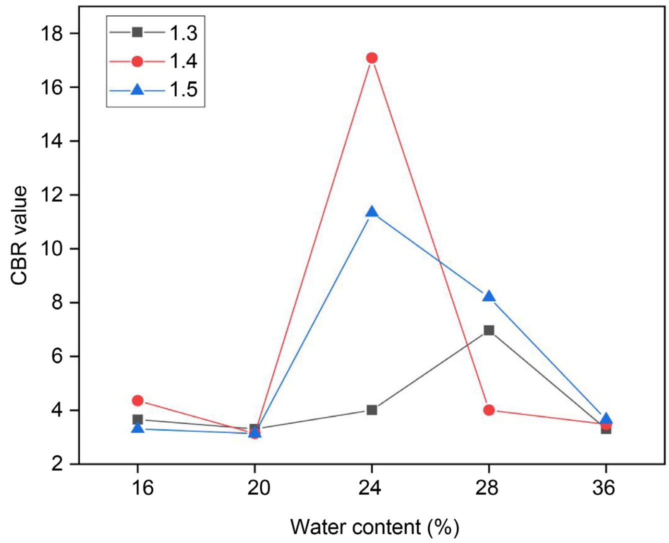

Figure 5. CBR test in water content.

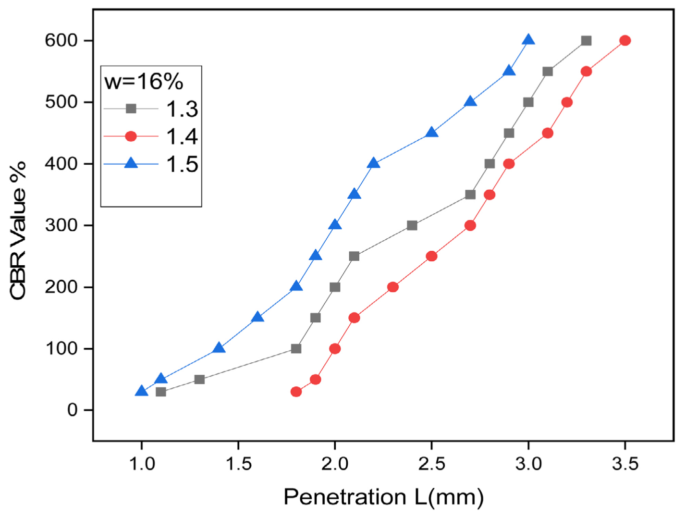

Figure 6. CBR test in penetration L (mm).

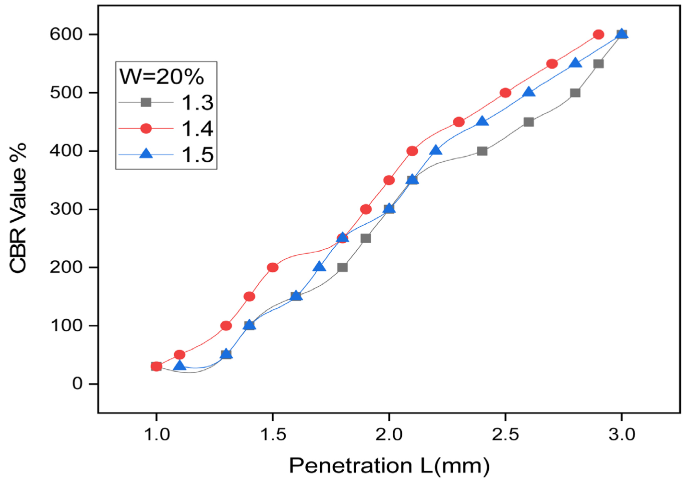

Figure 7. CBR test in penetration L (mm) (2).

Table 3. Table of the red clay sample CBR at temperature 105˚C wet density (1).

Water content	Expansion	Lecture of compaction (mm)	Pressure	Dry Density 1.3	CBR Value % (2.5 - 5.0 mm)	Average CBR Value %
98 times 16%	0.55%	2.1	254.47 366.38	1.42	3.66% 3.48%	3.57%
20%	0.55%	1.9	232.04 341.96	1.3	3.31% 3.25%	3.28%
24%	0.63%	2.3	280.89 378.59	1.33	4.01% 3.60%	3.80%
28%	0.63%	4	488.51 671.70	1.46	6.97% 6.39%	5.18%
36%	0.61%	1.9	232.04 305.32	1.34	3.31% 2.90%	6.21%

Table 4. Table of the red clay sample CBR at temperature 105˚C wet density (2).

Water content	Expansion	Lecture of compaction (mm)	Pressure	Dry Density 1.4	CBR Value % (2.5 - 5.0 mm)	Average CBR Value %
98 times 16%	5.08%	2.5	305.32 390.81	1.42	4.36% 3.72%	4.04%
20%	11.72%	1.8	219.83 305.32	1.5	3.14% 2.90%	3.02%
24%	2.54%	9.8	1196.86 1367.87	1.23	17.09% 13.02%	15.05%
28%	9.35%	2.3	280.89 464.08	1.46	4.01% 4.41%	4.21%
36%	0.90%	2	244.25 341.96	1.32	3.48% 3.25%	3.36%

an increase in the amount of penetration at high grade, not friction.

Figure 8 the relationship between penetration and load of clay with a content of 24%.

Figure 9 the relationship between penetration and load of clay with a content of 28%.

Figure 10 the relationship between penetration and load of clay with a content of 36%.

4. Discussions

It is found that the unsaturated soil that goes through the immersion procedure

Table 5. Table of the red clay sample CBR at temperature 105˚C wet density (3).

Water content	Expansion	Lecture of compaction (mm)	Pressure	Dry Density 1.5	CBR Value % (2.5 - 5.0 mm)	Average CBR Value %
98 times 16%	0.96%	1.9	305.32 390.81	1.52	4.36% 3.72%	4.04%
20%	2.66%	1.8	219.83 317.53	1.5	3.14% 3.02%	3.08%
24%	1.66%	6.5	793.83 1086.94	1.46	11.34% 10.35%	10.84%
28%	0.80%	4.7	574.00 757.19	1.31	8.20% 7.21%	7.70%
36%	0.72%	2.1	256.47 354.17	1.53	3.66% 3.77%	3.51%

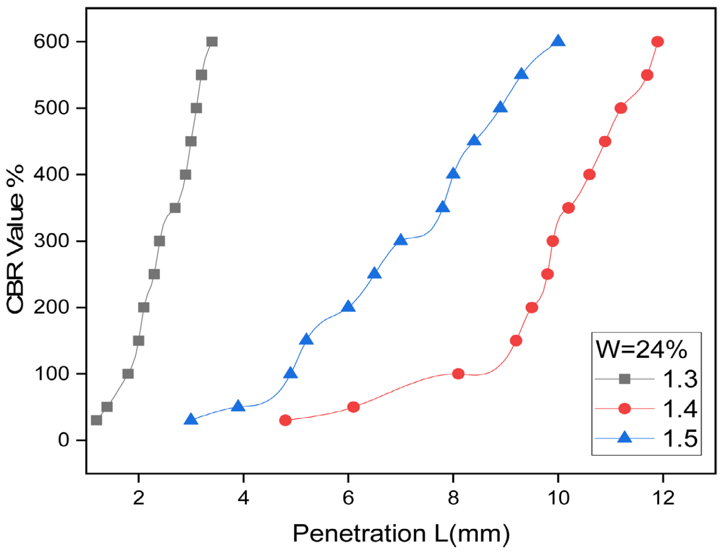

Figure 8. CBR test in penetration L (mm).

increases the water content which leads to water saturation, which causes the unsaturated soil to become saturated.

According to geotechnical testing regulations (JTG-E-40-2007) when the density is high, the CBR value is high and when the water content is high, the CBR value decreases.

Figure 4 and Figure 5 show that the density gradually increases as the CBR value increases and decreases, which is to say the CBR value is flexible.

Figure 6 the relationship between Penetration and Load of Clay with a content of 16% and Figure 9 the relationship between Penetration and Load of Clay with a happy with 28%. The figures show the penetration curves of the sample and the pressure whenever the pressure of the sample increases the penetration

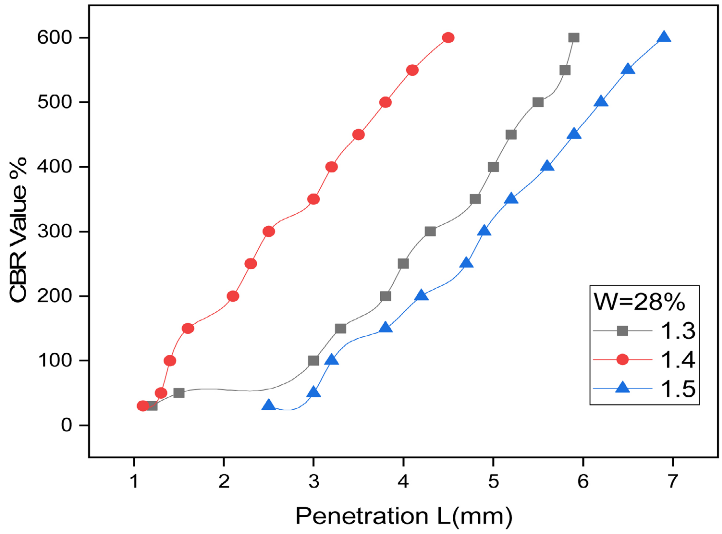

Figure 9. CBR test in penetration L (mm).

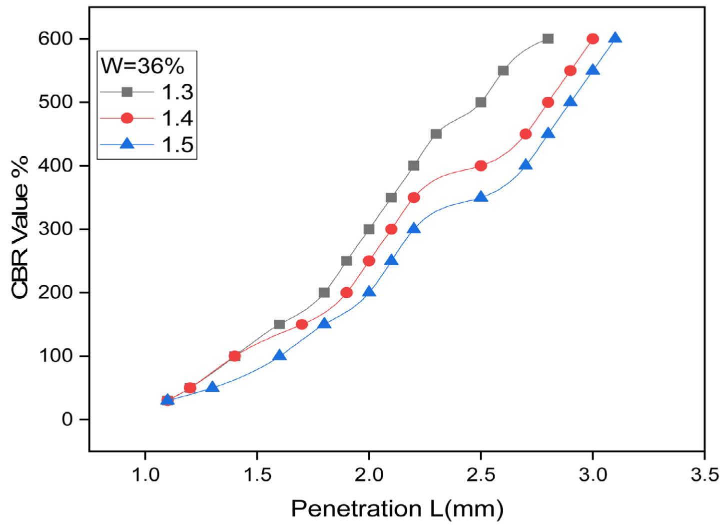

Figure 10. CBR test in penetration L (mm).

increases when the amount of penetration is the same, the pressure of the sample are aligned. May explain that the dimming of the sample is different, it is impression at each level there is a slowdown and we see that the depth of penetration a curve of the pressure and the penetration of the sample made.

Figure 7 the Relationship between Penetration and Load of Clay with a content of 20% and Figure 9 the Relationship between Penetration and Load of Clay with a happy with 36%. These figures show the penetration curves and the pressure of the sampling of a wet content when the pressure of the sampling effects slowly with an increase in penetration. A presents we tend the quantity of penetration is the same and there is an increase in pressure.

Curves 7 and 8 increasingly show slowing in pressure, curve deformation and an increase in the amount of penetration at high grade, not friction.

The curve of the pressure and penetration of the sample of a moisture content

24% is seen a pressure increase in the sample and penetration. When the penetrating rod penetrates the pressure is relative and we observe a Pressure curve-Text ration of the sample. A depth of penetration and a growing pressure.

In fact, the sparse expansive soils in non-cold regions of China, such as the Baise region (IS: 2720 (Part 2), 1973) and along the Xiangjing and Hanshi highways (Zhang, Yin, & Li, 2003), were considered as fillers. However, the compaction and CBR values according to the data are not sufficient for soils in cold regions. According to Highway Basement Design Code (JTG D30-2015) (Ministry of Transport of the People's Republic of China, 2015) for top fill, CBR value should be more than 3%, for bottom fill, it should be more than 3% for expressways and greater than 2% for expressways with low gradients. The CBR values in this study were all measured on soaked samples. As mentioned above, the dipped specimens had the lowest rolling resistance. The results show that the bearing capacity of the soil can still meet the requirements of the backfill after being immersed in the compacted water at the maximum dry density. The CBR test plays a very important role in the construction of highways and its values allow us to evaluate the works well. These experiments take time to have satisfactory values. The CBR value is the ratio of the force required per unit area to penetrate the sample with a standard piston to the degree required to penetrate the corresponding standard material. In this study, a penetration lift ratio of 2.5 mm was used. Expansive swelling of the soil due to water absorption (Al-Yaqoub et al., 2017; Por et al., 2017), the loose structure of the expansive floor slab will significantly reduce its strength. Soils swell when immersed in water during the CBR test immersion process.

5. Conclusion

In this article, the red clay used for experiment was collected in Hunan province. Based on the existing research results at home and abroad, the basic physical indicators of red clay were measured, and the compaction characteristics and CBR value of red clay as a load of foundation on unsaturated ground. It appears that:

The soil sample taken in this experiment is red clay, its optimum silt is 22.01, its maximum particle density is 2.73, its liquid limit is 42.87, its plastic limit is 25.56, belongs to clay soil.

Based on performed compaction tests and CBR value on unsaturated soil are insufficient. For top fill, CBR values should be greater than 3%; for the lower embankment, they must be greater than 3% for highways and greater than 2% for low-grade highways. The CBR values in this study were all measured on soaked samples. As described, quenched specimens exhibited the lowest bearing resistance. The results show that the bearing strength of the soil after immersion in compacted water at the maximum dry density, could not still satisfy the requirements of an embankment. CBR testing plays a very big role in the construction of highways and its values allow us to properly evaluate the work. These experiments really require time to have satisfactory values. With a lift ratio at penetration of 2.5 mm adopts, the CBR value refers to the ratio of the force per unit area required to penetrate the sample with a standard plunger to that required for the corresponding penetration in a standard material.

It is good to combine the experiments made in the field and those in the laboratory for a thorough research and to have exact values on the CBR test to proceed to a good construction.

Acknowledgements

The authors are thankful to the Pr. Tao Gaoliang as a supervisor for providing necessary assistance.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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