

Investigation of the Effects of Different Laboratory Compacting Methods on the Properties of Cement Stabilized Materials

P. Wu & L.J.M. Houben

Department of Road and Railway Engineering, Delft University of Technology, Delft, the Netherlands

Christophe Egyed

PowerCem Technologies B.V., Moerdijk, the Netherlands

ABSTRACT: Cement stabilized materials have been attractive for pavement base construction. There are many factors influencing the properties of cement stabilized materials, including the soil type, mix proportion, the compaction degree, etc. Among these variables, the compaction process plays a significant role in the final behavior of these materials. That is because the cement stabilized mixture should be compacted to a certain density to achieve maximum strength. Optimum compacted materials may reduce the moisture susceptibility and increase the durability. The materials can be mechanically compacted by static or vibratory pressure. However, due to the variable characteristics of the soil or aggregate, it is essential to choose the appropriate compacting methods for each type of material. Therefore, this research is conducted to investigate the effect of compaction methods on the properties of cement stabilized materials. Three typical types of soil, i.e. sand, sandy clay and clay are stabilized with cement and RoadCem additive to evaluate the compressive strength and indirect tensile strength. Proctor and vibratory compaction technical are applied to each type of stabilized soil. Based on the experimental results, the mechanical performance of cement stabilized material samples obtained through these two compaction methods is compared. Consequently, the appropriate compaction technique for specified soil types is determined.

KEY WORDS: Compaction methods, Vibrating hammer, Proctor test, RoadCem, Cement stabilization

1 INTRODUCTION

A cement stabilized material is a mixture of cement, water and soil or aggregate, compacted to maximum density. During the process of stabilization the compaction plays a major role in the final performance of the material. Compaction of the mixture is normally achieved by mechanical methods by reducing the volume of the air and hence increasing the density, bearing capacity and durability to ensure adequate long-term performance. Furthermore, a well-compacted mixture exhibits less shrinkage because the soil/aggregate particles are

packed tightly together resulting in reduced voids content (Adaska and Luhr 2004). In laboratory tests mechanical compaction methods are performed by applying static or vibratory loading. The Proctor test, developed in 1933, is one of the most widely used compaction technique today. The vibratory compaction can be applied by using an electrical vibrating hammer, which has also spread widely since its development in the early 1970's (Shahin 2010). However, due to the variability of the soil or aggregate type, the option of compaction methods is dependent. It is reported that the Standard Proctor test method is not efficient in compacting granular materials for reason that the granular materials may displace or break down when struck by the impact hammer (Farrar 2000, Felt 1968). In order to improve the compaction technique related to the soil type, in a research (Kenai 2006) the effects of different compaction methods on the mechanical properties and water resistance of cement stabilized clay soil were studied, which shows that dynamic compaction gives the best results in certain mix compositions. In addition, numerous studies (Prochaska 2005, Drnevich 2007, Parsons 1992) evaluated the effect of vibrating hammer compaction method on granular materials. The vibrating hammer method is considered better due to the fact that it better simulates the field compaction (Drnevich 2007).

Based on these previous studies, this research aims to assess the effect of the laboratory compaction method on the mechanical properties of the cement stabilized soil by comparing the use of the Proctor compactor and the vibrating hammer. Sand, sandy clay and clay are stabilized to give comprehensive test results associated with the effect of the soil type. Meanwhile, a Zeolite Nano based additive is applied during the cement stabilization process. RoadCem additive, based on the Nano technology, is specifically designed for application in road construction by enhancing the strength and flexibility of stabilized road layers. In research (Lemoine 2013) nanoindentation and Rockwell microindentation measurements were conducted and it shows that the stabilized samples with use of RoadCem have superior mechanical properties than those without using it. This particular study is a preliminary part of research on the effects of RoadCem on cement stabilized materials.

2 OBJECTIVE AND SCOPE

The primary aim of this research is to evaluate the effect of compaction methods on the properties of cement stabilized materials in order to obtain the appropriate compaction method for specified soil types. Two compacting methods (Proctor compactor and vibrating hammer) are used to prepare the cement stabilized samples. Three typical types of soil, sand, sandy clay and clay, are being stabilized with cement and an additive RoadCem.

The laboratory tests are mainly divided into two parts. The first part is to develop the relationship between moisture content and dry density of the soil by compacting the pure soil at different moisture contents to obtain the optimum moisture content and corresponding maximum dry density. Secondly, mechanical tests are conducted on the compacted stabilized samples, including compressive strength and indirect tensile strength tests. Based on the mechanical behavior of the compacted materials, the appropriate compaction method for each type of soil is achieved.

3 SOIL MATERIALS

In order to investigate the efficiency of the compaction methods, three types of soil are chosen to represent typical grain sizes. Manufactured sand, clay and sandy clay are stabilized in this experimental research. Sandy clay is obtained by mixing sand and clay (1:1, by dry mass). The grain size distributions of these three types of soils are shown in Figure 1.

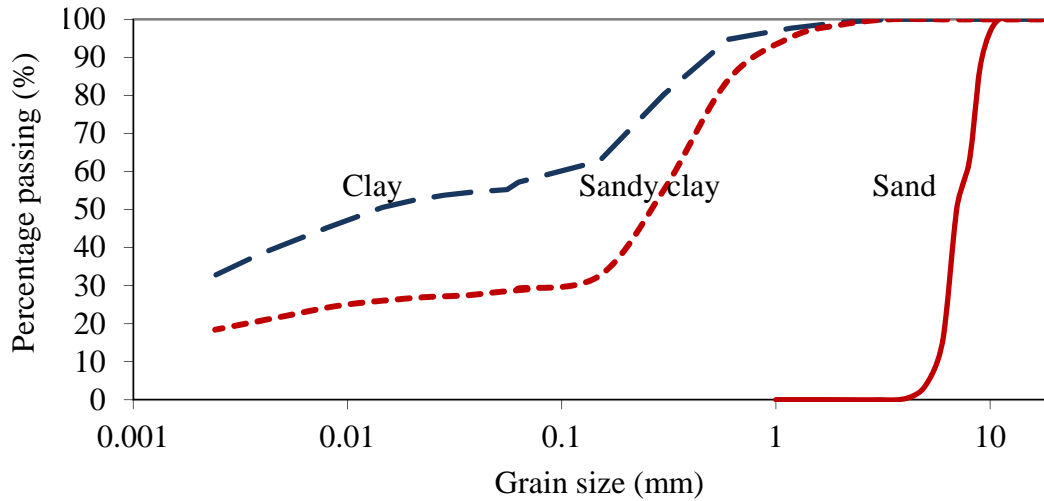


Figure 1: Grain size distribution of 3 types of soil

The general properties of these three types of soil are summarized in Table 1.

Table 1: Soil properties

Soil property	Sand	Sandy clay	Clay
Particle density (g/cm^3)	2.65	2.6	2.57
Coefficient of uniformity (C_u)	2.23	-	-
Curvature index (C_c)	0.96	-	-
Liquid limit (LL)	-	22	38
Plastic Index (PI)	-	8	21
Classification (USCS)	Poorly graded sand	Sandy lean clay	Lean clay

3 TEST PROGRAM

3.1 Sample preparation and compaction

(1) To determine the correlations between moisture content and dry density, each type of soil was compacted by two types of methods: Proctor compactor and vibrating hammer. Sand was compacted by standard Proctor test according to NEN-EN 13286-2, while clay and sandy clay were compacted by Modified Proctor test which provides more compaction efforts on the cohesive soil. The mass of rammer for standard and Modified Proctor compaction is 2.5 kg and 4.5 kg, respectively.

The vibratory compaction method is performed by impacting a vibrating hammer (Hilti TE1000-AVR) with an attached tamper. The diameter of the tamper is 90 mm, which is less than the internal diameter of the cylindrical mould (101.6 mm). The soil is subjected to the vibratory load at a frequency of 60 Hz. Sand was compacted for 3 layers and clay and sandy clay for 5 layers. The dry density is calculated on the pure soil excluding the moisture content

after compaction. Figure 2 gives the picture of the Proctor compactor (with rammer 4.5 kg for Modified Proctor compaction) and vibrating hammer utilized in this experimental study.

(2) For the cement stabilized samples a mix composition with 205 kg/m^3 cement and 1.9 kg/m^3 RoadCem (related to the dry soil) is used. The compaction methods for the cemented materials are the same as previously used for the pure soil. The stabilized sandy clay and clay mixtures were compacted by Modified Proctor test. For the sand-cement mixture the standard Proctor compaction was utilized.

After compaction and hardening for 24 hours the specimens were extracted from the moulds. Subsequently, the specimens were placed in a controlled-environment chamber at a temperature of 18.5°C and a constant relative humidity of 85% for 28 days.



1) Proctor compactor



2) Vibrating hammer

Figure 2: Compacting equipments

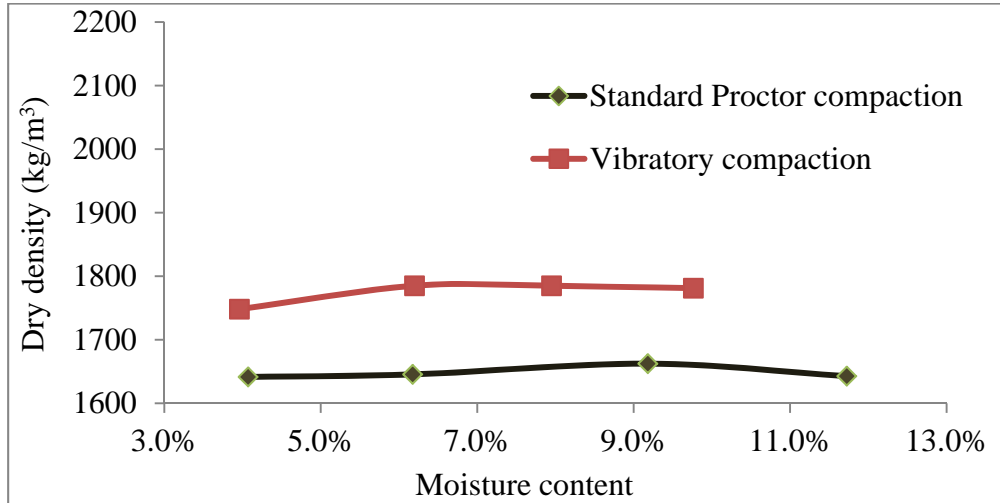
3.2 Mechanical test

After curing for 28 days the stabilized samples were subjected to the mechanical tests consisting of compressive strength test and the indirect tensile strength test. Prior to testing, the weight and dimensions of the samples were measured with accuracies of 0.01 g and 0.1 mm, respectively, in order to identify the obtained specimen density from different compaction methods. The compression and indirect tensile strength tests are widely used to characterize the properties of cement stabilized materials. The unconfined compressive strength test and indirect tensile strength test were carried out according to NEN-EN 13286-41 and NEN-EN 13286-42, respectively. The specimen is loaded at a specified constant loading rate ($0.5 \text{ (N/mm}^2\text{)/s}$ for compressive loading; $1.77 \text{ (N/mm}^2\text{)/s}$ for indirect tensile loading) until failure. The compressive strength is defined as the peak load (F) divided by the area of the cross section of the specimen. The indirect tensile strength is defined as the stress at failure of a cylindrical specimen subjected to a compression force applied on two opposite directions (NEN-EN 13286-42).

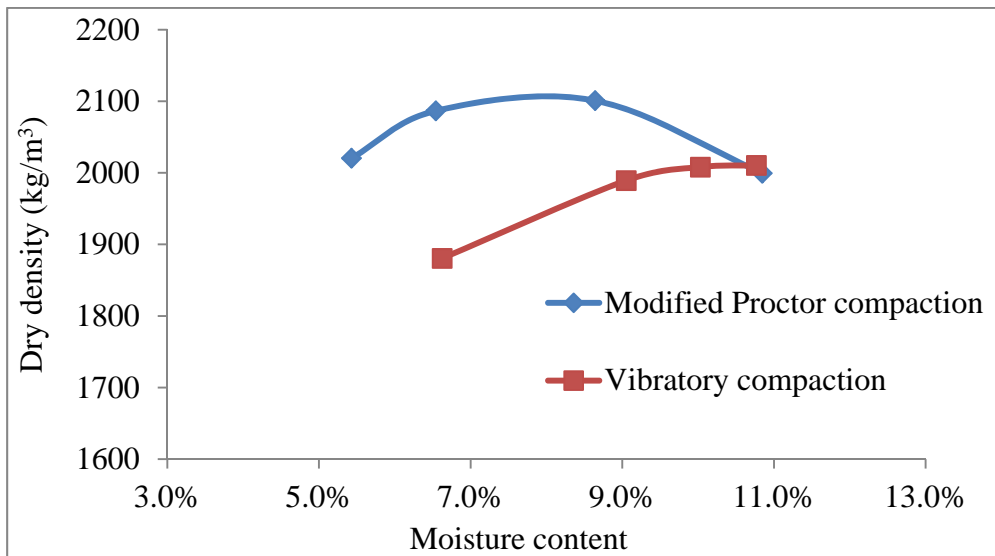
4 ANALYSIS OF EXPERIMENTAL RESULTS

4.1 Relationship between moisture content and dry density for the compacted unbound soil

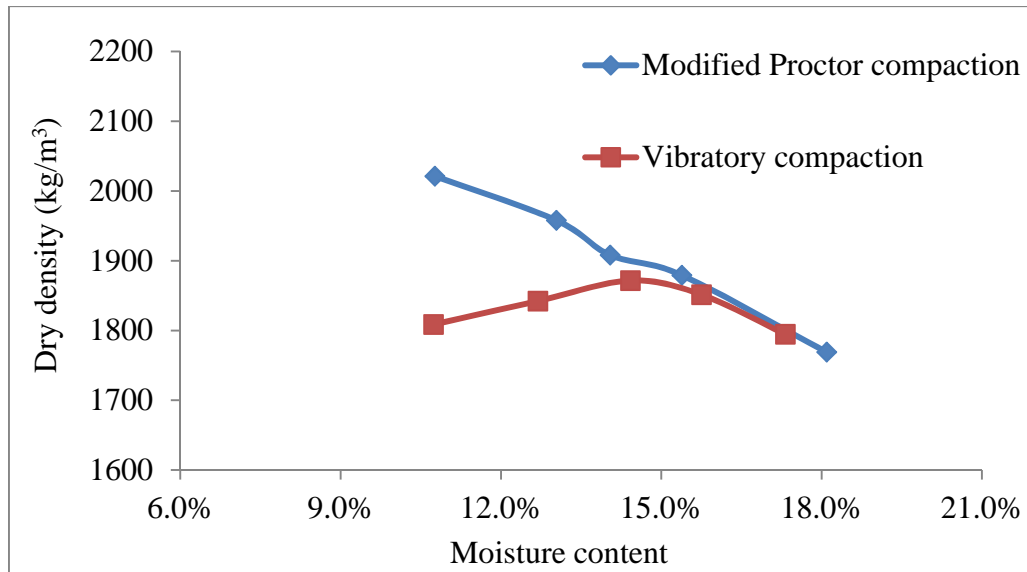
The comparison of the relationship between moisture content and dry density from the two compaction methods is presented in Figure 3.



1) Sand



2) Sandy clay



3) Clay

Figure 3: Comparison of relationship between moisture content and dry density for 3 types of soil and 2 compaction methods

Figure 3 clearly shows that the dry density of sand compacted by vibratory compaction is nearly 10% higher than the dry compaction resulting from the standard Proctor compaction. That is because when compacting the unbound sand materials by the Proctor test, the sand particles may move loosely under the impact of the hammer (the diameter of rammer is much less than the diameter of the mould) resulting in insufficient compaction. In contrast, the compaction with the vibrating hammer (the attached tamper almost fits the internal diameter of the mould) provides the confinement for the sand and the vibratory loading causes the soil particles to move into the denser configuration and hence reduces the voids in between them.

In contrast to this, the maximum dry density of cohesive soils (sandy clay and clay) is not achieved in the vibratory compaction but in the Modified Proctor test. It is also observed that through the vibratory compaction the surface of the compacted clay samples appears very porous. That is because the vibrating hammer can't supply sufficient compacting efforts to efficiently influence the particle arrangement of the cohesive soils which have a large amount of fines. Additionally, the cohesive soils both achieved the maximum dry density that corresponds to the optimum moisture content by vibratory compaction. In contrast, for the sand the curve of moisture and dry density remains stable and no obvious optimum moisture content is observed for both compaction methods. It indicates that the water content has no influence on the dry density of the uniformly graded sand. Besides, it should also be noted that the highest dry density was obtained for the sandy clay soil due to the well graded soil particles.

4.2 Mechanical test results on the compacted stabilized materials

1) Density of the stabilized samples

Figure 4 shows the density of the stabilized samples at the time of testing after 28 days curing. In the following graphs the compacted samples stabilized with cement and RoadCem are written as Soil-cement/RC.

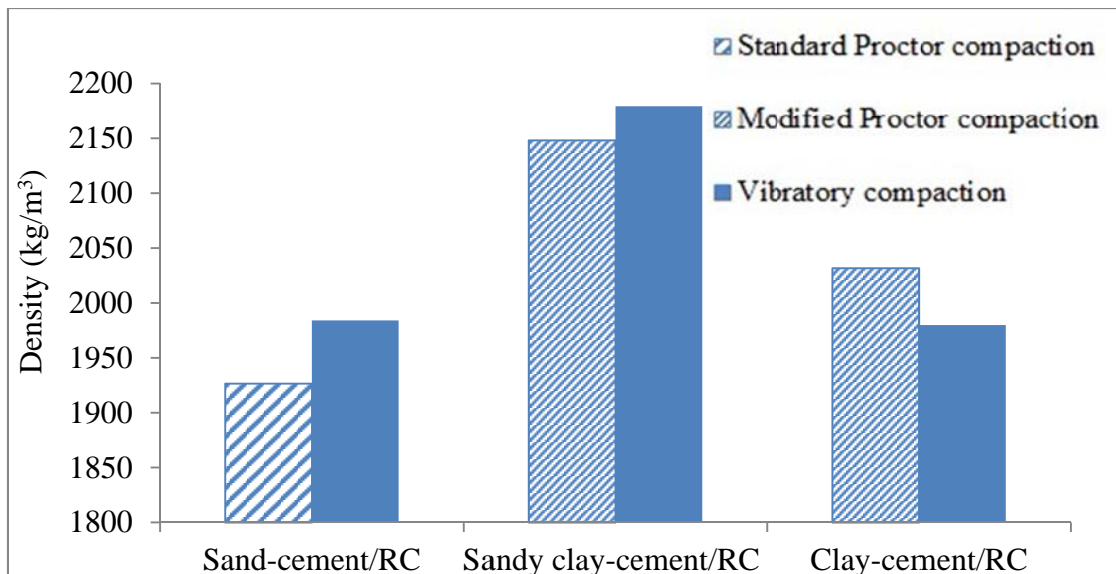
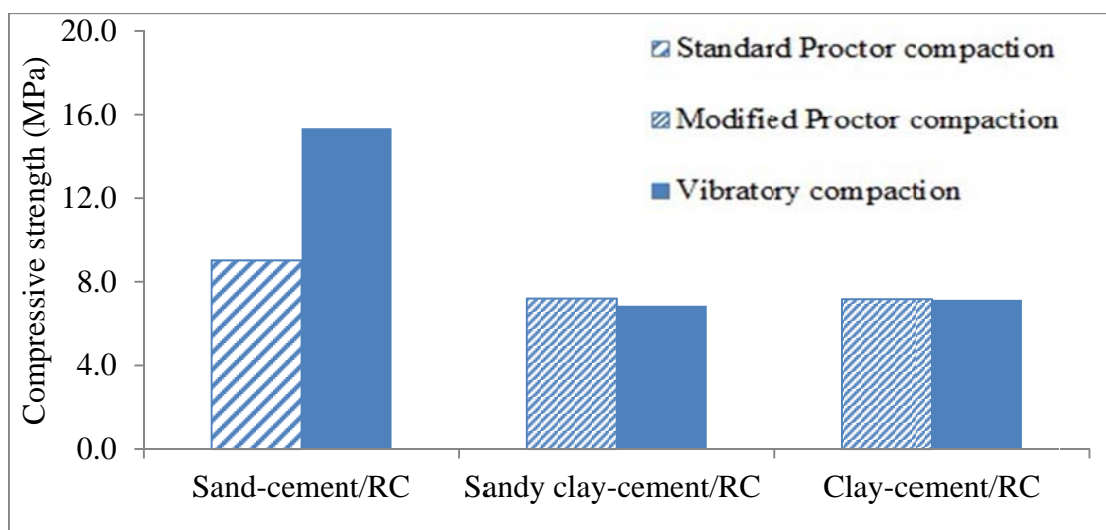


Figure 4: Density of stabilized samples at testing

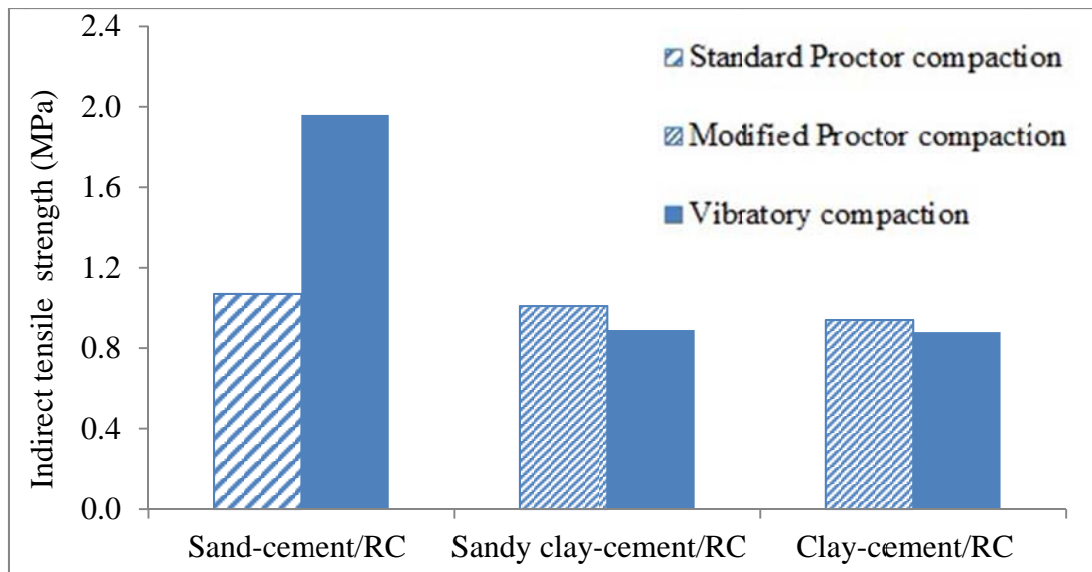
As can be observed from Figure 4, the density of cement stabilized sand and sandy clay materials achieved by using the vibratory compaction is slightly higher than the density using the Proctor compaction, which is 2.6% and 1.6%, respectively. That is because the vibratory compaction makes the fine particles of cement and clay filling in the voids between the sand particles, resulting in a dense particle arrangement. Compared with this, the cement stabilized clay exhibits a higher density from Modified Proctor compaction. So the vibrating hammer is more efficient in compacting the stabilized sandy materials than the clay materials because of the large amount of fines content present in clay. Moreover, the material of cement stabilized sandy clay achieves the highest density in comparison with sand-cement and clay-cement which is in agreement with the result of the unbound soil (shown in Figure 3).

2) Mechanical strength from two compaction methods

Figure 5 presents the experimental results of compressive strength and indirect tensile strength of cement stabilized soil, compacted with two different methods.



1) Compressive strength



2) Indirect tensile strength

Figure 5: Comparison of the mechanical strength from two compaction methods

As observed in Figure 5, the compressive strength and indirect tensile strength clearly show a similar trend. For sand-cement materials the compressive strength and indirect tensile strength obtained by using the vibrating hammer are approximately two times higher than those from the Proctor compaction. The strength results for sandy clay-cement and clay-cement however don't exhibit obvious differences between using these two compaction methods. Therefore, it can be concluded that the vibratory compaction can quite efficiently improve the final strength of cement stabilized sand materials than the traditional Standard Proctor test, which is more close to the field circumstances. The fact is that Nano based powders are due to the mass effect which shows in the field circumstances higher results estimated 25 ~ 40% (empirically monitored).

Another point that can be noticed is that sand-cement achieves the highest mechanical strength compared with the stabilized clayey materials owing to the fact that the larger the soil particle size, the higher the strength of cement stabilized materials. Moreover, a linear correlation between the compressive strength and the indirect tensile strength can be defined. The indirect tensile strength is approximately 12% of the compressive strength, independent of the compaction method in this study, which is in agreement with the literature review which indicates that the indirect tensile strength is about 10 to 15 percent of the compressive strength. Besides, in this study the soil type has no influence on this linear model.

5 IN SITU COMPACTION TEST

An appropriate compaction technique can greatly contribute to adequate long term performance of the pavement. In practice, due to the variability of the soil types, the execution of compaction must be achieved in order to prevent unexpected engineering problems. Namely, it is found that vibratory compaction may cause the redistribution of the moisture in the base course, which is demonstrated in Table 2. This result was obtained from the project of cement stabilized fine sand compacted by a 12 tons roller compactor in Hilvarenbeek, the Netherlands.

Table 2: Moisture content in the base field situation

Materials	Location	Compaction methods	Moisture content (%)	
			Before compaction	After compaction
Natural sand	Base surface	Vibratory	18	25.2
Natural sand	300 mm under surface	Vibratory	14	18.7
Sand-cement	300 mm under surface	Static	22.6	23

In Table 2, it can be seen that compaction has a big influence on the distribution of the moisture content throughout the base course. The moisture content of the soil increased by 30 ~ 40% after vibratory compaction. That is because the moisture goes up through the depth of the base course during the dynamic compacting process, resulting in the higher moisture content especially on the surface of the layer. Compared with this, the static compaction doesn't cause extreme variation in moisture content in the cement stabilized base.

6 CONCLUSIONS AND RECOMMENDATIONS

The presented results in this study can be summarized as follows:

- 1) As for the unbound sand materials, the vibratory compaction leads to a substantially higher density compared to the traditional Proctor test in the relationship between the moisture content and dry density.
- 2) In general, the vibratory compaction is also able to increase the density of the cement stabilized materials of sand and sandy clay.
- 3) For pure clay soil and the cemented clay, the vibratory compaction doesn't show obvious improvement.
- 4) By utilizing the vibrating hammer, both the compressive strength and the indirect tensile strength of cement stabilized sand are 2 times higher than by using the Proctor compaction, while no obvious difference is found in sandy clay-cement and clay-cement.
- 5) The vibratory compaction in the field construction can cause the redistribution of the moisture throughout the cement stabilized base course.

From the results of this research, the vibrating hammer is proven to efficiently improve the properties of the cement stabilized sandy materials. Therefore, it can be adopted as a promising and quick compacting method during the stabilizing process.

7 ACKNOWLEDGEMENT

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