# THE EFFECT OF THE CBR MOLD SIZE AND THE MAXIMUM AGGREGATE SIZE ON THE LOAD CARRYING CAPACITY OF BASE COURSE MATERIALS

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## ABSTRACT

*Many road failures have been noticed in eastern Saudi Arabia even for newly constructed roads. This could be related to the use of water sensitive calcareous base course materials or the inappropriate use of routine pre-qualification testing. The effect of testing procedures on the load carrying capacity of calcareous sediments (marls) was studied utilizing the CBR, Unconfined Compressive Strength and Clegg Hammer tests using two different marls. A large size compaction and CBR testing setup was used to study the effect of mold size and oversize particles on the load carrying capacity of the material. The results clearly showed that the maximum particle size, which was included in the specimens, has little effect on the CBR and Clegg Impact values. However, the mold confinement was found to produce an increase of about 100% in the CBR values. The oversize correction methods approximated the dry density of the entire material and produced density values close to those obtained using the large mold, with less than 2% tolerances. However, the AASHTO-1 and ASTM correction equations gave underestimated and overestimated density values, respectively, while AASHTO-2 equation and scalp and replace method gave accurate predictions.*

**Keywords:** *Calcareous sediments, road base, CBR, density correction, mold confinement.*

## الملخص

يلاحظ كثرة تدهور الطرق في المنطقة الشرقية للمملكة العربية السعودية وقد يحدث ذلك بعد الإنشاء بفترة قصيرة . وقد يُعزى ذلك إلي حساسية مواد طبقات الأساس الحجري الجيرية للماء أو عدم ملائمة طُرق الاختبار المتعارف عليها لتأهيل المواد . وقد تمت دراسة تأثير طُرق الاختبار على قوة تحمل التربة الجيرية ( المارل ) باستخدام اختبار نسبة تحمل كاليفورنيا، قوة الانضغاط غير المحصور و مطرقة كلج لنوعين من التربة الجيرية. وتم تحضير عينات اختبار نسبة تحمل كاليفورنيا في قالب اكبر حجماً من القالب القياسي بغرض دراسة تأثير اشتمال العينة على أحجار كبيرة الحجم وكذلك تأثير الحصر الناتج من جدار قالب الاختبار . وقد أثبتت النتائج أن الحد الأقصى لحجم الحجارة المشمولة في العينة كان له تأثير ضئيل على نسبة تحمل كاليفورنيا و مطرقة كلج ، أما الحصر الناتج من جدار قالب الاختبار فكان له تأثير قوي على قوة تحمل العينات ، حيث يُحدث زيادة في نسبة تحمل كاليفورنيا تقدر بحوالي 100%. كما دلت النتائج على أن المعادلات التي استعملت لتصحيح تأثير استبعاد الأحجار الكبيرة أعطت قيماً للكثافة ونسبة الماء قريبة من القيم التي أُوجدت باستعمال التدرج الكامل و التي تم تحضيرها في قالب الدمك كبير الحجم إذ لا يتعدى الفرق 2%. و من الملاحظ أن معادلة AASHTO-1 أعطت قيماً للكثافة ونسبة الماء أقل تقديراً ومعادلة ASTM أعطت قيماً اكثر تقديراً من القيم الفعلية، بينما أعطت معادلة AASHTO-2 وطريقة الإزالة والتبديل قيماً أكثر دقة من سابقتيها .

## 1. INTRODUCTION

Calcareous sediments, locally known as "marl", are commonly used in the eastern region of Saudi Arabia as base and subbase material for road and runway construction. The use of these materials for construction purposes is mainly due to the lack of good quality geomaterials within the region (Aiban et al., 1999). Calcareous materials have acute water sensitivity and their behavior under the prevailing environmental and loading conditions is quite variable and unsatisfactory. Despite the use of the international standards for characterization and strength determination for such materials, many problems in roads have been reported even when the material was designated as excellent-to-good as a base course material. The problems seem to be related to the applicability of the standards to the water sensitive material, the quality control of the final product in the field, the procedures used for utility trenches and the removal of oversize particles from the laboratory testing. Many flexible pavement failures are usually observed within a few months after construction. Typical road deteriorations are shown in Figure 1.


Figure 1. Typical road deterioration in the Dammam area (a) due to the use of water sensitive calcareous sediments as a graded base layer and (b) due to poor construction of utility trenches

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Marl soils are usually used as a base material after being processed and brought to a certain gradation. This may require the addition of crushed stones with different particle sizes. A growing confusion was observed among consultants about the suitability of the conventional testing procedures for these materials. This confusion is caused by the poor correlation between the laboratory and the field results, as a result of discarding the oversize particles from the laboratory samples and the use of the conventional CBR mold. The discrepancies between the field and laboratory results are observed for the same material and under the same testing conditions and the same quality control procedures. According to Aiban (1995), marl samples containing particle sizes up to ¾ in. (19 mm) have higher density and lower optimum moisture content values compared to those prepared using material passing ASTM sieve No. 4. Hence, it is expected that the field density will be higher than the laboratory value because of the presence of large size particles in the field. In addition, high percentages of oversize particles will influence the strength behavior of soils by the increase of stone-to-stone contacts. Winter et al. (1998) concluded that if the proportion of particles larger than 20 mm is greater than 45% to 50% then the stones will determine the behavior of the soil matrix. Furthermore, Garga and Madureira (1985) found that at gravel content of approximately 20–25%, particle interference begins to affect the compaction of fines. They tested materials containing up to 1¾ in. (45 mm) particles in a 9.4 in. (240 mm) diameter mold. The entire material tested using the standard plunger size, showed higher CBR values compared to the material, which was tested in the same mold but after replacement of the oversize particles by the same weight of material finer than ¾ in. and retained on No. 4 sieve.

Conventional laboratory test procedures usually require the removal of particles larger than a predetermined maximum size. This leads to inaccurate results and may need corrections. For example, in the unconfined compressive strength test, the largest particle size to be included in a specimen of diameter greater than or equal to 2.8 in. (71.1 mm) is one-sixth of the specimen diameter (ASTM D 2166). Similarly, for compaction test, when using the standard Proctor mold, which is 4 in. (101.6 mm) in diameter and 5 in. (127 mm) deep, only 20% or less by weight of the material retained on No. 4 (4.75 mm) sieve can be included (Proctor, 1933). However, for compaction in the CBR mold, which is 6 in. in diameter, 30% or less by weight of the material retained on ¾ in. (19 mm) sieve can be included (ASTM D 1557). Therefore, for material containing oversize particles, the correction for dry density and moisture content must be implemented in order to obtain equivalent values for the total material. Donaghe and Torrey (1994) suggested a ratio of specimen diameter (mold diameter) to the largest particle size of not less than 5 to 6, for the compaction test. However, Garga and Madureira (1985) obtained the maximum dry density values for gravelly soils in Brazil from a mold having a diameter eight times the maximum particle size after conducting the compaction using different mold sizes for the same compaction effort.

One of the most important factors that affects the results of the CBR test and causes discrepancies between field and laboratory results is the confinement provided by the mold. The confining effect of the rigid mold in which the laboratory tests are carried out may lead to CBR values many times greater than the in-situ tests. Black (1961) stated that the mold sides arrest the displacement of the soil along the shear surface produced by the CBR plunger for materials with an internal friction angle greater than 30°. According to Nataatmadja (1988), the CBR values obtained for different penetrations decrease with the increase in the mold diameter. Despite the variations between the field and laboratory CBR values, there is no reliable correction method to correct for the effects of mold confinement and maximum particle size included in the test specimen.

## 2. EXPERIMENTAL PROGRAM

### 2.1 Sample preparation and characterization

Two eastern Saudi marl samples were collected from different sources, which are still utilized for construction purposes within the region. The two marls were selected from different borrow areas in order to have some variation in the parameters (properties). The aggregates susceptibility to crushing was intended to be the major variable. Large quantity of each marl was sieved to separate different sizes. Each grain size was kept in separate container, and stored inside the laboratory in order to achieve stable initial moisture content values. All samples were then stored in plastic bags to prevent moisture changes. Preliminary characterization tests were performed to assess the basic engineering properties of the two collected marl samples. These preliminary tests included plasticity, grain size analysis, specific gravity, compaction, soaked and unsoaked California Bearing Ratio, Los Angeles abrasion, sand equivalent and soundness of aggregates.

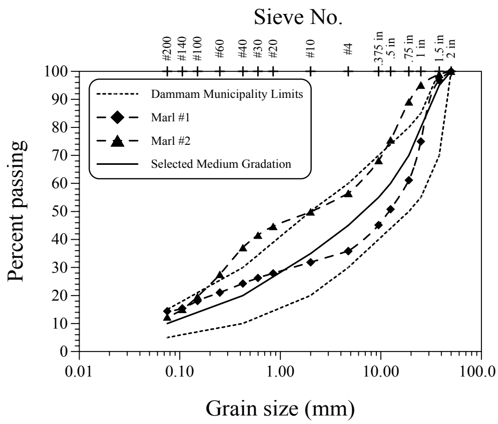


Figure 2. Grain size distribution of the collected materials and the selected gradation for the testing program

Samples for density, UCS and CBR tests were reconstituted to the medium gradation shown in Figure 2, which is an intermediate gradation falling between the limits of the Dammam municipality. This was done to eliminate the effect of gradation for both marls. For the conventional (using the standard CBR mold) tests, compaction processes for all samples were conducted following the scalp and replace method (ASTM D 1557, 1991) to correct for the elimination of oversize particles (particles retained on the ¾ in. or the 19 mm sieve). For the large size mold, the moisture-density relations were obtained using two different sets for each marl type. The first set was prepared using the scalp and replace method, which is used for the conventional "modified Proctor" setup, while the second set was prepared using the actual gradation, which includes all sizes up to 2 in. (50.8 mm).

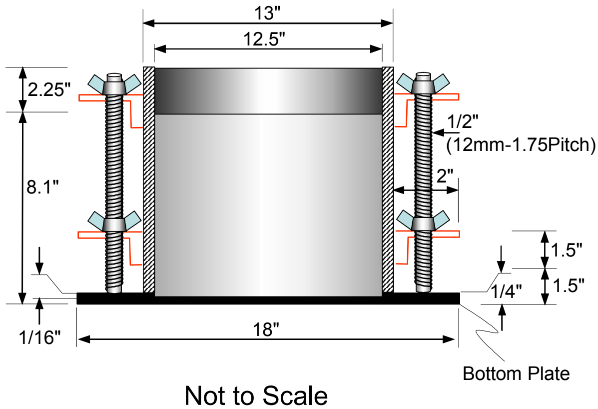


Figure 3. The large-size mold and accessories

## 2.2 Testing program using conventional methods

Compaction tests and unsoaked CBR tests were performed for each marl on two different sets. The first set was prepared using scalp and replace method. The second set was prepared using the elimination method, where the material retained on the ¾ in. (19 mm) sieve was excluded and the test was performed on material passing the ¾ in. (19 mm) sieve without replacement. The compaction test was repeated for each marl, in order to study the repeatability of the results. Samples were reconstituted to the selected (medium) gradations. All CBR tests were conducted in accordance with ASTM D 1883 for specimens compacted following the ASTM D 1557 procedure. The consistency of the testing conditions and its effect on obtaining reproducible results was investigated by repeating the CBR tests for each marl.

Samples for the unconfined compressive strength test were prepared in a steel cylindrical mold with a height of 8 in. (203 mm) and a diameter of 4 in. (102 mm). The mold size allows for particles ¾ in. (19 mm) in diameter. In order to achieve an appropriate similarity between the modified Proctor compaction method and the compaction in the UCS mold, samples were compacted in the UCS mold in five layers, and the compactive effort was applied by dropping a 10 lb (4.54 kg) hammer from a height of 18 in. (457 mm). It was found that 32 blows on each layer were adequate to produce a dry density identical to those obtained using the CBR mold.

The Clegg hammer consists of a falling part with the same shape and size of the modified Proctor rammer. It is equipped with a piezoelectric accelerometer, which is connected to a digital measuring device. The dynamic rebound of the soil against the falling weight of the hammer is recorded as the Clegg Impact Value (CIV) of the specimen (Asi et al., 1992). The test was performed on the marl samples right after the CBR test was finished. The specimens tested for CBR were inverted so that the surface of the specimen tested by the Clegg Impact Hammer was not the one used for the CBR test.

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### 2.3 Testing program using large size setup

In this experimental research program, new compaction and CBR testing procedures were used. This was achieved by modifying the traditional compaction machine and the modified Proctor mold in order to perform the tests on samples accommodating particles up to 2 in. (51 mm). The setup is shown in Figure 3. While developing the new method, many features of the conventional procedure were maintained. The modified compaction methodology was used throughout the testing program and a compactive effort approximately equivalent to the modified Proctor was maintained. This was achieved using a sector shaped hammer and a drop height of 18 in. (457 mm). The system was calibrated several times in order to achieve the same results (mainly dry density) produced by the conventional method for the same soil gradation and water content.

### 2.4 Commonly used oversize correction methods for the dry density

***a) Scalp and replace method:***

In this method, the material retained on the ¾ in. (19 mm) sieve is excluded from the sample and then replaced with the same mass of material passing the ¾ in. (19 mm) sieve and retained on the No. 4 sieve.

***b) ASTM equation:***

The American Society for Testing and Materials (ASTM) suggested the following equation to correct for discarding the oversize particles from the test specimen:

$$D = \frac{\gamma_w}{\dfrac{P_c}{G_m} + \dfrac{\gamma_w (1 - P_c)}{D_f}} \qquad (1)$$

***c) The AASHTO equations:***

The American Association of State Highway and Transportation Officials (AASHTO) suggests the following empirical equation to correct for the absence of the oversize particles in the tested specimen:

$$D = (1 - P_c) D_f + 0.9\, P_c\, (\gamma_w) G_m \qquad (2)$$

However, for better predicted values, AASHTO suggests the following equation:

$$D = \frac{\gamma_w}{\dfrac{P_c}{G_m} + \dfrac{\gamma_w (1 - P_c)}{r_a\, D_f}}$$

where:

$D$ = dry density of the total soil

$D_f$ = dry density of the fine material (material passing the ¾ in. or 19 mm sieve)

$P_c$ = percent rock by weight (decimal)

$G_m$ = bulk specific gravity of rock

$r_a$ = correction factor in AASHTO equation to account for interference of large aggregate values or range

$\gamma_w$ = unit weight of water

## 3. RESULTS AND DISCUSSION

### 3.1 Preliminary characterization

The gradations for graded base material of both marls are shown in Figure 2. Generally, Marl #2 shows finer gradation when compared to Marl #1. Marl #1 is classified as GM according to USCS system and as A-1-a according to AASHTO system. However, Marl #2 is classified as SM according to USCS system and A-1-b according to AASHTO system. Marl #1 shows higher average specific gravity, plasticity index, maximum dry density, unsoaked CBR value and percent wear (using Los Angeles Abrasion Machine). However, Marl #2 shows higher maximum soaked CBR value, sand equivalent and percent loss (by disintegration using sodium sulfate solution). The classification of the two samples and some of their characteristic parameters are shown in Table 1.

Although the percent passing the ASTM No. 200 sieve were almost similar for both marls, Marl #1 showed a plastic behavior, which was absent in Marl #2. In addition, it was observed that the percent loss by weight was higher in Marl #1, compared to Marl #2, when using a mechanical abrasive agent (steel balls in the Los Angeles Abrasion Test) but it was lower when using a chemical disintegrating agent (sodium sulfate in the Soundness Test).

### 3.2 Testing program using conventional methods

*3.2.1 Compaction test*

In order to check whether the obtained results are reproducible under similar testing conditions, compaction of samples reconstituted to the specified gradation was repeated for the two marls. The results are shown in Figure 4. For both marl samples, the maximum difference between the dry density values was found to be 0.013 gm/cm$^3$, which indicates good repeatability of results.

Table 1. Classification and characteristic properties of the collected marls

| Property | Designation | Marl #1 | Marl #2 |
|---|---|---|---|
| Classification | USCS | GM | SM |
| | AASHTO | A-1-a | A-1-b |
| Specific Gravity (for fine fraction) | ASTM D 854 | 2.71 | 2.71 |
| Specific Gravity (for coarse fraction) | ASTM D 127 | 2.46 | 2.47 |
| Weighted Average Specific Gravity | | 2.61 | 2.54 |
| Liquid Limit (LL) | ASTM D 4318 | 18.1 | Non-Plastic |
| Plastic Limit (PL) | ASTM D 4318 | 14.2 | Non-Plastic |
| Plasticity Index (PI) | | 3.9 | Non-Plastic |
| Maximum Dry Density (g/cm$^3$) | ASTM D 1557 | 2.26 | 2.23 |
| Optimum Moisture Content (%) | ASTM D 1557 | 5.5 | 5.8 |
| Maximum Soaked CBR (%) | ASTM D 1883 | 138 | 243 |
| Maximum Unsoaked CBR (%) | ASTM D 1883 | 278 | 258 |
| Percentage Wear | ASTM C 131 | 41 | 33 |
| Percentage Weight Loss | ASTM C 88 | 4 | 8 |
| Sand Equivalent | ASTM D 2419 | 15 | 27 |

### *3.2.2 California bearing ratio (CBR) test*

The CBR test was repeated for samples prepared with the specified medium gradation, for both marls, in order to check whether the results obtained are reproducible under similar testing conditions. The CBR results presented in Figure 5 show that For Marl #1, the maximum difference between the CBR values was 19% (7.4% of the average value of the two readings). Similarly, the CBR values for marl #2 gave a maximum difference between the two sets of 23% (9.4% of the average value of the two readings). The CBR results clearly show the effect of plasticity where on the wet side of optimum, the CBR for marl #2 (non-plastic) was much higher than the corresponding values for marl #1, which has some plasticity. This is mainly due to the effect of water on reducing the cohesion. However on the dry side of optimum, the plastic marl (marl #1) at low moisture content produced higher CBR values compared to the non-plastic marl (marl #2) mainly due the increase in cohesion as the moisture content decreases. Such increase in cohesion values will not be obtained for the non-plastic material. It is observed that the dry density curves are more reproducible than the CBR curves, due to the sensitivity of the CBR test to the presence of stony particles near the plunger.

### *3.2.3 Unconfined compressive strength test*

In order to study the load carrying capacity of the collected marl soils for different gradations, a more reliable test is needed to supplement the CBR results. The variations of the UCS with

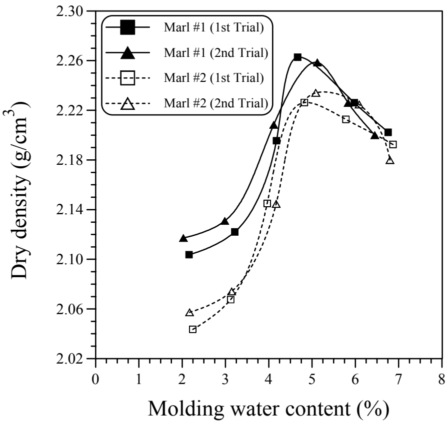


Figure 4. The moisture-density relationships for both marls using two trials

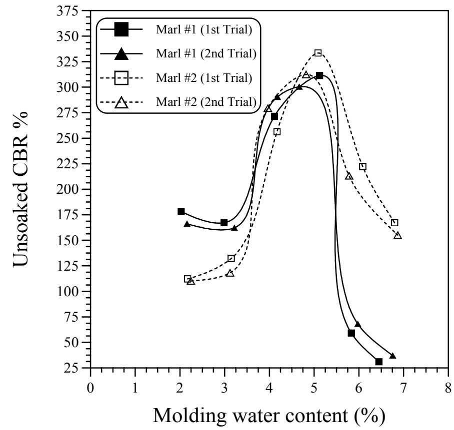


Figure 5. The CBR-moisture relationships for both marls using two trials

the molding moisture content for both marls are shown in Figure 6. It is observed that, for both marls the maximum UCS values, for the samples prepared using the selected medium gradation, were obtained at relatively low moisture contents i.e. on the dry side of optimum. It is noticed that the on the dry side of optimum the UCS was higher for marl #1, which has some plasticity, compared to marl #2 due to the increase in cohesion for marl #1 at low moisture content values.

*3.2.4 The effect of molding water content*

It is clear from the CBR and UCS curves plotted in Figures 5 and 6, respectively, that Marl #1 has higher strength characteristics, compared to Marl #2, on the dry side of optimum. However, this is reversed on the wet side. This phenomenon is attributed to the plastic behavior of Marl #1 since the cohesion of calcareous soil is highly dependent on the molding water content as stated by Aiban (1995). It is also known the UCS is dependent more on the cohesion of the material due to the lack of confinement, which enhances the frictional component more than the cohesion component.

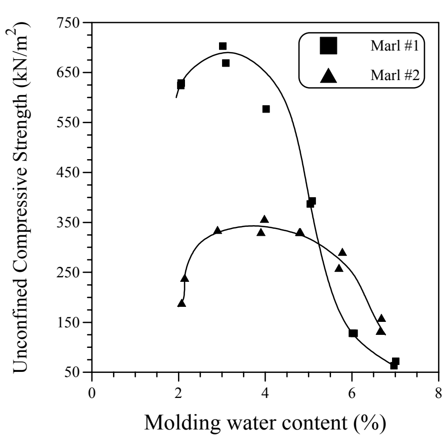


Figure 6. The UCS-moisture relationships for both marls

**3.3 Testing program using large size setup**

*3.3.1 Compaction test*

For the two marls, a maximum difference of less than 0.025 gm/cm$^3$ was observed between

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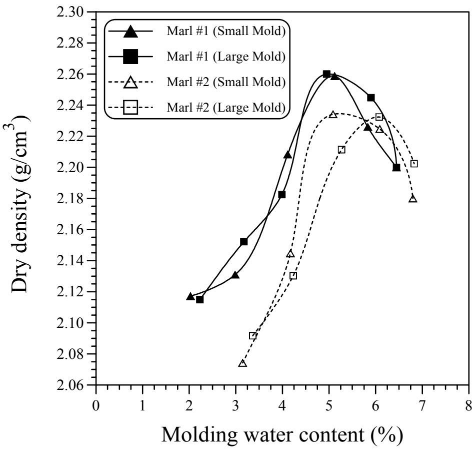


Figure 7. The moisture-density relationships for both marls using both molds

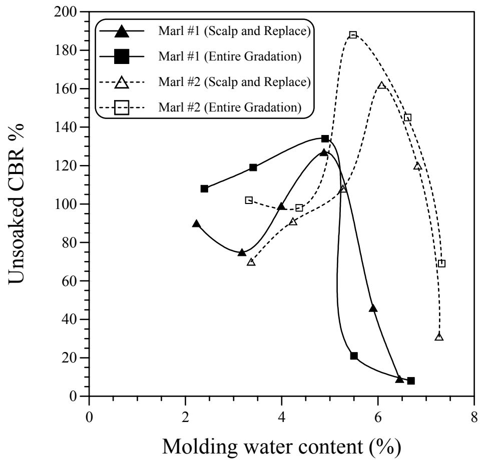


Figure 8. The CBR-moisture relationships for both marls using the large mold

the dry densities obtained, using the modified Proctor mold and the large size mold, for material prepared using scalp and replace method, as shown in Figure 7. Such difference is small compared to the value of 0.06 gm/cm$^3$ reported by Donaghe and Townsend (Garga and Madureira, 1985). As shown in the figure, the large and small setups gave almost equal dry density values. Therefore, the large setup can be used as a possible replacement of the small setup. This has an advantage where larger particles can be included in the specimen prepared in the large mold. The entire gradation was used for both marls when reconstituting the soil into the selected medium gradation, but without discarding any of the large particles.

### *3.3.2 California bearing ratio test*

The CBR-moisture relationships for both marls, for samples prepared using both scalp and replace method and the entire gradations, are shown in Figure 8. It is clear that the material prepared using the entire gradation (without excluding the oversize particles) has higher maximum CBR values. An increase of 16% and 5.5% in the maximum CBR values for marls 1 and 2, respectively, resulted when using the entire gradation instead of the scalp and replace method. This little increase is caused by the presence of the large particles in the samples. It is clear that the difference between the CBR values for the two curves is more clear on the dry side of optimum moisture content, while on the wet side of optimum the curves approach each other due to the presence of excess water, which will reduce the effective strength of the sample and soften the connectors and filler. Hence, the inclusion of coarse particles will not have significant effect on the strength at high moisture content values.

The CBR values for specimens compacted using scalp and replace method, and small and large molds, are shown in Figure 9, for both marls. A sharp decrease in the CBR values is

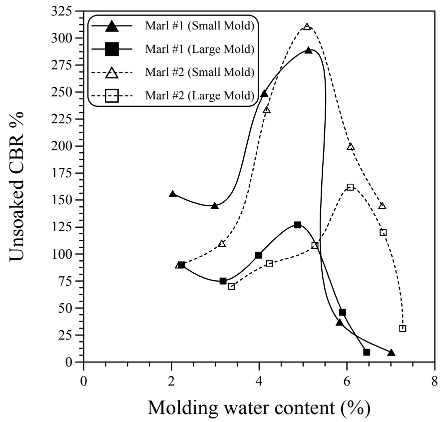


Figure 9. The CBR-moisture relationships for both marls using the conventional and large size molds

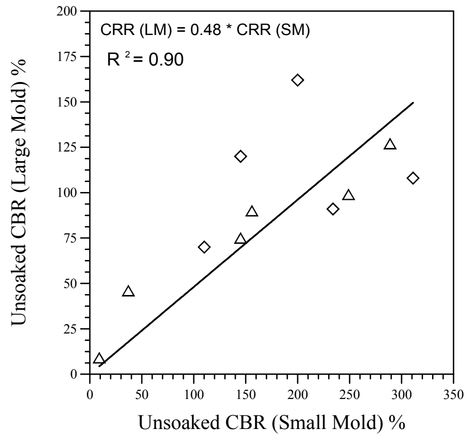


Figure 10. The correlation between the CBR values obtained using both molds for both marls

observed when using large molds as compared to the same material tested using the small mold. For Marl #1, the maximum CBR obtained from the small mold was 289% while maximum CBR value obtained from the large mold did not exceed 127%. This corresponds to a decrease of about 56% in the maximum CBR value obtained from the conventional mold. Similarly, for Marl #2, the maximum CBR value obtained from the small mold was 311% and the maximum CBR value obtained from the large mold was 162%. This gives a decrease of about 50% in the maximum CBR value when using the large mold. This remarkable difference between the two curves is attributed to the effect of mold restraining effect or confinement in the case of small mold, which is absent or at least reduced when the large mold was used. However, it should be noted that the differences in the CBR values obtained from the small and large molds were reduced on the wet side of optimum, for both marls.

The CBR data are summarized in Figure 10 for the large and the conventional molds for the two marls. The relation between the CBR of the two molds clearly indicates that an average reduction in the CBR value of 52% is noticed when using the large mold. This confirms that the laboratory data need to be adjusted when used for field samples. Furthermore, this difference could be a major cause for road failures since the design is based on the laboratory results.

### *3.3.3 Clegg hammer test*

Clegg hammer tests were performed on samples prepared in the large mold to study the effect of the maximum particle size on the CIV values. The Clegg hammer tests were conducted on samples prepared using scalp and replace method in addition to samples prepared using the entire gradation. The CIV-moisture relationships for the two marls prepared using the selected medium gradation are shown in Figure 11. The material prepared using the scalp and replace method shows higher maximum CIV value compared to the material prepared using the entire gradation. However, the variations of the values are highly dependent on the moisture content values. Generally, the differences between the CIV values obtained from the two preparation methods are small when compared to those for the CBR values. Hence, the CIV show less sensitivity to the maximum particle size compared to the CBR value. This supports the data obtained by the CBR test on similar samples as shown in Figure 8.

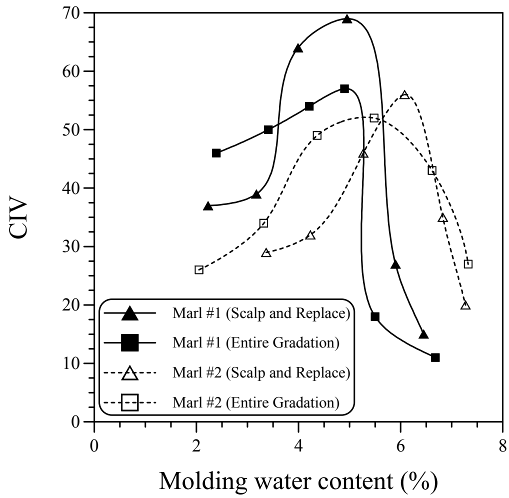


Figure 11. The CIV-moisture relationships for both marls using the large mold

### 3.4 Comparison between the commonly used correction methods

The moisture-density curves obtained using different empirical methods as well as the experimental curves for both marls are compared together in Figures 12 and 13 for the two marls. Results clearly show that the scalp and replace method and the AASHTO-2 equation gave good approximation for moisture-density relationships, obtained for the entire material. For the scalp and replace method, the maximum differences between the densities were 0.04% and 0.9% for Marl #1 and Marl #2, respectively. For AASHTO-2 equation, the maximum differences were 0.04% and 0.9% for Marl #1 and Marl #2, respectively. However, the ASTM equation gave overestimated values and the maximum differences between the dry density values obtained were 1.5% and 1.12% for Marl #1 and Marl #2, respectively. On the other hand, the AASHTO-1 equation and the elimination

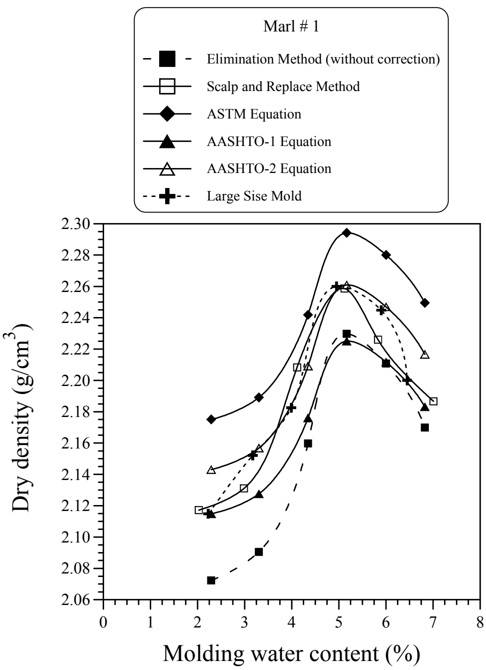


Figure 12. The moisture-density relationships for Marl # 1 using different correction methods

method gave underestimated density values. The maximum differences between the dry density values obtained using the AASHTO-1 equation and the large mold, were 1.54% and 1.88% for Marl #1 and Marl #2, respectively. Results clearly indicate that the scalp and replace method and the AASHTO-2 equation can give adequate predictions for dry density values obtained from the large size mold.

By comparing the differences between the maximum dry densities obtained using the correction methods and using the entire material compacted in the large mold, it is found that the maximum difference obtained from all methods is less than 2% of the maximum dry density obtained from the large size mold. Hence, the correction methods used can be adopted for calcareous soils, however, ASTM equation and AASHTO-1 equation gave overestimated and underestimated density values, respectively and not as accurate as AASHTO-2 method.

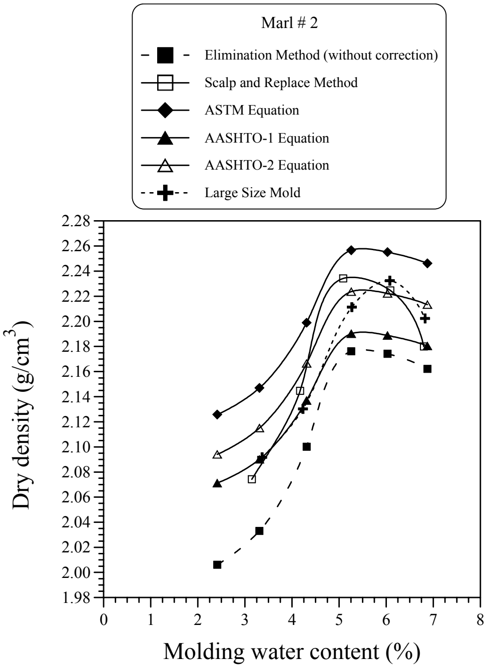


Figure 13. The moisture-density relationships for Marl # 2 using different correction methods

## 4. CONCLUSIONS

1. The assessment of the load carrying capacity of marl soils using one testing procedure may give misleading results, especially when the testing methodology requires some modifications on the soil gradation. Hence, different testing procedures need to be performed in order to have better engineering judgment.
2. The maximum particle size, which is included in the specimens, has little effect on the strength, when using conventional testing procedures, such as the CBR and CIV tests.
3. The strength of the tested marls is extremely sensitive to the molding moisture content. There was remarkable loss of the bearing capacity as a result of increasing the moisture content beyond the optimum values, especially for samples with plastic fines.
4. The mold confinement was found to have a significant effect on the CBR values. More than 100% increase can occur on the CBR values as a result of mold confinement.

5. The AASHTO-2 equation, for oversize correction, was found to give the best prediction for the maximum dry density of the entire material while AASHTO-1 equation failed to predict the maximum dry density of the total material.
6. Scalp and replace method was found to be an adequate oversize correction method. However, it gave slightly lower maximum dry density and optimum moisture content values compared to those obtained for the entire material.

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