CBR ACCURACY IN QUESTION

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ABSTRACT

When soil samples are prepared for density and CBR testing the procedure requires that aggregate larger than 19 mm be replaced by crushing the oversize material to less than 19 mm. Depending on the magnitude of the oversize material so treated and the manner of the crushing process the resulting density and CBR values obtained from duplicate tests may vary considerably and misrepresent the actual properties of the soil. The aim of the paper is to investigate the influence of oversize replacement (OR) on the laboratory CBR. The variations in maximum density and CBR that oversize replacement affect for materials with oversize fractions ranging from 20 to 40% are significant. Materials with large fractions greater than19 mm should not be tested for CBR as a strength criterion but should be treated in the manner of crushed stone materials by compacting to a specified solids ratio.

1. INTRODUCTION

The California Bearing Ratio (CBR) test is used extensively to assess the probable field strength of a road foundation layer by relating its field density relative to a maximum laboratory density, (termed Relative Compaction, RC), to which a soaked CBR value has been assigned. By performing a soaked CBR test on samples of field material moulded to different relative compaction from 100% down to 90% of maximum density, a range of CBR strengths for different densities of the material is prepared in the form of a CBR/RC graph. (When the term CBR appears in this text it shall be deemed to mean the soaked CBR condition)

For the preparation of this range of CBR values versus RC for a given material the following operations are generally performed in a soil testing laboratory in accordance with the methods as laid down in TMH1(1986):

- Preparation of representative samples.
- Up to 10 samples may be required.
- Determination of maximum density.
- Generally Modified density.
- CBR tests
- Normally on three samples each compacted to a different density.

As the field strength assessment is dependent on the CBR/density relationship prepared in the laboratory, it is surely essential that he laboratory material represents the field material and that the test procedure gives consistent and reliable results.

The aim of this paper is to investigate the influence of oversize replacement on the laboratory CBR. It is a report of a study made by the writer of data obtained from the results of routine testing of field materials for a road improvement construction made available to him and are not from more desirable specially prepared samples from a single stock. It is probable that the materials studied may differ in particle relative density.

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2. PREPARATION OF TEST SAMPLES

In Methods A7 and A8 of TMH 1(1986) for the determination of maximum density and CBR for gravel and sand, under *Preparation* ,the following is stated: "The aggregate retained on the 19 mm sieve is crushed lightly by means of a steel tamper (or laboratory crusher) to pass the 19 mm sieve and added to the portion passing the sieve. Care should be taken that the aggregate is not crushed unnecessarily small".

As the density and CBR tests done in the manner prescribed in TMH 1 are done in moulds of 152 mm diameter it is generally considered impracticable to include aggregate particles greater than 19 mm in diameter and the above crushing of such oversized aggregates is a necessary requirement in the preparation of samples.

3. A THEORETICAL APPROACH

In order to avoid any confusion the following symbols and terms are defined:

CBR The bearing capacity of a moulded soil sample after soaking it for 4 days.
D Density of a moulded soil sample.
RC Relative Compaction: density of a moulded soil to that of modified density.
L Solids Ratio: the bulk volume of solids to the total volume of a soil mass.
N Porosity: the volume of voids to the total volume of a soil mass
E Voids Ratio: volume of voids to bulk volume of solids (= N/L).
OR Oversize Replacement: the fraction of material greater than 19 mm in diameter replaced by crushing it to less than 19 mm in the preparation of samples for moulding

Material containing an appreciable amount of aggregate larger than 19 mm, after the above treatment may thus no longer represent that in the field. When spheres of equal size are packed in the tightest tetrahedral fashion the porosity, N, cannot be less than 30%. This implies that by crushing say Z% oversize aggregate to produce only material between 13.2 and 19 mm, in a compacted mass of the prepared gravel the voids will exceed by Zx30%, that of an uncrushed sample compacted under equal effort. Depending on the amount of fines produced during the crushing process this excess in voids will be reduced as these fines will tend to fill the excess voids produced by the OR but will nevertheless still exceed that of the untreated material (see appendix). The larger the fraction Z of solids greater than 19 mm in a given material the greater the treated sample will differ from the original by the resultant increase in voids.

A well graded gravel can readily be compacted to a solids ratio of say 83% or to a porosity N, of 17% or voids ratio E, of 20,4%, If the gravel has 35% of its mass larger than 19 mm in diameter, the volume of this portion would also be 35% of the aggregate volume. If this volume of oversize material was carefully crushed to between 19 and 13,2 mm in diameter the voids increase in the compacted material would be 0.3 x 35% = say 10% under the same compactive effort, resulting in an increase in total volume of 10%. But the volume of the aggregate remains unchanged. The solids ratio decreases to: L = 83/11o = 75,5% and the voids ratio, E, now increases from 20,4% to 32,5%.It is thus evident that the OR operation can result in an increase in porosity, causing a decrease in the solids ratio and an increase in voids ratio and a corresponding decrease in moulded density. The extent of these changes will depend on the degree of fines produced by the OR operation, as well as on the degree of oversize aggregate treated.

In the preparation of samples for duplicate tests the OR process can not only result in a CBR less than the true non-OR CBR but variations in the fines produced can result in a variance in duplicated CBR test values. It is this variance in CBR values which forms the main object of this study.

A good grading and high degree of compaction will give a low voids ratio and a high strength i.e. high solids ratio L, and high CBR. Thus, in theory, for a given soil with a given grading the CBR is directly related to the density. That is to say: for a given material, the ratio of any two densities is equal to a function of their corresponding strengths or CBR .In mathematical terms: $CBR_2/CBR_1 = f (D_2/D_1) = f (RC) = f (L_2/L_1)$. Savage (2012) established this relationship as follows:

$$CBR_2 = CBR_1 (D_2/D_1)^9 = CBR_1 (RC)^9 = CBR1 (L_2/L_1)^9 \qquad (1)$$

The validity of this relationship is also examined.

4. LABORATORY TEST REPORTS

The writer had access to a broadsheet of soil test results produced by an accredited soils laboratory prior to a road widening construction. The existing pavement had been in service for over 15 years and exhibited no foundation failures which confirmed that the materials forming the foundation were of good quality and provided excellent strength to carry the heavy truck traffic using the road. Some hundred and twenty material samples had been tested and the results recorded.

A study of the grading results showed that many of the samples contained aggregates up to 53 mm or more in diameter and that the fraction above the 19 mm sieve ranged in the order of 15 to 40%.Other materials had none or only a few particles above the critical 19 mm size. These records presented an excellent opportunity to examine the effect of crushing oversize material to pass the 19 mm sieve (Oversize Replacement, OR) on the determination of maximum density and CBR. Although samples for testing may have identical initial gradings, the crushing of oversize aggregate may not always produce material less than 19 mm of identical grading. The resultant CBR values of these samples may vary considerably. It was felt that the data presented by these laboratory tests albeit not extensive would certainly help to provide some form of answer to the following question:

> Although it is accepted that tests for maximum density and CBR done repeatedly on the same material would produce an acceptable variation both in density and CBR, to what extent if any would OR affect this variation?

From the available test results four groups were selected, each of which was made up of three or more samples with virtually the same gradings and which fell within the following limits:
- Material with no aggregate larger than 19 mm
- Material with 20% of its mass between 19 and 37,5 mm
- Material with 30% of its mass between 19 and 37,5 mm
- Material with 40% of its mass between 19 and 75,0 mm

From a study of the maximum densities and CBR values recorded for the materials within each of these groups it was hoped to achieve some form of answer to the above question.

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The writer wishes to make it quite clear that no attempt is made or intended in any way whatsoever, by this study to discredit the validity or the accuracy of the laboratory records in which he has full confidence. The variations reported in this investigation are deemed to be entirely due to the vagaries of the materials tested and do not in any way reflect faulty or inaccurate testing.

5. VARIATIONS IN MAXIMUM DENSITY AND CBR

In order to establish the range of variation in the determination of maximum density and CBR without the application or OR,, the group containing only aggregate less than 19 mm was first examined.

5.1 Variations for <19 mm gravel

The only material falling below a maximum size of 19 mm was from that making up the shoulder material and consequently maximum densities and CBR values would tend to be on the low side. Three examples of practically identical gradings were identified and their corresponding maximum Modified density and CBR values at different RC noted. The gradings and CBR values are shown in plotted form in Figure 1.
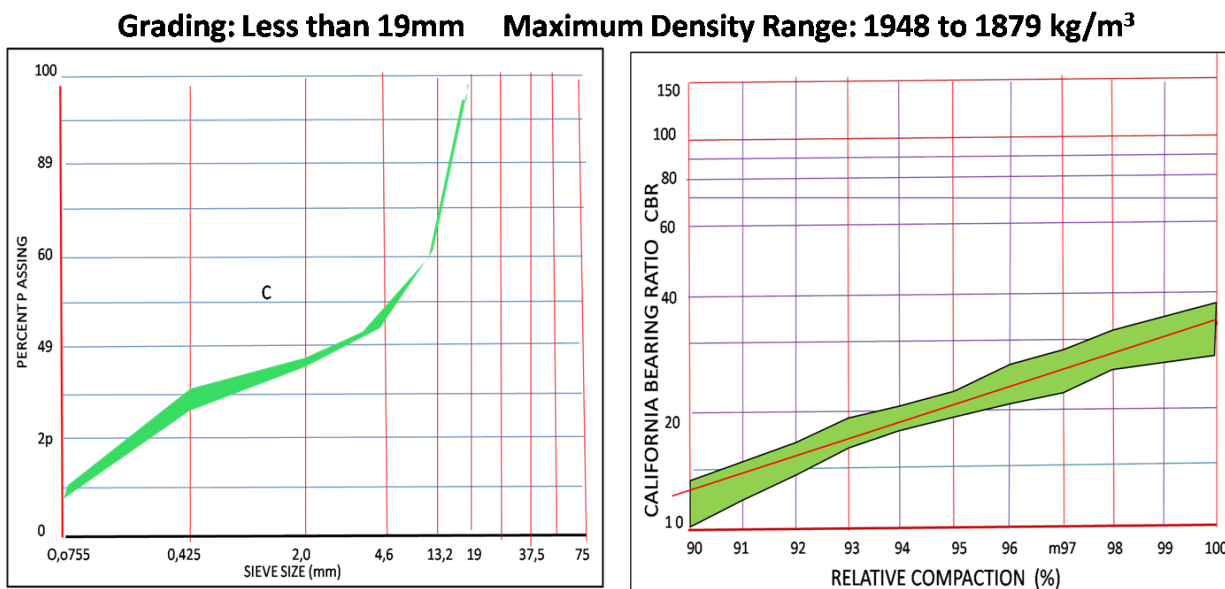

Grading: Less than 19mm   Maximum Density Range: 1948 to 1879 kg/m³

Fig.1 Density, grading and CBR values for material requiring no Oversize Replacement

From a study of the figure the following can be observed:

- The material was not treated for Oversize Replacement.
- The grading of the different materials can be considered as virtually identical.
- The maximum density variation is only 31 kg/m^3 or 0.8% from the average density.
- The variation in CBR values is in the order of 14 to 20% from the average, with the larger variation at RC equal to 90%; this variation is considered as acceptable for CBR evaluation

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It is interesting to note that if the mean maximum CBR of 36 is substituted for CBR_1 in equation (1)) above a value for CBR_{90} at 90% of the maximum density would be given by:

$CBR_{90} = 35(90/100)^9 = 13.2$

This is virtually equal to the mean of 12.5 determined by the laboratory tests as shown by the red line which depicts equation (2) in the right hand graph in Figure 1.

5.2 Variation for material with 20% aggregate between 19 and 37,5 mm

Samples of shoulder material having similar grading but with only 20% greater than 19 mm were examined for density and CBR variation. Figure 2 reflects the grading and CBR values far RC between 90 and 100%.
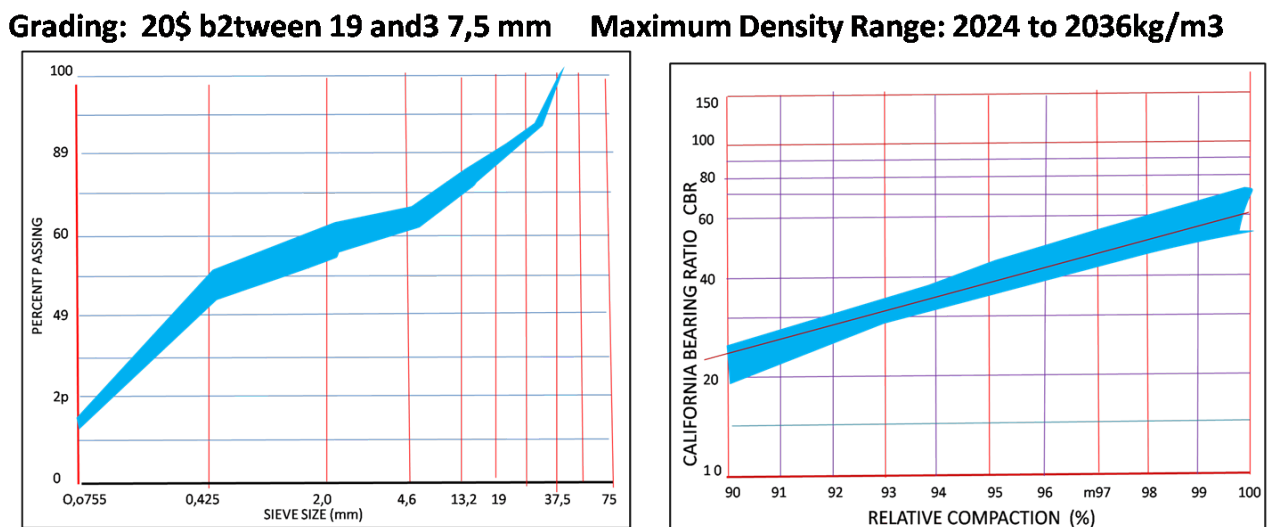
Grading: 20$ b2tween 19 and3 7,5 mm   Maximum Density Range: 2024 to 2036kg/m3

Fig.2 Density, g,rading and CBR values for material with 20% treated for Oversize Replacement

A study of Figure 2 shows the following:

- Some 20% of the aggregate was treated for OR.
- The original gradings were not fully identical but still within reasonably acceptable limits of variation.
- The range in maximum density is 12kg/m^3 or 0,3% from the mean
- The variation in CBR values is in the order of 14 to18% from the mean with the larger variation also at the lowest RC value.
- The laboratory mean CBR at RC equal to 90%, (CBR_{90LM}) is 22 and the mean CBR_{90cm} calculated by means of equation (1) and the mean CBR at Mod density, CBR_{100LM} equal to 62 is given as:

$$CBR_{90CM} = CBR_{100LM}(RC_{90})^9 = 62 \times o,9^9 = 24 \qquad (3)$$

5.3. Variation for material with 30% aggregate between 19 and 37,5 mm

Three examples of equally graded base material with a maximum size of 37,5mm were studied. Their grading is shown in Figure 3. The field of variation in CBR at different relative densities is also shown. The dotted envelope around the grading curve is a Fuller envelope and confirms the high quality of the grading which is also of a crushed stone standard. A study of Figure 3 shows the following:

- The variation in maximum density is 55kg/m^3 or some 1,3% from the mean density.
- Some 30% of the aggregate was treated for OR.
- The original gradings were almost identical but after OR could be very different.
- The variation in CBR values is from about 20% from the mean for RC above 95% but then increases to about 43% at RC = 90%. Here again the greater variations are at the lower RC values.
- Here CBR_{90LM} is 42 and CBR_{100LM} is 95, from which CBR_{90CM} = 39.

Grading: 30$ b2tween 19 and37,5 mm   Maximum Density Range: 1979to 2034kg/m3
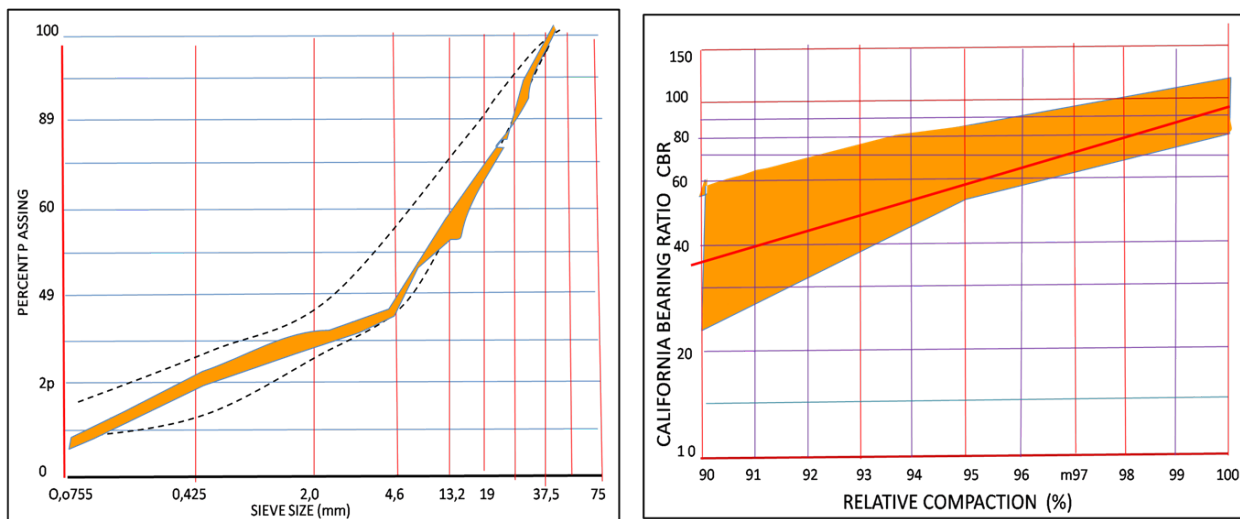

Fig.3 Density, grading and CBR values for material with 30% treated for Oversize Replacement

5.4 Variation for material with aggregate 40% between 19 and 75 mm

Five examples of virtually equally graded base material with a maximum size of 75mm were studied for CBR variation and their grading is shown in Figure 4. The field of variation in CBR at different relative compaction is also shown. The dotted envelope around the grading curve is a Fuller envelope (COLTO, 2006) and confirms the high quality of the grading which is of a crushed stone standard and in the field could be compacted to 88% of bulk relative density. This quality of the aggregate forming the base course is a clear good reason for the sound condition of the existing carriageway.

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Grading: 40% between 19 and 75mm   Maximum Density Range: 2050 to 2186kg/m3
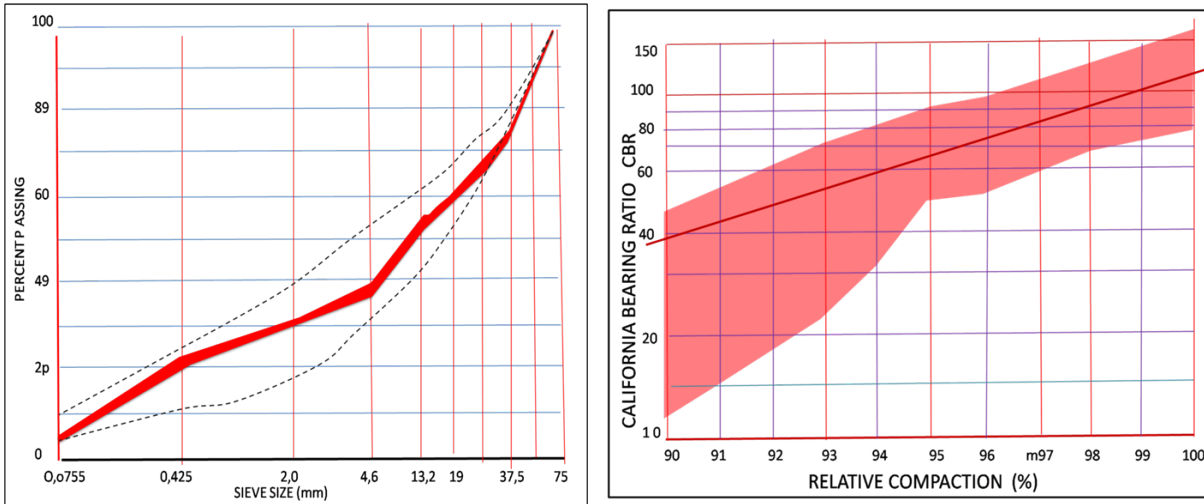

Fig.4 Density, grading and CBR values for material with 40% treated for Oversize Replacement

From a study of the recorded maximum densities and CBR/relative density graph in Figure 4 the following is noted:

- Some 40% of the aggregate was treated for OR.
- The original gradings were almost identical but after OR could be very different.
- The variation in density is 123kg/m^3 or some 3% from the mean density.
- The degree of variation also becomes larger as the RC drops to 90%.
- In this case CBR_{90LM} is 26 and from $CBR_{100LM} = 120$, $CBR_{90CM} = 40$.

6. DISCUSSION

It is not normal practice to perform a grading analysis on samples that have been treated for OR. The writer was thus unable to verify that the crushing process produced differing gradings when each sample was prepared but it is reasonable to assume that the variation in CBR values can be attributed to these differences.

Table 1 is a summary of the variations in maximum density and CBR determination when oversize replacement is applied in the preparation of laboratory samples. It is to be noted here that the term variation implies deviation from the mean and that range is double this amount.

Table 1. Summary of variations resulting from oversize replacement

Material >19mm (%)	0	20	30	40
Density variation (%)	0,8	o,4	1,5	3,0
CBR variations (%)	14-29	15-18	20-45	30-75
CBR_{90CN}/CBR_{90LM}	13,2/12,5	24/22	39/43	40/26

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From a study of this table, in spite of the rather limited data available, the following facts are evident:

- When OR is applied on samples, where the oversize fraction is less than 20 % the range of variance in maximum density and CBR even at 90% RC is small and reasonably acceptable.
- The range of variance in maximum density and CBR values increases rapidly as the degree of OR increases over 20%.
- When high OR is applied, the variation in CBR at maximum density is much less than that at lower values of relative compaction.
- The application of equation (1) to assess the value of CBR at densities less than that at maximum appears to be fully reliable.

When a material has a solids fraction larger than 19 mm in excess of 20% the variation in the CBR would seem to place in doubt the CBR as a strength criterion for the material in question. As the solids ratio, L, is a direct measure of strength such materials should be treated in the same manner as a G1 or G2 crushed stone by specifying a minimum L, or solids ratio of 86 or 88% and a low clay content.

Since tests for CBR at low values of RC tend to produce larger variations than at maximum density it is suggested that the multiplying factor $(RC)^9$ be applied to CBR_{max} to assess the CBR at lower densities.

7. CONCLUSIONS AND RECOMMENDATIONS

It is evident that when a material contains aggregate above 19 mm in diameter in excess of say 15 to 20% the variation or errors in the determination of maximum density and CBR become unacceptably large; increasing successively as the oversize fraction increases.

The variations in CBR are exacerbated by variations in density on which the test for CBR is based.

Provided that the oversize fraction is in the order of 29% or less the errors introduced by OR may be tolerable but above this limit the tested CBR value becomes unreliable and meaningless as an assessment of strength. In such cases the CBR should not be used as a criterion for minimum field compaction. Compaction should preferably be to a specified minimum solids ratio as is the requirement for crushed stone layers.

In the assessment of CBR at densities less than maximum these values may be calculated to a practical accuracy by use of the equation

$$CBR_n = CBR_{nax}(RC_n)^9 \qquad\qquad (4)$$

APPENDIX

Extent of fines in OR to produce minimum voids

Let it be assumed that after crushing the Oversize Replacement material consists of p fines and 1-p large particles and that the fines and the coarse particles are all in the shape of equal size spheres. When well compacted, the voids produced by each fraction will be 30%. Let it further be assumed that the fines fill either wholly or partly, the voids produced by the coarse particles.

If the fines just fill the coarse voids there is a balance between fines and coarse materials and a minimum voids equal to that in the fines will result. If the fines are either too few or too much, the voids will increase, depending on the extent of this deficiency or excess of fines. The voids produced by the OR operation thus depends on the degree of fines produced by the crushing process.

For minimum voids the volume of the compacted fines must equal the coarse voids; i.e.:

$$0,3(1-p) = p/0,7 \qquad\qquad (A1)$$

From which P = 17%
And the minimum voids - 0,3X17% = say 5%

Note: The voids referred to here are the extra voids produced by the OR only and do not include the voids in the rest of the compacted material.

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