Relative Density

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by

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Preface

This guide deals with relative density - an index that quantifies the degree of packing between the loosest and densest possible state of coarse-grained soils as determined by experiments.

The guide is part of a series, which explain the execution of geotechnical classification experiments as carried out at the Geotechnical Engineering Laboratory at Aalborg University.

The guide is constructed as follows:

- *Appertaining standards*
- *Definitions*
- *Apparatus*
- *Equipment calibration*
- *Preparing the test sample*
- *Procedure for experiment*
- *Calculations*
- *Reporting*
- *Remarks*
- *Schema for experiment execution*
- *Appendix, if any*

It is recommended that the user of this guide reads the entire guide before the experiment is started.

Numbering of figures in the text is indicated by { }.

Units are indicated by [ ], e.g. [%].

Appertaining standard

For this experiment, no national or international standards exist.

Definition

For the characterization of sand and gravel (≤16.0 mm), the concept of relative compactness has been introduced:

$$D_r = \frac{e_{\max} - e_{insitu}}{e_{\max} - e_{\min}}$$

$e_{\text{in situ}}$ is the current void ratio of the soil in situ.

The maximum void ratio (loosest state) of granular soil is given by e_{max} and the minimum void ratio (densest state) is given by e_{min}. These void ratios are determined by standardized laboratory tests.

D_r is a number which groves from 0 to 1 when the compactness varies from the loosest to the densest packing.

One of two types of experiments is conducted, depending on the maximum grain size d_{max}:

$d_{\max} \leq 5.0\,\text{mm}$

Small cylinder:	Diameter:	3.57 cm
	Height:	7.00 cm
	Area:	10.00 cm^2
	Volume:	70.0 cm^3

$5\,\text{mm} < d_{\max} \leq 16.0\,\text{mm}$

Large cylinder:	Diameter:	7.00 cm
	Height:	14.40 cm
	Area:	38.48 cm^2
	Volume:	554.00 cm^3

Apparatus

Apparatus used in the experiment. Numbers refer to figure 1.

- Cylinder (large/small) {1}
- Funnel {2}
- Steel ruler {3}
- Punner fitting the chosen cylinder {4}
- Special vernier calliper for chosen cylinder {5}
- Scale, weight accuracy 0.01 g
- Sieve with mesh width at 5 mm or 16 mm, respectively.

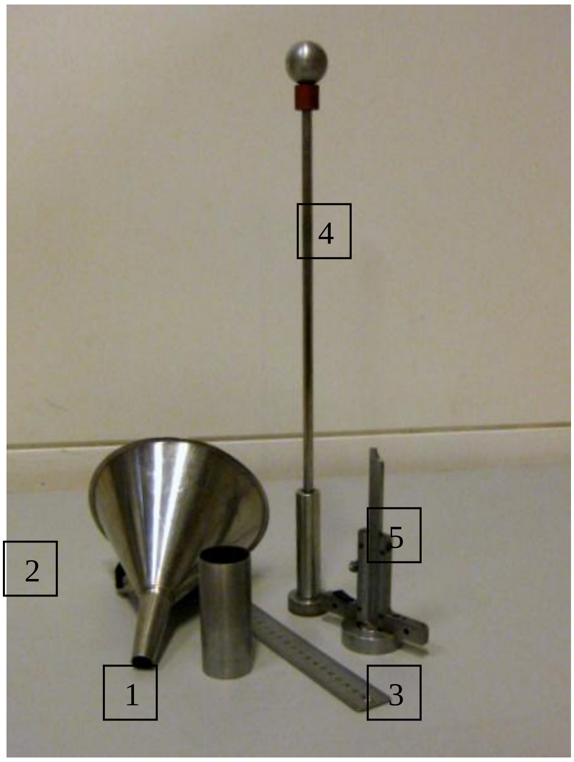

Figure 1: Used apparatus for experiment with small cylinder. Numbers refer to apparatus stated above.

Equipment calibration

The equipment does not require any special calibration. The dimensions of the cylinder must be checked before each experiment. If the measured values deviate from the stated measurements, this must be noted, and the measured values are used.

Preparing the test sample

A representative subsample is taken from the soil sample.

Small cylinder approx. 300 g dry soil (sand/gravel)

Large cylinder approx. 2500 g dry soil (sand/gravel)

The subsample is dried in the incubator (oven) at 105^{o}C until stationary weight. See the description about how to make the water content. After drying, the material is broken up with your fingers or with a rubber pestle (mortar with rubber pestle). For the small cylinder, the material is poured through the 5 mm sieve. For the large cylinder, the material is poured through the 16 mm sieve. The material that goes through is used for the experiments.

Procedure for the experiment

Loosest state, e_{max}

Small cylinder (d_{max} ≤ 5.0 mm)

- The cylinder is placed on a tray or a piece of paper.
- The funnel is placed in the cylinder.
- The funnel is filled carefully in small portions, and the material must glide on the funnel in order to avoid blocking in the funnel nozzle as illustrated in figure 2. A sufficient amount of material is filled in until complete filling of the cylinder so that the material runs over the rim of the cylinder when the funnel is lifted.

Figure 2: Material is filled in a small cylinder by carefully letting it slide down along the rim of the funnel.

- The funnel is now lifted slowly and carefully over a period of approx. 1 minute. The funnel must be handled in one uniform, sliding motion where shaking and jerks are avoided. The mouth of the funnel must, at all time, be just over the surface of the material and in the middle of the cylinder.
- When the cylinder is filled with top in and the material is running over, the funnel is removed; illustrated in figure 3.
- The surface of the material is levelled with a steel ruler over the top side of the cylinder with the ruler moving from the middle and out to the sides, see figure 4.
- Knock hard twice on the table next to the cylinder so the material settles and thereby avoid spilling; illustrated in figure 5.

- The material on the outside of the cylinder is brushed off with a brush and the cylinder with the material is weighed, $Cyl+W_s$.
- All material is removed from the cylinder, if necessary, use a brush or air pressure, and the cylinder is weighed, Cyl.

The experiment is carried out 3 times, and e_{max} is found as the mean value of the measurements.

Figure 3: Small cylinder filled with material, and excess material running over.

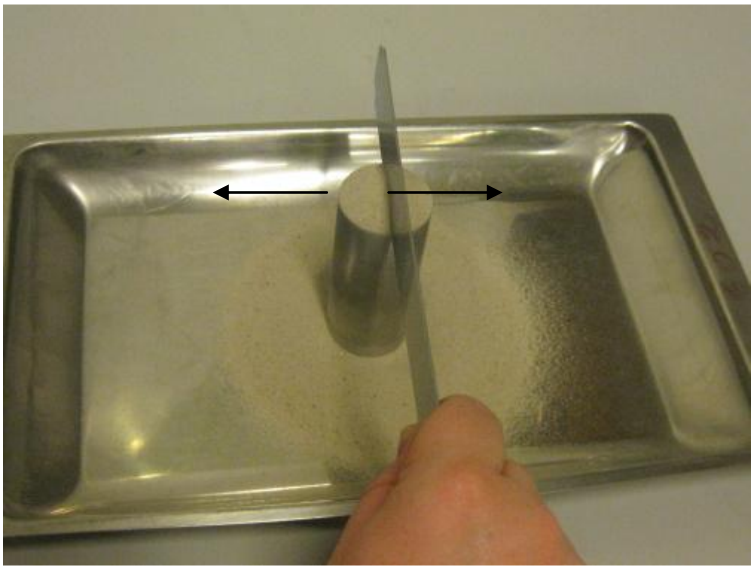

Figure 4: Levelling the material along the topside of the cylinder. Levelling is done from the middle and out.

Figure 5: Levelled cylinder, before and after hard knocks in the table.

Large cylinder

Instead of a funnel, a spoon can be used. The cylinder is tilted and the material runs slowly down into the cylinder. When the cylinder is full, the sample is carefully levelled as with the small cylinder.

Densest condition, e_{min}

Small and large cylinder

Usually, the same material, which has just been used for loosest condition, is used.

The material are build into the cylinder with 5 layers of the same height. Each layer is tamped with the punner with a numbers of impacts, see table 1.

Table 1: Number of impacts used for the specific layers.

Layer	Impacts
1	5
2	10
3	20
4	40
5	80

Every time a layer is build in, the surface is levelled carefully with a steel ruler, figure 6, before the punner is carefully placed down on to the levelled layer of sand.

Figure 6: Levelling of the surface with a steel ruler.

The punner is kept vertical, and the drop weight must be taken all the way up to the stop block whence it must drop freely.

Figure 7: The drop weight is taken up to the stop block in the tamping.

With interval for every 10 of 20 impacts, the punner is lifted in order to ensure that no material is wedged in between the punner and cylinder wall. Any material which is pressed against the bottom side of the punner is removed.

When the last layer is tamped, the cylinder must be nearly filled. The distance from the cylinder top to the top side of the tamped sample must, however, be:

Small cylinder approx. 0.5 cm

Large cylinder approx. 1.0 cm

After the last tamping, check that no material is stuck to the bottom side of the punner. Any material on the punner is carefully brushed back into the cylinder. The special slide gauge is put on top of the cylinder, and the sample height, *h*, is measured directly, figure 8, meaning that it is the height of the material, which is measured with the special vernier calliper.

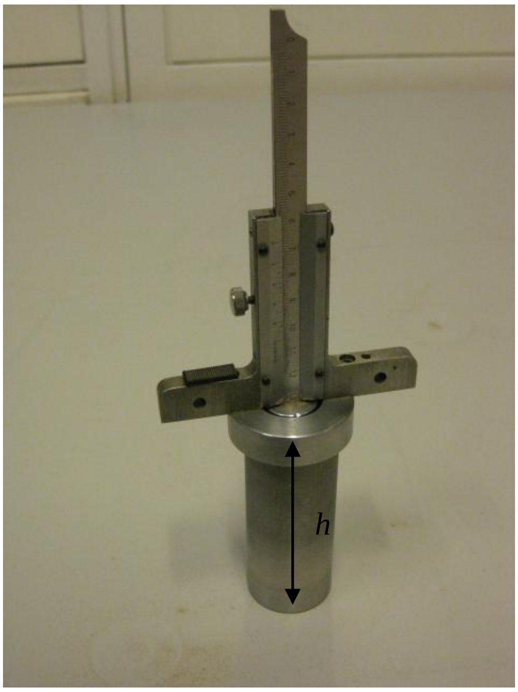

Figure 8: Measuring the height of the material with the special vernier calliper.

Any material on the outside of the cylinder is removed, and the cylinder with the material is weighed, $Cyl+W_s$. The material is taken out of the cylinder, and the cylinder is weighed, Cyl.

The experiment is carried out 3 times, and the mean of the three calculations is $e_{\min}$.

Calculations

The void ratio is determined from each experiment with the expression:

$$e = \frac{G_s \cdot \rho_w \cdot V}{W_s} - 1$$

G_s is the grain density

V is the volume of the material [cm^3]

ρ_w is the water density, 1 g/cm^3

The natural void ratio e_{insitu} can be determined with the expression:

$$e_{insitu} = (1 + w)\frac{G_s}{\gamma} \cdot \gamma_w - 1$$

w natural water content

γ material unit weight [kN/m^3]

γ_w water unit weight, 10 kN/m^3

Reporting

Void ratio and relative densities should be indicated with two decimals.

The reporting should contain information on the sample material as well as any amount of material remaining on the 5 mm or 16 mm sieve.

The measured amounts, the void ratio for the soil sort, loose and solid state, respectively, and the compactness is stated.

State whether the relative density for the soil grains is determined in the experiments if it is estimated.

Remarks

For the execution of the test to determine void ratios in the loosest and densest states, do not use sieved material. The experiments regarding the minimum and maximum void ratios and sieving are done on separate subsamples.

The loosest state must always be examined before the densest state. Material, which has been used for densest condition experiments, must not be used for the like or other experiments.

Fine grained material will sometimes not fall through the funnel. In that case, the material is put in the cylinder as described for the large cylinder.

The stated standard method for execution of the tests related to the loosest state and densest state experiments is not international.

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Loosest and densest state

Case			Case no.
Examined on	to	Lab. no.	Boring no.
Controlled. d.	Approved. d.	Level	Appendix no.

Specific gravity G_s ☐ measured ☐ estimated

Void ratio $e_{insitu} = (1+w)\cdot\frac{G_s}{\gamma}\gamma_w - 1 =$

LOOSEST STATE

Sample	no					
A (10,0/ 38,48)	cm^2					
h (7,0/14,4)	cm					
V (70,0/554,0)	cm^3					
Cyl. + W_s	g					
Cyl.	g					
W_s	g					
$e = \frac{G_s \cdot \rho_w \cdot V}{W_s} - 1$						

$e_{\max} =$

DENSEST STATE

Sample	no					
A (10,0/38,48)	cm^2					
h	cm					
V	cm^3					
Cyl. + W_s	g					
Cyl.	g					
W_s	g					
$e = \frac{G_s \cdot \rho_w \cdot V}{W_s} - 1$						

$e_{\min} =$

Relative density

$$D_r = \frac{e_{\max} - e_{insitu}}{e_{\max} - e_{\min}} =$$

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