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# Äspö Hard Rock Laboratory

## Comparison between density measurements obtained with a nuclear meter and mass/volume determination

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July 2002

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*Keywords:* Nuclear meter, density, compaction, backfill, bentonite

# Abstract

To verify the density measurements made with Campbell Pacific nuclear density meters in the various tunnel backfilling projects run by the SKB a test, where mass/volume estimations of density was compared to the results from a nuclear meter, has been made. Backfill material containing 30 % bentonite and 70 % crushed rock manufactured for the Prototype Repository was compacted in a 1.8 m diameter concrete ring. Three layers were compacted to a thickness of 20 cm. The two methods of determining density were compared and the difference was found to be small (less than 2 %).

# Sammanfattning

För att verifiera de densitetsmätningar som gjorts med Campbell Pacifics densitetsmätare i tunnelåterfyllnad i olika SKB projekt så har ett test där massa/volym bestämningar av densiteten jämförts med resultaten från densitetsmätaren. Återfyllningsmaterial bestående av 30% bentonit och 70% krossat berg som tillverkats för Prototypförvaret packades i ett betongrör med diametern 1,8 m. Tre lager packades till 20 cm tjocklek. De två metoderna för att bestämma densitet jämfördes och skillnaden var liten (mindre än 2 %).

# Contents

# 1 Introduction

The Campbell Pacific MC-3 Portaprobe nuclear gauge has been used for determining the density of materials tested for backfilling tunnels in SKB projects Field Test of Tunnel Backfilling /1-1/, Backfill and Plug Test/1-2/ and the Prototype Repository /1-3/. The purpose of the tests reported here was to compare the results from the meter with mass/volume determination of density. The same type of material as was used in the backfilling in the SKB projects listed above (crushed rock mixed with 30% bentonite) has been used for this test.

# 2 Measuring principle

The measuring principle of the Campbell Pacific MC-3 Portaprobe (Figure 2-1) is based on the use of radio physics, it measures bulk density and water ratio and calculates the dry density. A probe in the device is inserted into the soil from the surface (see Fig. 2-2). The probe contains a small, safely sealed Caesium 137 radioactive source that emits gamma radiation into the soil. A Geiger - Mueller (GM) detector in the meter, detects radiation passing through the material to the surface. If the measured material is of low density, a large amount of radiation will pass through and the meter reading will be high. If the measured material is of high density it acts as a radiation shield and absorbs much of the gamma radiation and the meter reading will be low. A calibration curve permits use of the meter on material of unknown density. The density reading hence represents the mean density of the soil located between the tip of the probe and the surface.

***Figure 2-1.*** *The Campbell Pacific (CPN) MC-3 Portaprobe.*

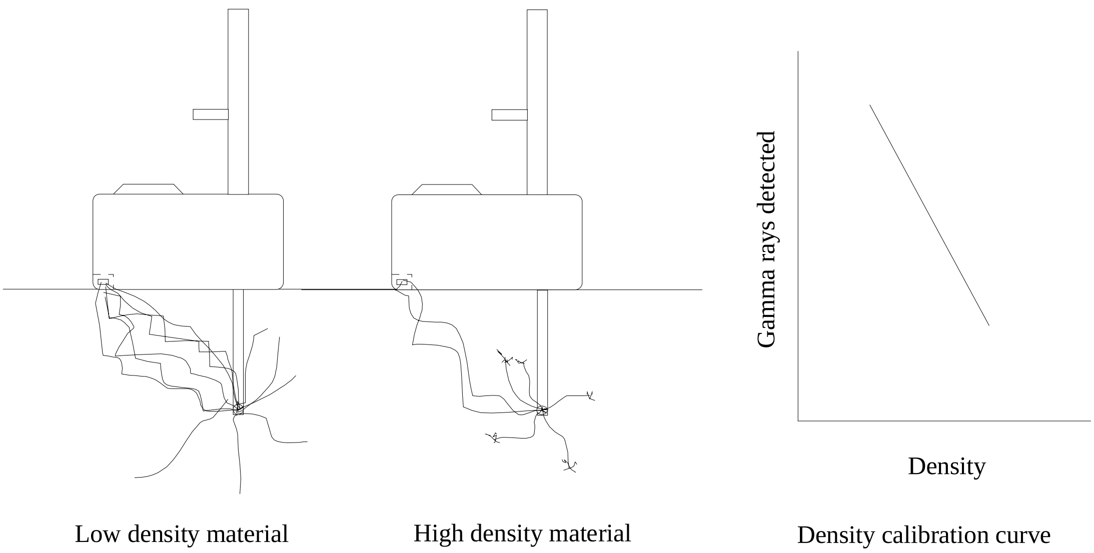


***Figure 2-2.*** *The working principal of the MC-3 Portaprobe.*

The device also measures the water content. A small, safely sealed Americium 241 radioactive source emits neutron radiation into the material. The high energy neutrons emitted by the radioactive source are strongly moderated or slowed down by collisions with hydrogen atoms in the moisture present while they are not very much affected by the rest of the larger atoms of the material. The detector in the meter only identifies low energy neutrons that have been affected by the moisture. If the material is dry the meter will have a low response, and if the material is wet the material will have a higher response /2-1/. A suitable calibration curve permits the use of the meter on materials of unknown moisture. The meter measures how much hydrogen is present in the material. Normally practically all of the hydrogen atoms are located in the water molecules but they form an appreciable part of the crystal lattices of the smectite in the bentonite, which turns out to give incorrect water content data. The water content measurements have not been used.

<u>Accuracy and precision</u>

The accuracy of the device is defined as the measured value of the gauge as compared to a known set of density or moisture standards using the mean of a statistically valid number of readings on the standards. It is a function of the gauge's chemical error and surface roughness characteristics.

The precision of the device is defined as the repeatability of the measured values of the gauge in a stable condition. Precision does not really give any information on the actual accuracy of the gauge. The manufacturer gave the following specifications concerning precision at a one-minute count:

| | |
|---|---|
| Density by transmission | ± 0.004 g/cm3 |
| Density by backscatter | ± 0.008 g/cm3 |
| Moisture | ± 0.004 g/cm3 |

Transmission and backscatter

Transmission is the "normal" way of measuring density with a nuclear density meter. The probe containing the radioactive source is extended into the material. If a so called backscatter measurement is used the probe is not extended into the material. The radiation travels through the top layer of the material. More than 50% of the backscatter measurement is within the upper 2.5 cm of the material and 99 % of the measurement is within the upper 7.5 cm of the material. The backscatter measurement is sensitive to surface roughness and requires careful seating due to the importance of the surface and the top of the upper 2.5 cm in relation to the total measurement. This type of measurement has not been used for determining the density of backfill material.

The method in practice

Before the measurements can start a standard count is made in order to obtain a value of the background radiation. This value is used when compensating for the background radiation. For each density measurement with the transmission method a small hole is made in the material with a spike or a slide hammer. The instrument is placed over the hole and the rod containing the radiation source is inserted into the hole. Measurements could be made with an interval of 25 mm down to a depth of 300 mm. A standard depth of 200 mm (theoretical layer thickness of backfill layers used in the SKB projects) has been used in most cases.

# 3 Description of the test

In order to compare the mass/volume determination of density with the results from the CPN Portaprobe three layers of 30/70 material produced for the Prototype Repository was compacted to approximately 20 cm thickness each in a concrete ring (Figure 3-1). The inner diameter of the ring was approximately 1,8 m and the height 1,7 m. The volume and mass of each layer was determined and the density calculated. The density was measured in 43 places in each layer with the MCA Portaprobe and compared to the mass/volume determination.

Before the test started the ring was positioned horizontally on a paved surface and a bottom layer with an approximate thickness of 20 cm was placed and compacted for 30 minutes. The position of the surface was measured in the following way: At the top of the ring four directions A - D, all passing the center point of the ring were marked according to Figure 3-2. A straightedge was placed in directions A – D and the distance from the top of the concreter ring to the surface was determined in 23 places according to Figure 3-2. The distances were determined with a plummet and a ruler.

***Figure 3-1.*** *Compaction in the concrete ring.*

965,5 kg material for the first layer was placed in a big bag and weighed using Clay Technology's PIAB DKV-105 scale (serial number 2009). The material was then placed in the concrete ring, evened out and compacted for 30 minutes with an ES 52 Y Wacker rammer. The rammer weighs 56 kg, has a frequency of up to 800 Hz and a length of stroke of 65 mm. After compaction the position of the top surface was determined in the same way as for the bottom layer and the density was measured with the CPN Portaprobe. To do the measurements holes were made according to Figure 3-3. Each hole, except from the four holes closest to the walls, was used for making three measurements in different directions according to Figure 3-3. In the measurements closest to the walls of the concrete ring the Gauge was placed so that it measured the density as close to the walls as possible. The density was measured in the same way in layer two and three.

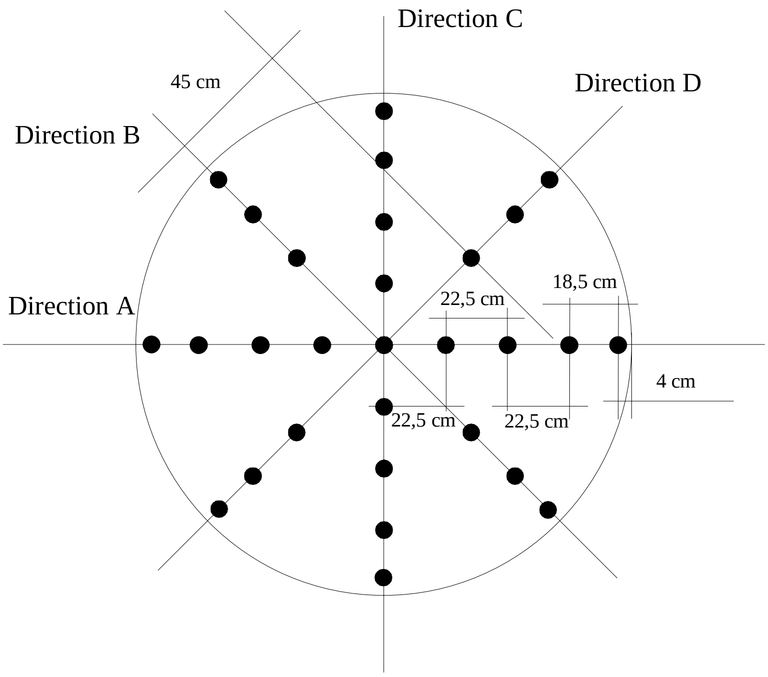


***Figure 3-2.*** *The positions of the points where the distance to the top surface of the concrete ring was determined*

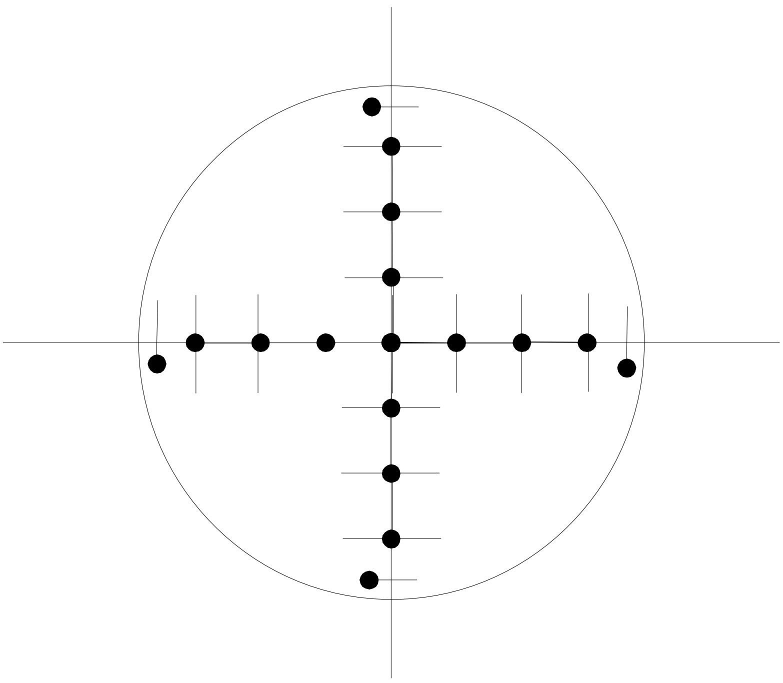

***Figure 3-3.*** *The positions of the density measurements*

# 4 Results

The results are summarised in table 4-1.

**Table 4-1.**

| Layer | Density derived from mass & volume (kg/m$^3$) | Weighed mean of density measurements (kg/m$^3$) | Difference |
|---|---|---|---|
| 1 | 1800 | 1817 | 1,0% |
| 2 | 1808 | 1829 | 1,1% |
| 3 | 1802 | 1860 | 3,1% |
| Mean | 5410 | 5506 | 1,8% |

The mass/volume estimations were made in the following way:

The thickness of the layers was calculated in the measured points (Figure 3-2) and the mean thickness of the layers were calculated. The diameter of the concrete ring was measured and the volume of the layer calculated. The mass and volume was used for calculating the density.

The density from the measurements with the Portaprobe showed that the density close to the walls of the ring was lower than the average. To calculate a correct mean density the layers were divided into three different density zones according to Figure 4-1. The results from the measurements with the Portaprobe are plotted against the distance from the ring wall in Figure 4-2. The scatter is quite large, from 1,7 to 2,0 g/cm$^3$. The main reason for the scatter is differences in density in the material.

The water ratio was determined in the places were the holes for the Portaprobe were made, i.e. in 17 places in each layer. The average water ratio was 11,27 %for layer 1, 12,23% for layer 2 and 13.35% for layer 3. Based on the density obtained with the Portaprobe this would correspond to an average dry density of 1,63 g/cm$^3$ in the first and second layer and 1,64 g/cm$^3$ in the third layer. The water ratio was determined by weighing a sample before and after drying for 24 hours in 104 degrees Centigrade and then calculating the water ratio.

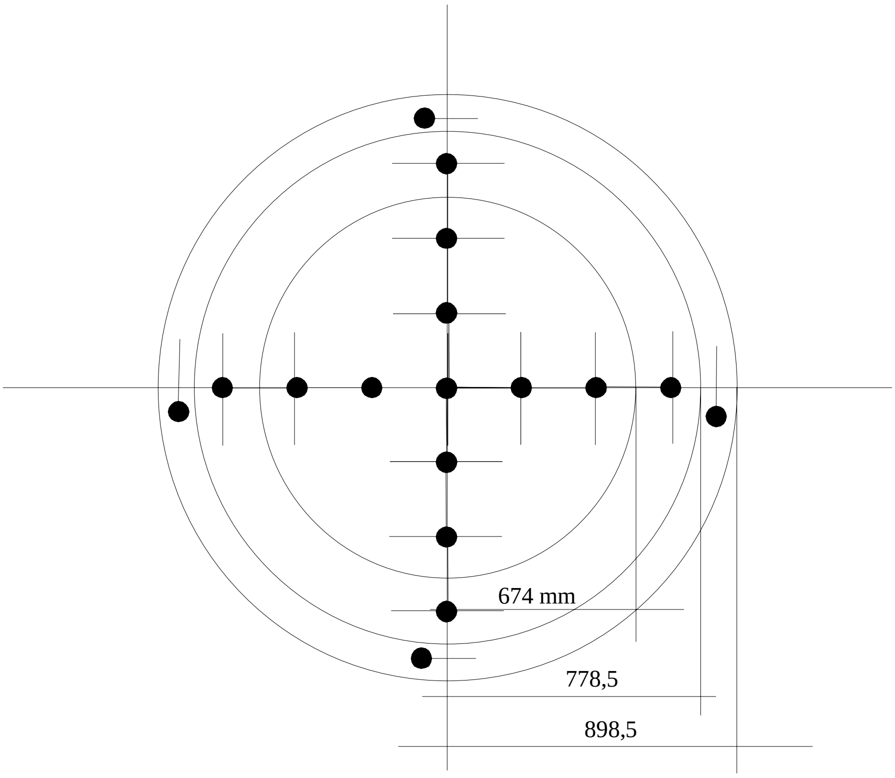


***Figure 4-1.*** *The density zones used for calculating the mean measured density from the Portaprobe.*

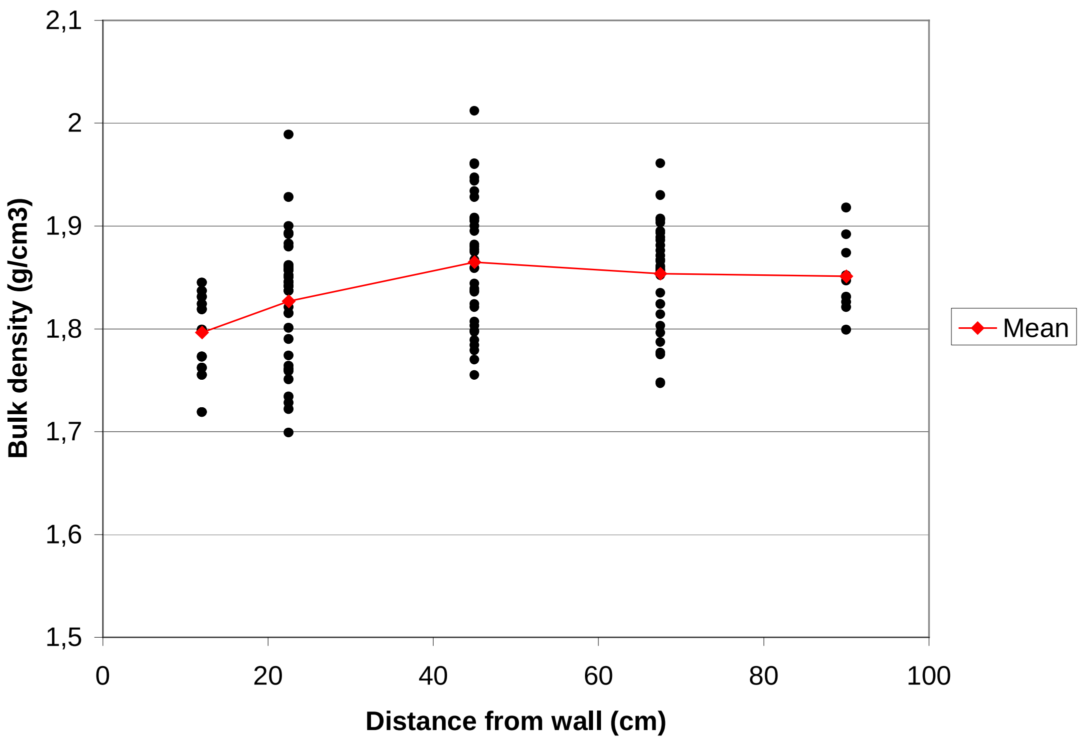


***Figure 4-2.*** *The results from the measurements with the nuclear meter plotted against the distance from the concrete wall.*

# 5 Comments and Conclusions

The main conclusion is that for the three compacted layers the difference between the average density obtained with the CPN Portaprobe and the density determination based on mass and volume is less than 2 %. When considering the difference it is relevant to consider the possible errors in the mass volume determination. The error can be divided into mass error when weighing the material and error in volume due to error in measured radius and thickness of the layer. The maximum error in density was calculated in the following way: The maximum density was calculated as the maximum mass divided by the minimum volume and the minimum density was calculated as the minimum mass divided by the maximum volume. The maximum error in density was calculated as the difference between the maximum density and the minimum density divided by the minimum density. The errors are summarised in Table 5-1.

In the two first layers the difference between the density measured with the Portaprobe and the density derived from mass/volume estimations was only 1,0 and 1,1 %. In the third layer the difference was 3,1 %. One reason for the higher difference in the third layer might be that the shape of the layer was slightly different than in the first two layers. In the first two layers the rammer was working entirely down in the ring, this made it impossible to compact the material close to the wall totally horizontally since the handle of the rammer was in contact with the ring wall. This resulted in the layers having a higher elevation at the wall (Figure 5-1). When the third layer was compacted the handle of the rammer reached over the edge of the ring and this made it possible to compact the material close to the wall more horizontally and thus the layer was more flat. Since the method of determining the volume of the layers assumes that the layers surfaces have similar topography this leads to a slight overestimation of the volume, and thereby an underestimation of the density, of the third layer. This can explain the larger difference between the density measured with the Portaprobe and the mass/volume determination in the third layer. If this is taken into account it is possible that the difference between the determinations is less than 1,8 %.

The scatter in the results from the measurements with the Portapobe is large, especially considering that the material was compacted in a very structured way so that the different parts of the surface received the same amount of compaction energy. The agreement between the density estimated from the results obtained with the Portaprobe and the mass volume estimation shows that the Portaprobe results are correct. The conclusion from this is that the scatter when backfilling a tunnel must be large and that a large number of measurements thus are needed to be able to estimate the density correctly.

**Table 5-1 Estimation of errors in the mass volume determination of density.**

| | Highest density | Lowest density | Absolute difference | Relative difference |
|---|---|---|---|---|
| Diameter (mm) | 1795 | 1797 | 2 | 0,1% |
| Thickness (mm) | 211,5 | 214,5 | 3 | 1,4% |
| Mass (kg) | 972 | 962 | 10 | 1,0% |
| Density (kg/m$^3$) | 1816 | 1768 | 48 | 2,6% |

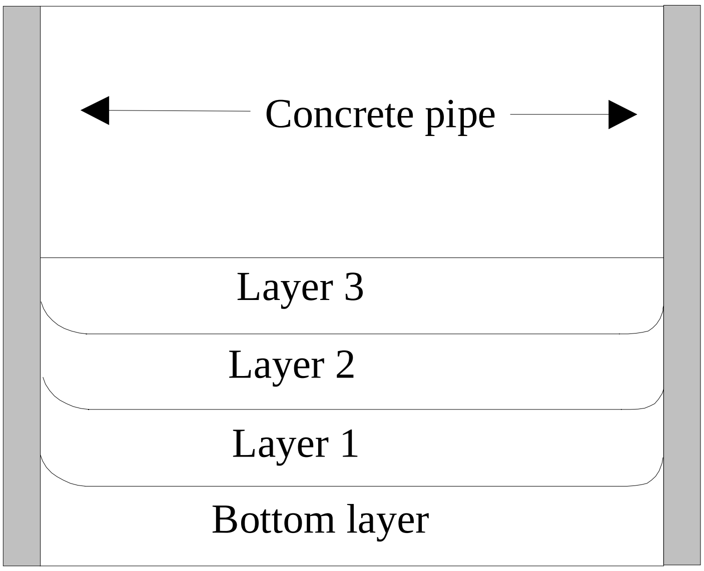


***Figure 5-1.*** *Schematic drawing of compacted layer and concrete ring*

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/2-1/ CPN Application note AN 2180