# SOIL COMPACTION ON CONSTRUCTION SITES

**by Thomas B. Randrup**

**Abstract.** Soil compaction was estimated on 17 construction sites and bulk densities were measured from the soil surface to depths of 1.0 m, at 0.1 m intervals, using a nuclear moisture/density probe. Soil on construction sites was heavily compacted at depths from 0.3 - 0.8 m. Suggestions for a new attitude to soil compaction on construction sites are made.

## Introduction

When soil is compacted bulk density increases and total porosity decreases (1,5). These effects inhibit plant growth (9,15,16).

Compaction on new construction sites can be divided into two categories—deliberate and unintended. Deliberate (or intended) compaction is done in order to secure physical soil stability for structures. Unintended compaction is due to inadvertent construction traffic.

Efforts at preventing soil compaction by either protecting (7) or ameliorating (2) the soil have largely been failures. Even natural processes of freeze - thaw have questionable capacity to reduce soil compaction (6). The focus on new construction sites, therefore, must be preventing both deliberate and unintended compaction.

In Denmark most building activity is on former farmland. The landscapers main concern is to protect the soil from compaction during construction. Top soil, with a content of organic material of approximately 4-5%, is not suitable as a construction material. Therefore, on Danish construction sites, the top soil is always stripped before the actual building process begins. On such sites the degree of unintended soil compaction was investigated.

## Materials and methods

Seventeen construction sites were randomly selected as described by Randrup (10) and Randrup & Dralle (11). All sites were farmed prior to construction. All soils were clayey glaciated soils (15 - 70% clay + silt) and all construction was completed 1-5 years prior to the investigation.

Six sites were commercial developments with a few large buildings per site. Eleven sites were residential developments with dense housing covering 30 - 40% of the site.

Special test areas at each construction site were selected by considering terrain, utility lines and planting areas. Test areas were selected where construction traffic was not expected. Nearby fields were used to represent the site conditions before the building activity began. Nine control areas (fields) were selected.

Bulk densities were measured on one to four test areas on each construction site (35 test areas in all) and on all nine control areas. Measurements were made from the soil surface to depths of 1.0 m (approx. 3 feet) at 0.1 m intervals (approx. 4 inches). In order to obtain a fair representation in the expected layered and un-homogeneous soils (4), bulk densities were estimated three times at each depth in every test area. The number of sub-samples at each depth are shown in Table 1.

The measurements were taken by a gamma-ray single-probe. With the single-probe method it was possible to take measurements at greater depths than has been reported in the literature previously. The method is described in detail by Gardner (3) and by Saare (13).

The instrument measures transmission or scattering of gamma radiation. When calibrated, these transmissions measure the wet soil bulk density. The moisture content of the soil was measured by a neutron source in the instrument. The dry bulk density was calculated by deducting moisture content from the wet soil density.

Prior to any measurements, an aluminum tube was inserted into the soil. The radiation sources were lowered into this tube. Great care was taken not to disturb the soil around the tubes during insertion.

A calibration between wet bulk density (core sampling) and transmission counts per minute was made using 21 different test sites. The sites varied in soil type (pure sand to 50% clay + silt), moisture content (0-31% $H_2O$ by volume), measurement depth (10-60 cm, 4-24 inches), distance between radiation source and soil sample (0.2-30 cm, 0.5-12 inches) and counting rate (1 min. - 9x2 min. - 3x4 min.). The number of core samples varied between 3 and 8 at the individual locations. An overestimation of around 0.10 - 0.15 Mg/m$^3$ on all measurements may be due to local compaction around the aluminum tube. This, however, has to be studied in detail.

**Table 1. Average soil bulk densities on construction sites and control sites.**

| | Average bulk densities Surface to 1.0 m | | | | | |
|---|---|---|---|---|---|---|
| Depth | Construction sites | | | Controls | | |
| | n | Mg/m$^3$ * | std. | n | Mg/m$^3$ * | std. |
| 0.1 m | 93 | 1.65 | 0.22 | 23 | 1.72 | 0.18 |
| 0.2 m | 93 | 1.61 | 0.27 | 27 | 1.76 | 0.17 |
| 0.3 m | 93 | 1.77 | 0.28 | 27 | 1.81 | 0.23 |
| 0.4 m | 93 | 1.91 | 0.28 | 27 | 1.77 | 0.25 |
| 0.5 m | 93 | 1.96 | 0.24 | 27 | 1.73 | 0.23 |
| 0.6 m | 92 | 1.95 | 0.23 | 27 | 1.77 | 0.24 |
| 0.7 m | 87 | 1.91 | 0.22 | 27 | 1.78 | 0.23 |
| 0.8 m | 84 | 1.88 | 0.18 | 27 | 1.85 | 0.25 |
| 0.9 m | 71 | 1.84 | 0.23 | 26 | 1.91 | 0.21 |
| 1.0 m | 31 | 1.79 | 0.24 | 23 | 1.96 | 0.19 |

* An overestimation of around 0.10 - 0.15 Mg/M$^3$ is assumed to be due to local compaction around the aluminum installation tube.

## Results

The bulk densities in the top 0.3 m of the soil were lower inside the construction sites than in the control locations. Bulk densities at depths of 0.4 - 0.8 m were higher inside the construction sites than the controls. Below 0.8 m, bulk densities inside the construction sites were lower than the controls. Outside the construction sites the bulk densities were similar in all depths.

## Discussion

In the top layers of a Danish clay soil exposed to annual farming, soil bulk densities of about 1.55 - 1.65 Mg/m$^3$ are regarded as 'normal'. In this survey higher bulk densities were found both inside and outside the construction sites (Table 1). Bulk densities above 'normal' were also found by Hansen *et al.* (4) who estimated bulk densities between 1.59 and 1.72 Mg/m$^3$ at depths of 0.1 - 0.9 m in a similar Danish agricultural field with clay soil.

The relatively high bulk densities found in this study may be due to the measurement technique used. In the clay moraine glaciated soils, which were often dry and stony, the gentle insertion of the measurement aluminum tube proved to be difficult. Therefore, an overestimation of around 0.10 - 0.15 Mg/m$^3$ on all measurements could be due to local compaction around the aluminum tube.

Construction practice in Denmark commonly involves stripping and stockpiling the upper 0.1-0.5 m of soil during the grading phase. Following grading and construction, the soil is replaced. As this was the case on the sites examined, the higher bulk densities seen in the 0.4 - 0.8 m depth should be the result of unintended compaction.

Even if the bulk densities were overestimated by 0.1 - 0.15 Mg/m$^3$, the sub-soil was still compacted at depths of approximately 0.3 m (1 foot). The compaction level found in these depths must be regarded as detrimental to root growth (15,16,17). The decrease in porosity occurring from compaction (5) will, in many cases, also slow drainage. A zone of saturated soil could develop just above the sub-soil, also reducing plant growth.

When compaction is found at depths below the subsoil, equipment used to alleviate compaction must operate at great depths especially if the loosening procedure is carried out from the topsoil surface. In this study the soil had been loosened in 12 of the 17 cases, according to the contractors. Positive soil loosening effects could be found occasionally, but in the overall results shown in Table 1, no effects were found. Previously, several people have stated that alleviating soil compaction is difficult and usually not successful (6,8,12,14).

Håkansson & Reeder (6) said that if machines weighing more than 15 metric tons were used on clay soils, compaction to depths of 0.6 m (2 feet) and below could be expected. On Danish construction sites machinery weighing from 17-25 tons is generally used (10). Dozers, scrapers, and motorgraders of the same size (and probably even larger) are used worldwide today.

Heavy machinery is a fact on construction sites. The focus on efficiency in all phases of modern living makes it difficult to foresee a change in attitudes towards the use of lighter machinery on construction sites. So, the ideal situation seen from a soil handling point of view cannot be achieved at present.

One way of dealing with the problem is to consider soil compaction as a fact on construction sites. The planner must take precautions every time a new landscape design is made. Once this is done planners can inform developers, contractors, etc. about their intentions.

Given the results of this study and the standards of construction practice (i.e. stripping of top-soil and using heavy equipment) the following four steps are recommended in handling the soil compaction problem on construction sites:

I. Expect the soil to be compacted.
II. Make all possible efforts to reduce the spread of compaction. Better to keep the compacted zones in certain areas than spread it all over.
III. Fence off all possible future planting areas. Soils meant for future planting should be protected, just as existing trees should be protected.
IV. Alleviate the compacted soil, knowing that alleviation is only helping the soil to reconsolidate itself, and that a real effect of the loosening may take many years.

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**Résumé.** Les recherches sur le tassement des sols se sont surtout concentrées dans le domaine agricole durant de nombreuses années. Quoiqu'il en soit, plus d'attention a été portée aux sols en milieu urbain au cours des 20 dernières années. Dans cette étude, le degré de tassement du sol a été estimé sur 17 sites de construction et la densité mesurée à partir de la surface jusqu'à des profondeurs de 1 m par intervalles de 0,1 m à l'aide d'une sonde nucléaire de mesure de l'humidité et de la densité. Le sol des sites de construction était lourdement compacté à des profondeurs de 0,3 à 0,8 m. En général, le niveau de soins idéaux à apporter au sol n'est pas atteint lors des travaux de construction. Une façon de gérer le problème est de considérer sérieusement au préalable les mesures de protection à prendre lorsqu'un nouvel aménagement est conçu. Des suggestions pour un nouveau regard des problèmes liés au tassement du sol sont proposées.

**Zussammenfassung.** Die Erforschung der Bodenverdichtung konkentriert sich schon seit einigen Jahren auf landwirtschaftlich genutzte Flächen. Dennoch wurde während der letzten zwanzig Jahre die Aufmerksamkeit immer mehr auf urbane Böden gerichtet. In dieser Studie wurde die Bodenverdichtung von 17 Baustellen geschätzt und dabei die Körperdichte von Proben aus 1 m Bodentiefe im Raster von 0.1 m mittels einer nulekularen Feuchtigkeits-/Dichteprobe gemessen. Der BaustellenBoden war bei einer Tiefe von 0.3 bis 0.8 m sehr startk verdichtet. Gegenwärtig ist keine optimale Bodenbehandlung auf den Baustellen durchführbar. Ein Weg, mit diesem Problem fertigzuwerden, ist es, die Vorkehrungen bei einer neuen Landschaftsplanung treffen. Es wurden einigen Anregung für eine neue Betrachtungsweise der Bodenverdichtung gegeben.