A METHOD FOR CHARACTERIZING THE BULK DENSITY OF COMPRESSIBLE PARTICULATE MATERIALS

D. Guenther
Research Assistant

S. Schaub
Graduate Student

J. Leonard
Professor

Department of Agricultural, Food and Nutritional Science,
University of Alberta, Edmonton, Alberta, Canada, T6G 2P5

INTRODUCTION

Any description of a material would be incomplete without consideration of the physical properties of that material. For materials that exist as particles in a bulk, the properties of the bulk material are often as important as properties of the individual particles, and perhaps the most basic bulk property is that of bulk density. This is simply defined as the mass of a bulk material divided by the volume that the mass occupies.

For relatively hard materials, such as soil or grain, measurement of bulk density can be carried out very simply by measuring the mass of material required to fill a container of known volume or measuring the volume occupied by a known mass of the material (Mohsenin 1986; Stroshine and Hamann 1994). If the particles are incompressible, this can be assumed to give the maximum bulk density of the material. However, if the material is compressible, bulk density values obtained from small, disturbed samples will reflect only the properties of material on the surface of a bin or pile. Material at some depth will have higher bulk densities due to compression under the weight of the material above it. This could be of significance in determining the mass of material in a pile of a given volume, in the estimation of other physical parameters (such as thermal conductivity, porosity, or resistance to air flow) deep within piles of such a material, or in the design of storage structures and materials-handling systems.

Consequently, the first problem of characterizing the bulk density of compressible materials is how to obtain a value at any location in a pile. This invariably involves disturbing the sample to some extent, or disturbing the surrounding material so that the load on the sample is changed, or both. This paper describes an alternative approach in which the loading at any depth in the bulk is simulated to obtain a relationship between depth and bulk density. This relationship can then be used to derive a value for the effective bulk density of the entire mass of material.

The objective was to develop a laboratory method of characterizing bulk density that was cheap, simple, precise, and accurate. Since it has the potential to be applied to a wide range of materials, the approach was tested with compost, wood shavings, straw, and peat moss.

METHOD

The basic apparatus required was a container for the material, a set of weights with which to apply vertical loads, and a platform scale. In order to minimize wall effects, a large steel cylindrical container, approximate diameter 500mm and height 750mm, was used. However, this container size was too large for practical in-field use. Therefore, smaller containers have been designed using schedule 40 pipe (approximate diameter 300mm and height 400mm). Results using the small containers are not available at this time as data are in the process of being collected.

The containers were weighed and a line was marked on the inside, from the bottom. Material was filled to the 500mm mark for the larger container and to the 250mm mark for the smaller container. The containers were filled with water to these marks and weighed. Assuming the density of water to be 1000 kg/m^3, the volume of the container to the mark ($V_{500\text{ or }250}$) was determined.

Presented at the 21st Annual Meeting, Canadian Land Reclamation Association,
Calgary, Alberta, September 18-20, 1996

The material to be measured was placed in the container to a level exceeding the mark and shaken to ensure that the material settled. Material above the mark was removed then the container was weighed and the bulk density (D) of the material was determined.

This represents the bulk density in the top 500mm or 250mm of a pile. The next step was to determine the bulk density in the next 500mm or 250mm layer. To do this, a load equivalent to the mass of material was applied to the material in the container, by placing known masses on top of the material. To ensure uniform loading, the masses were placed on a plywood disk with the diameter slightly less than the container. This loading compressed the material and was applied for about one hour so that the material could consolidate to a constant volume.

Compression distances were measured and the values used to determine how much material needed to be added to bring the level back to the mark. After adding this material, and after a 1 minute consolidation time with the load applied, the level of material was checked to see if it was at the selected mark. Adjustments were made as required adding or subtracting material until the level was at the desired mark. The added mass plus the previous mass of material represented the final mass of the second layer.

The above procedure could be repeated for any number of layers. In general, the bulk density (D_n) of the nth layer is given by:

$$D_n = \frac{M_t - (M_c + \sum_{i=0}^{n-1} M_{mi})}{V_{500 or 250}} \text{ kg/m}^3 \tag{1}$$

Where:

M_t = Total mass of the material and container

M_c = Mass of the container, and

M_m= Mass of material in ith layer

= Mass of applied load

The trials conducted were repeated, layer by layer, to a simulated depth of 3.5m (1.75m for the small containers) and resulted in a set of bulk density determinations corresponding to successive 500mm or 250mm layers of material. These were plotted against depth and a least-squares regression routine was used to fit curves to the plotted points.

Once a bulk density versus depth curve had been obtained, an effective bulk density (D_{eff}) could be defined as the bulk density which, if constant with depth (z), would give the same area under a bulk density-depth curve as the experimental values.

This is expressed mathematically in Equation 2 as follows:

$$Deff = \frac{1}{z}\int_0^z D(z)dz \text{ kg/m}^3 \tag{2}$$

RESULTS AND DISCUSSION

The method of bulk density characterization presented above was conceptually simple and did not require any expensive or particularly sophisticated equipment. Results from the large container experiment, tested in two separate trials, indicate similar trends in describing the characteristics of the materials tested and the density as a result of a load exerted upon the material. This was seen by the similarity between equations to curves for like materials and the high R^2 values ranging from 0.88 to 0.99.

In fitting curves to the data, the selected best-fit equation was a power function, of the form $y=Ax^B$. This regression equation was selected as its could described the behaviour or properties of materials. Thus, y represents the bulk density, x represents depth, and A and B are constants that depend on the material.

The coefficients (A) provide an indication of the order of magnitude of the bulk density of the material. The exponents (B), on the other hand, give an indication of the compressibility of the materials. The higher the exponent, the higher the compressibility. A completely incompressible material whose bulk density was constant with depth would have an exponent of zero. Examination of the equations shows that wood shavings was the least compressible of the materials tested and had a minimum exponent of 0.0518, while compost was the most compressible material and had a maximum exponent of 0.28.

Of the materials tested, the most variable was compost. This may have been due to the physical differences of the material being initially compressed and the material having had another year for decomposition. On the other hand, peat moss had the least variance which may be explained by the relatively homogeneous and stable make-up of peat.

Although power function equations, as described above, provide a convenient description of the bulk density of compressible materials, practicality demands a single number to characterize this property. Effective density (D_{eff}) is proposed as this number on the grounds that it is more representative and, potentially, of greater practical significance than a simple average of a number of measurements. By definition, determination of D_{eff} requires measurements of bulk densities at a range of compressions and, the larger the range, the better will be the estimate of D_{eff}. This encourages a complete characterization of the behaviour of the material rather than simply taking a few measurements at the surface or at low levels of compression which are not representative of most of the bulk.

The formula for D_{eff} (Equation 2) is based on the area under the density-depth curve. This area has units of kg/m^2 which, by multiplying by grams, is easily converted to N/m^2 and, thus, is an indicator of the vertical load exerted by a pile of material with a height corresponding to the integration interval in Equation 4. Similarly, the total mass of material in a pile can be calculated easily using D_{eff} directly without the need to make further allowances for variation of density with depth.

ACKNOWLEDGMENTS

The work described in this paper was carried out with funding from the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

Mohsenin, N.M., 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Scientific Publishers. New York, NY.

CLRA
ACRSD

CANADIAN LAND RECLAMATION ASSOCIATION
ASSOCIATION CANADIENNE DE RÉHABILITATION DES SITES DÉGRADÉS

Conservation and Reclamation:
An Ecosystem Perspective

Canadian Land Reclamation Association's
21st Annual Meeting

Calgary, Alberta
September 18-20, 1996

Conservation and Reclamation:

An Ecosystem Perspective

Canadian Land Reclamation Association's
21st Annual Meeting

Calgary, Alberta
September 18-20, 1996

This report may be cited as:

Powter, C.B., M.A. Naeth and D.A. Lloyd (compilers), 1996. Conservation and Reclamation: An Ecosystem Perspective. 21st Annual Meeting, Canadian Land Reclamation Association, Calgary, Alberta. 153 pp.

ACKNOWLEDGEMENTS

The compilers acknowledge the assistance of Jamie Legarie, Alberta Environmental Protection, Land Reclamation Division in preparing the manuscript. We also thank the authors for providing their papers on short notice.

The compilers edited some of the papers for format and length. We apologize for any errors that may have resulted.

TABLE OF CONTENTS

INDUSTRIAL FACILITIES

FORESTS

MOUNTAINS

GENERAL ISSUES

WATER AND WETLANDS

RUNOFF/EROSION

PRAIRIE

VEGETATION

BULK DENSITY

LIST OF SPONSORS

Diamond Level

Alberta Environmental Centre
TransCanada Pipeline Limited

Gold Level

AGRA Earth & Environmental Limited
CHEMEX Labs Alberta Inc.
Government of the Northwest Territories
TransAlta Utilities Corporation

Silver Level

Canadian Energy Pipeline Association
Cardinal River Coals Ltd.
Inco Limited
Olds College
Imperial Oil Resources

Bronze Level

Alberta Treasury Branches
Cigar Lake Mining Corporation
Enron Oil Canada Ltd.
Estevan Coal Corporation
Hudson Bay Mining & Smelting Co. Ltd.
Inland Industrial Materials
Manalta Coal Ltd.
Nelson Dynes & Associates Inc.
NOVA Gas Transmission Ltd.
PanCanadian Petroleum Limited

Iron Level

EnviResource Consulting Ltd.
Morgan Hydrocarbons Inc.
Petroleum Industry Training Service
Western Ecological Systems Management Consulting Inc.