Determination of Bulk Volume of Asphalt Specimens with Image-based Modeling

Eyal Levenberg and Alex Manevich
Technion - Israel Institute of Technology, Technion City, Haifa 32000, Israel
elevenbe@technion.ac.il, alexman@technion.ac.il

ABSTRACT
An approach is explored for modernizing the determination of bulk density of compacted asphalt specimens. It is based on calculating the bulk volume of the specimen in a three-dimensional model reconstructed from its images. The paper presents the basics of image-based modeling, founded upon the science of photogrammetry and computer vision. Next, a demonstrative application is described, in which a field core is photographed from many viewpoints with a consumer grade camera, and the images are combined into a sparse point cloud. This cloud is subsequently 'meshed' with planar polygons into a closed 3D shape and its volume calculated. It was found that the model-core volume was very close to that measured with a traditional liquid-displacement approach. It was also found that while the volume was relatively insensitive to the quantity and quality of the images used for the reconstruction, the computational time varied significantly from minutes to hours. Based on the favorable findings of this limited application, the approach is deemed promising and viable, worthy of more in-depth examination.

1. INTRODUCTION
Pavement projects are typically accompanied by tests for measuring the bulk density of compacted asphalt specimens that are either laboratory-molded or cored from the field [1]. These densities are needed during mix design to assess volumetric properties and serve as basis for selecting the design binder content; they are also needed during construction as a primary tool, alongside thicknesses, for quality control activities.

Formally, the concept of 'density' is defined for a point in a continuous medium and calculated as the ratio of mass to volume of an infinitesimally small element encapsulating the point of interest. Asphaltic mixtures are heterogeneous materials, composed of aggregates of a range of sizes, asphalt binder, and air voids (pores). For these materials, the 'bulk density' is of engineering significance and not the 'density' as defined above. The difference between the two resides in limiting the size of the encapsulating element. For bulk density, the element size cannot be infinitesimally small; it must be large enough to allow statistical representation of the different mix phases. The calculation formula is as follows:

$$\rho(\mathbf{x}, \Delta V) = \frac{\Delta M}{\Delta V} \tag{1}$$

where ρ is the bulk density of the medium at the calculation point with units of mass over volume; $\mathbf{x}$ is a position vector with respect to a given coordinate system that identifies the location of the calculation point, ΔV is the bulk volume of the element encapsulating the point, and ΔM is the mass of the material inside ΔV. As explicitly shown, ρ depends not only on the position vector $\mathbf{x}$ but also on ΔV [2–5]. In general terms, the minimum size scale of ΔV for asphaltic materials is about three to four times the size of the maximum aggregate in the mix [6–8].

In the pavement engineering community, Equation (1) is typically employed assuming the bulk volume is representative. The single most accepted measurement approach of ΔV is the saturated-surface dry method in ASTM D2726 [9] where it is indirectly obtained by measuring the weight of the specimen while suspended in water. Especially for irregular shapes, this liquid-displacement approach is a workable method [10]. However, if the specimen includes large interconnecting pores, the saturated-surface dry condition cannot be achieved; in this case the specimen must be encapsulated in an impermeable 'membrane' closely conforming to its surface before immersion. For this purpose, the use of a plastic paraffin film is specified by ASTM D1188 [11]. A relatively newer approach calls for vacuum-sealing the specimen inside a (disposable) plastic bag; the procedure is described in ASTM D6752 [12].

Referring to Equation (1), the bulk density may be regarded as a random variable because both ΔM and ΔV are measured entities that contain error. Assuming they are independent of each other, the error propagation law [13] establishes the following relationship:

$$(\sigma_\rho)^2 = \left(\frac{\partial \rho}{\partial \Delta M}\right)^2 (\sigma_{\Delta M})^2 + \left(\frac{\partial \rho}{\partial \Delta V}\right)^2 (\sigma_{\Delta V})^2 \tag{2}$$

where σ_ρ is the standard deviation of the bulk density, $\sigma_{\Delta M}$ is the standard deviation of the mass of the specimen, and $\sigma_{\Delta V}$ is the standard deviation associated with the bulk volume. The partial derivatives are computed from Equation (1): $\partial\rho/\partial\Delta M = \Delta V^{-1}$ and $\partial\rho/\partial\Delta V = -\Delta M \Delta V^{-2}$.

From Equation (2) it is possible to evaluate the present uncertainty level associated with bulk volume measurements. The accepted standard deviation for the bulk density is $\sigma_\rho = 0.0124$ g/cm^3 [9]. Also, the specimen mass is typically measured with a Class GP2 digital balance [14], characterized by a measurement precision of $\sigma_{\Delta M} = 1$ g, equal to the last resolvable digit. Therefore, as an example, if a given asphalt specimen has a bulk density of $\rho = 2.400$ g/cm^3 and is cylindrical in shape with a 10 cm diameter and