*Inventories of Raw and Bulk Materials**

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ABSTRACT: *This paper deals with the need by owners and management for a dependable method by which they may maintain records of their stockpiles of raw and bulk materials. The ground survey method is compared to photogrammetric methods, both terrestrial and aerial, with elaboration of a certain aerial photogrammetric method notwithstanding the acknowledgment that other variations of the aerial method may certainly be employed. The projected conclusion is that the aerial photogrammetric method has advantages that should be considered in planning inventory programs.*

THE systems of utilizing aerial photographs, exposed stereoptically in photogrammetric measuring instruments, are now universally depended upon by firms who periodically inventory their stock-piles of such raw materials as sand, gravel, limestone, coal, pulpwood, sawdust, fertilizer and iron ore.

These systems have been employed for a number of years by a limited number of firms, but in recent years, confidence has been placed in these systems by large and even small firms which stock these materials all over the world. These firms have been motivated to this acceptance by their controller and accountants, because of time and personnel economies, plus Governmental tax and assessment agencies. Also because of acceptance of these systems for reporting inventories on which taxes are paid. In addition civil engineer and survey personnel, due to relief from a somewhat tedious task, have time made available for use on more directly productive duties.

To an extent, the photogrammetric determination of stock-pile inventories may be regarded as an outgrowth of the tremendous demand for rapid cross-section information in determining earthwork movements and quantities. The Federal Interstate Highway program was largely responsible for this demand. In addition large construction projects have resulted in great quantities of grading and cut-and-fill.

The heretofore conventional methods of ground surveying were and are incapable of meeting the time requirements of such programs.

Today, most all Federal and State Highway Departments and Commissions and Consulting Design Engineering Firms either approve or specify the Aerial Photogrammetric Method.

Basically, there are three systems utilized in determining stock-pile inventory volumes: (1) Ground Survey, (2) Terrestrial Photogrammetry, and (3) Aerial Photogrammetry. This discussion will deal primarily with the third method. The first and second methods will be discussed very briefly for comparison with the third method.

GROUND SURVEY METHOD

The ground survey method in early times often resulted in only a calculated guess by men experienced in the respective field of operation and coupled with their "eyeball and thumb." Thus was determined an inventory satisfactory to management. The advent of taxes and increased emphasis on inventory control and the size and value of stock-pile materials necessitated accurate systems of measurement.

A normal ground survey procedure may consist of obtaining vertical cross-sections at intervals along the longitudinal axis of the pile, and together with spot elevations for determining the average depth of the pile. An evened-off measurement is made to establish the length and width of the pile. For determining the pile area, these measurements may be used permanently. The field data are computed and reduced for plotting on the cross-section. These are then planimetered for end areas and volume computations.

The cross-section data can also be used to

* Presented at March 24–30, 1963 ASP-ACSM Convention, Hotel Shoreham, Washington, D. C.

plot contours at intervals of one foot on a plan map of the pile. The contours are then planimetered to measure the pile volume.

This method does not offer a completely accurate result. Sometimes grading a pile is necessary to make possible a crew to survey it without a complicated procedure or even gaining access. A certain amount of danger is also involved, and weather is always an element to contend with. Perhaps the most detracting feature from this method is the inability to define an inventory cut-off time because the process will require hours or even days, and during that period the pile may undergo continuous additions and removals.

Terrestrial Photogrammetry

The terrestrial photogrammetry method is really applicable only to very small operations. Even so it may be more economical for small stock-piles than the ground survey method, particularly when speed and accuracy are desired.

This system may utilize ground level horizontal photographs or oblique angle photographs erected to certain heights above the ground. These photos are exposed stereoptically and are guided by targets on the pile which indicate the areas covered by each stereo exposure and are so controlled as to make certain of total continuous coverage. These targets can also serve as control points where appropriate.

These photographs need both horizontal and vertical control to be established by standard survey procedures. If these photographs are taken from ground elevations only, they must be taken completely around the perimeter of the pile. If the camera location is elevated, oblique exposures can be made at such locations as will cover the far sides of the pile and the top. Normally, an elevated object such as a building, crane or boom may be available for this purpose.

While a contour map cannot be drawn, vertical profiles can be obtained which will be equivalent to cross-sections obtained by ground survey methods.

Aerial Photogrammetry

There are basically two procedures of aerial photogrammetry that may be followed. Each has several variations. With either of these systems there are two functions which will not be changed. These are the vertical aerial photography and ground control requirements.

The photography should be flown with a precision-type aerial camera, single lens. Dependent upon the type of stereo-plotter to be used, the flight altitude will probably be 1,200 or 1,500 feet above mean terrain. The photo flights are made in continuous straight, single or parallel lines with a forward lap between individual exposures averaging 57 per cent, and a side lap between flight lines, if needed, averaging 35 per cent. The photographic requirement is approximately the same as in a normal topographic mapping assignment. To assist the sharpness of the resultant film negatives, a slow flight photo plane should be used coupled with the fastest camera shutter speed allowable under the existing lighting and terrain reflection conditions.

The ground controls should be located where they will be permanent in nature to the greatest extent possible. They should be of not less than third-order accuracy. The vertical datum may be of local origin since the interest is in the elevations of the material piles and not in the ground elevation above sea level. In large areas however, different sections of pile locations should be on relative datums to avoid possible computation errors. The horizontal control is necessary to establish scale and does not need to be coordinated. In very large areas with numerous materials piled throughout them, establishing a grid system may assist the control of pile locations and reference.

In any event, the survey controls should be placed within the photographic coverage and yet sufficiently away from the working areas of pile to allow horizontal addition to the pile.

With these considerations being observed, the same control should serve future photo flights and inventories without being repeated.

A description of the inventory operations on the stereo-plotter will follow. This may be accomplished by developing a one-foot contour map of the pile which may then be cross-sectioned and planimetered to establish the volume.

A more expedient and possibly more accurate method is the "spot grid" method. The procedure used in rendering a photogrammetric inventory service is one that obtains the basic volume of material in each pile as it exists at the time of exposing the photographic negative. From this point on such factors as significantly affect the tonnage content are applied to these basic volumes in accordance with the direction of the Engineer in Charge of each plant site.

Following satisfactory completion of the

aerial photography and basic ground control surveys, each stereo-model is brought into cimplete horizontal and vertical orientation. Once this is determined to be compatible with all horizontal and vertical survey controls, the physical limit of each stock pile is outlined as it exists on the basic hardstand or storage area.

This "limit line" representing the base of each pile is then transcribed on a gridded highly stable base of cronaflex drafting film template. The grid lines are spaced at 25 foot intervals. The geometric center of each resultant grid square is located at points where pile elevations will ultimately be read.

The area bounded by the "base of pile" limit line is then measured and double-checked by independent polar planimeter readings for subsequent application to the later determined average pile height.

After the limit line of the pile being inventoried has been accurately delineated as described above, the average elevation of this limit line (pile base) is determined by establishing elevations at intervals on the line not to exceed 15 feet.

Upon completion of determining the "pile base mean elevation" the pile height at each superimposed grid intersection is established and recorded relative to the "pile base mean elevation." Once the pile height is measured for each grid intersection, the average pile height is determined by dividing the total pile height by the number of points at grid intersections read. The average pile height is then applied to the area bounded by the "base of pile" limit line. The resultant computation of average height of pile times area of pile base equals volume of pile as portrayed in each photogrammetric stereo-model.

From the point of volume determination, factors such as compaction, density etc. are applied to achieve a final volume, which will be expressed in either cubic feet or cubic yards or tonnage.

The same entire process as described above is then repeated exactly, except that pile heights are established in the template grid square centers, and then used to establish a second "average pile" height. Ultimately another volume is arrived at as described in the preceding paragraph.

At this point the two independently arrived at volumes are checked against each other for possible errors. If they agree within 3% they are "meaned" together in order to obtain the final volume to which compaction, density and other pertinent factors are applied.

The elevations may be recorded by hand in adding machines, calculators or computers. They may also be recorded electronically by automatic read-out devices, attached directly to the stereo-plotters, and are thereby punched on tapes or cards for computations on a programmed computer system. There are several such electronic and computer systems available, and proven. No attempt will be made to discuss their comparisons.

The inventory report is made showing the date of photography—the date of inventory of every pile within the area—each pile number, type and classification of material, cubic feet, cubic yards and tonnage (weight). Historical experience records reveal that anticipated and guaranteed total volumetric inventory accuracy will be within 3 per cent of the actual material stored. The three per cent factor comparison is related to ground survey inventories made as a check against the reported inventory. It must be remembered that a ground survey method is physically and technically much more difficult. Therefore expecting an accuracy check of greater than three per cent is unrealistic.

The photogrammetrist must be furnished with compaction and density factors of the various materials in order to compute the tonnage. The records of moisture and density are normally maintained by the owners, and the information is readily available.

From experience, it is known that the Aerial Photogrammetric Method is at least 25% less costly than the ground survey method and is usually less by far on large programs. The accuracy is consistently reliable to within three per cent even on the smallest of projects.

All who may have an inventory requirement should investigate the application of Aerial Photogrammetry for this purpose.