TABLE 2

Paragraph	*Subject*	*Radial displacement*		
		Standard deviation	*Maximum value*	*Maximum spread*
		μ		
2.1.	Calibration, with collimator	2	3	6
2.1.	Calibration, with goniometer	1	2–5	5
2.2.	Asymmetrical distortion	3– 5	10	20
2.2.	Various lenses of same type	5	10	20
2.2.	Various lenses of same type	7– 5	15	30
2.3.	Different wavelengths	4	—	15
2.4.	Different diaphragms	—	3	6
2.5.	Different temperature	—	5	10
2.7.	Unflatness of suction plate	4.5	—	12
2.7.	Unflatness of best glass plates	—	—	10
2.7.	Unflatness of glass plates, due to developing	—	—	25
2.7.	Unflatness of diapositive glass plates	—	—	25
2.8.	Earth curvature, $h=3,000$ ft.	—	—	7
2.8.	Earth curvature, $h=24,000$ ft.	—	—	58
2.9.	Accuracy of plotting instruments	5–10	20	40
4.	Compensation device in plotting instrument	2– 5	—	25

6.5. *Desirable treatment.*

"Distortion" should be determined under flight conditions (section 2.11.) and treated with a projection printer (section 3.4.1.). Proceeding that way, residual "distortion" can possibly be kept within the $\pm 5\ \mu$ belt.

*Raw Material Storage Volumes by Photogrammetry**

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(*Abstract is on following page*)

GROUND METHODS

THE most common bulk material of which the volume must be determined periodically is stock-piled coal used for power generation. However, other materials stored in bulk piles include fertilizer, iron ore, limestone, sawdust, sand, and pulpwood. These piles range in size from 30 feet to 80 feet in height and from 125 feet in width to 3,000 feet in length. Early methods of measuring

* This is a slight revision of the prize-winning papers submitted in competition for the Bausch & Lomb Photogrammetric Award in 1959.

volume were usually educated guesses made by experienced men. But as the piles grew larger and as the bulk material increased in unit value, it became important to obtain more accurately determined volumes.

With the advent of fairly accurate physical measurements, the shape and density of the material became important factors. In the case of coal, which is inventoried by weight, its density may vary by as much as ± 8 per cent.[3] Density tests must then be taken at random in each pile. If the volume of a pile is to be measured physically in the field, then the surface of the pile must be so graded that a fairly regular solid is being measured. This is the current practice with coal and is accomplished using company graders.

Field measurements fall into two categories—vertical cross-sections taken at intervals along the longitudinal axis of the pile, and spot top-of-pile elevations determining average depth of the pile.[1] Vertical cross-sections are taken by means of transit-tape surveys using ground control previously laid out. Data are then taken into the office for reduction and plotting onto cross-sections which are then planimetered for end areas and volume computations. Cross-section data are also used for plotting elevation contours, contour interval one foot, on a plan map of the pile. Areas enclosed by these contours are then planimetered for the pile volume. Top-of-pile elevations can be obtained by transit-tape methods or by lowering a calibrated weighted chain from the bottom of the crane-way employed at many installations. Data are reduced to average heights of pile and the volume is computed using columnar sections. In either case a field survey party is required to spend several days crawling around on the graded pile making inventory cut-off time difficult to establish.

Aerial Photogrammetry

In 1951 the Tennessee Valley Authority began using vertical aerial photography for determining coal pile volumes.[2,4] The piles involved covered 30 to 40 acres and contained about 600,000 tons of coal piled 30 feet high. At first, only large piles of coal were photographed, but the method is now being used for small piles and for volume determination of fertilizer stock piles.

Photography is taken with a low altitude precision aerial camera, calibrated by the U. S. Bureau of Standards. Time and day of each photo is recorded. Photos are taken near noon to avoid shadows which, due to the color of coal, can cause trouble in final reduction to contour maps. Flight heights must be high enough to avoid blind spots on the edges of the pile, due to the high angle of repose (greater than 45 degrees) of the material. (For an $8\frac{1}{2}$ inch focal-length lens and two-foot contours a flight height of approximately 1,700 feet is required.) TVA maps are plotted to a scale of 1 inch = 40 feet, with one-foot side slope contours and a one-half foot contour on the top of the pile, using a Kelsh Plotter. The areas inside the contour lines are then planimetered to obtain a volume accurate to within 3 to 5 per cent. Sharp and distinct photographic images are required. Photos are taken with a fixed wing plane flown at an air speed of 50 to 60 MPH. Overlap is 55 per cent.

Under the proper conditions the photogrammetric method is more accurate than the field survey method and less expensive by approximately 25 per cent.[4] Usually several flights over each pile are made to insure photos free from the inevitable smoke cloud from the plant. Then the best stereopair may be chosen for mapping. The fact that the photos define the piles at a definite time is a distinct advantage. No dressing or grading of the pile is necessary beforehand. Ground-control, once laid out, can be used from year to year if undisturbed.

In summary then, volume determination by aerial photogrammetry has advantages of convenience, accuracy, economy (for large and numerous piles), definite inventory cut-off time, and the provision of a permanent photographic record.

Disadvantages include weather, smoke clouding, the color of coal (or the other ex-

Abstract: *Periodically companies having bulk materials stored in outdoor piles find it necessary to determine their volume for inventory purposes. Several methods are used at present for determining these pile volumes. This paper describes the volume determination methods currently in use and suggests a new method for use by small companies.*

treme, sand and fertilizer), and the time lag between photography and final volume determination.

In the above discussion photogrammetric volume determinations have been used for large and numerous piles by a large organization. If the same methods were to be applied by smaller companies with less numerous piles, the economical aspect would become a disadvantage outweighing the remaining advantages. However, the author believes that the original advantages may be profitably retained by using a different approach to the problem.

Terrestrial Photogrammetry

Therefore, it is proposed that the configuration of the surface of material storage piles, and thus their volumes, be determined by means of terrestrial photogrammetry. Most stockpiles have adjacent structures, such as power plants, that rise far enough above the tops of the material to provide photographic coverage of the pile from the top and all sides. Two photos will be from above and two from ground level or slightly above, to obtain coverage on the far side. Camera locations can easily be established on crane runways and building parapets, and can be used repeatedly as can ground-control points. Direction and horizontal-control data can easily be determined, using standard field methods. Oblique terrestrial photographs of a material pile can be oriented in plotters of the Multiplex or Kelsh type.[5] Such an oblique orientation is useful for horizontal and spot vertical control, but not contour lines. While contour lines cannot be drawn using these instruments, vertical profiles can be constructed which will be equivalent to the cross-sections obtained in the field. The elevations from these cross-sections can then be plotted and contours drawn and planimetered to obtain areas, with volumes being easily obtained in the usual manner. The accuracy of this volume determination will be essentially the same as that obtained using vertical photography.

The foregoing method has the advantages of aerial photogrammetry and several others. Smoke is less likely to be a problem due to lower altitude and also the ease of waiting for it to clear. Photographs may be taken under the smoke billows, with the final picture being affected by a shallow and not a hazy cloud. The cost of the ground camera set-up is less per photo than for a flown vertical photo. The ground camera station location data may be re-used repeatedly. Images can be larger, due to proximity of camera to material, making the use of scattered targets on the pile surface profitable.

The scattered target system involves the placing of 4 to 6 inch contrasting color targets of cardboard, wood, or aluminum on the surface of the pile so that they will show up in the photographs as man-made picture points. Such systems can be controlled as to cross-sections or left uncontrolled for spot elevations. The contrast in color of the targets with pile material makes them readily visible to aid in the surface location and definition. If many targets are used, a large numeral, different for each card, is advisable.

Disadvantages include a longer processing time for the topography, and possible difficulties in obtaining profiles from the photos.

This ground photo process of inventorying stockpiles can be easily handled by available plant personnel, requiring outside assistance only for obtaining the profiles from the photos. Even the use of a Multiplex type plotter may be omitted by using the scattered target system on a graded pile and computing the positions of the target points by conventional terrestrial photogrammetric methods.

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