cedures: that human errors can and do creep into the data with unfortunate frequency. The TDT was designed to eliminate most of the sources of human errors normal to conventional measuring and recording methods. This has been done by limiting the principal function of the human operator to setting the floating mark on the ground at points along the selected profile or cross-section. Station number, distance in feet left and right from centerline, and elevation of individual points on the line are all automatically recorded in digital form by the TDT when the record button is depressed.

Terrain notes compiled in this manner by the TDT are free of human and machine errors providing the stereo model is accurately scaled, leveled, and free from excessive warpage. The photogrammetric engineer can best assure this model accuracy by:

1. Utilizing precision "distortion free" mapping photography.
2. Establishing sufficient horizontal and vertical ground control points (signalized if possible for positive identification in the plotter).
3. Maintaining the stereoplotter in good calibrated condition.
4. Performing a rigorous and exact relative and absolute orientation when setting up the model.
5. Checking model accuracy from spot height readouts on known elevation control points.
6. Possible use of convergent photography in place of the normal vertical photography in order to achieve a "harder" model.

The Terrain Data Translator successfully automates one aspect of the terrain data problem. Many groups are working on additional automatic devices and soon equipment should be available which will further enable the production of engineering data using only a minimum of human effort and time.

Some Applications of Terrestrial Photogrammetry to the Study of Shorelines

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(*Abstract is on next page*)

INTRODUCTION

THE analysis of shoreline processes requires accurate descriptions of the ephemeral features of the shore zone. The investigator usually requires a sequence of dated topographic maps, each having been completed with sufficient rapidity as regards changes in shore features so that it is, in effect, synoptic. The sequence of synoptic maps then provides the basis for identifying and analyzing processes which vary with the passing of time. One seeks to map variations in size, shape, and slope of beaches and bluffs; changes in inshore hydrography; height, period, length, and direction of approach of water waves; and trajectories and velocities of water currents.

Conventionally, the topography of beaches, bluffs, and nearshore shallow areas has been mapped by plane-tabling. The recording echo-sounder has provided inshore hydrography in depths greater than the safe draft of the survey vessel. These mapping techniques usually require so much time that parts of a shore sector often change radically by the time the survey party has worked the length of the sector.

Typically, data on currents and waves have been obtained by hydrologic and oceanographic methods which are fairly widely used, but are rarely synoptic in their execution.

Within the last decade, the delineation of shore features by photography has met the needs of many studies. McCurdy (11), Dietz (5), Teichert and Fairbridge (13), Shepard (12), and McBeth (10) have described and illustrated delineative and interpretative photographic operations.

The Beach Erosion Board (2) has presented a discussion of the relative merits and costs of aerial (stereo) photogrammetric and plane-table mapping of beaches. Tewinkel (14) has shown how aerial photography can be used to furnish control data for inshore hydrographic surveys.

Cattelain (4) has mapped trajectories and velocities of water currents along the Belgian coast, using two sequences of aerial stereophotographs of current transported target-floats. Marks and Ronne (9) have devised ingenious methods for stereophotography of ocean waves, utilizing synchronized exposures from two airplanes; "ground" control has been provided by a ship towing a target at a fixed distance.

Zeigler and Ronne (15) have taken timelapse oblique aerial color photographs of the entire coastline of the United States from Eastport, Maine, to Brownsville, Texas, at the rate of two photographs per second at flight speed of 110 knots. The photographs are then shown as a motion picture. They plan to repeat this flight at least once a year.

Baker and Chieruzzi (1) have used aerial photography for producing detailed topographic maps of a section of the Lake Erie shoreline in which they were studying bluff recession.

ABSTRACT: *Normal horizontal and normal oblique terrestrial photogrammetry applied to field and laboratory shoreline situations, respectively, yield results which nearly or fully meet the requirements of coastal engineering geology. The photogrammetric theory underlying this work is that presented by Zeller (16).*

In studies of this kind terrestrial photogrammetry provides: topographic information which is synoptic, or nearly so; views of gentle beach features which present their outlines in their most conspicuous aspect; the opportunity to obtain the photography during weather which might prevent aerial work; the opportunity to collect samples while the photography is being obtained; probably a significantly lower operating cost than the cost of aerial work for the repeated mapping of discrete strips of shoreline.

A Speed Craphic camera has been used for recording beach profiles drawn by the image of a point source of light which is dragged over the beach along the desired line of profile.

Limitations of these techniques are discussed, as is a suggestion for future work.

Reasons for Using Terrestrial Photogrammetry in Shoreline Studies

The author has undertaken an investigation of the possibilities of using terrestrial photogrammetry in studying shorelines, for the following reasons:

a) Photographs taken on the beach and in a direction parallel to the shoreline yield a wealth of synoptic topographic and geologic information not available from plane-table mapping. A few pairs of photographs can often cover waves, beach, and dunes or bluffs. The mapping of waves requires, of course, special equipment to insure synchronized exposures in each pair of photographs.
b) Terrestrial photographs of steep-faced bluffs yield more information than do aerial photographs, particularly if the plane of the photograph is nearly parallel to the bluff surface. In general, this requires camera stations on the beach, directed away from and perpendicular to the shoreline. Jury (7) has presented an analysis of an almost identical situation involving mapping a moving ice-cliff by terrestrial photogrammetry; the use of a vertical datum-plane yields a mapping situation very similar to that of the aerial case.
c) Shoreline features of low relief present their most distinctive aspects when

viewed and photographed horizontally. Gentle but genetically important surfaces might well be missed in aerial photography.

d) A field party for terrestrial photogrammetry can accomplish the necessary photography in weather conditions that might prevent aerial operations. Furthermore, the same party can supply the necessary geodetic controls and can collect samples of sediment at points to be located precisely by the mapping.

e) The operating cost of terrestrial photogrammetric mapping is clearly lower than that of aerial photogrammetric mapping if discrete strips of shoreline are to be mapped repeatedly, as for example, before and after storms during certain seasons over a period of several years. This requires that control points survive for the duration of the survey.

f) Only the camera stations and the control points need be occupied, thus surfaces can be left undisturbed to a far greater extent than is possible in plane-table mapping.

g) The theory of horizontal terrestrial photogrammetry is quite simple, although certain problems of plotting arise in such work.

An Application of Terrestrial Photogrammetry to the Study of Lake Erie's Shorelines

Kelley (8) has applied the principles of Zeller (16) and Hallert (6) while assisting in a mapping project undertaken by the author, under terms of a grant from the Ohio State University.

The fundamental difficulty to be overcome arises from the geometry inherent in the problem: the optic axis of the camera is very nearly parallel to the surface to be mapped.

For the type of work in engineering geology done by the author on the Ohio shoreline of Lake Erie, it is required that in general horizontal distances and elevations of beach and bluff surfaces be mapped accurately to 1.0 foot and 0.1 foot, respectively.

Kelley has used a Wild photo-theodolite (on loan from the Arctic Institute of North America) in the field; profiles can be then plotted from data yielded by the Wild Autograph A-7. He has applied an analogous method to the study of a laboratory model, obtaining the photography with a Wild

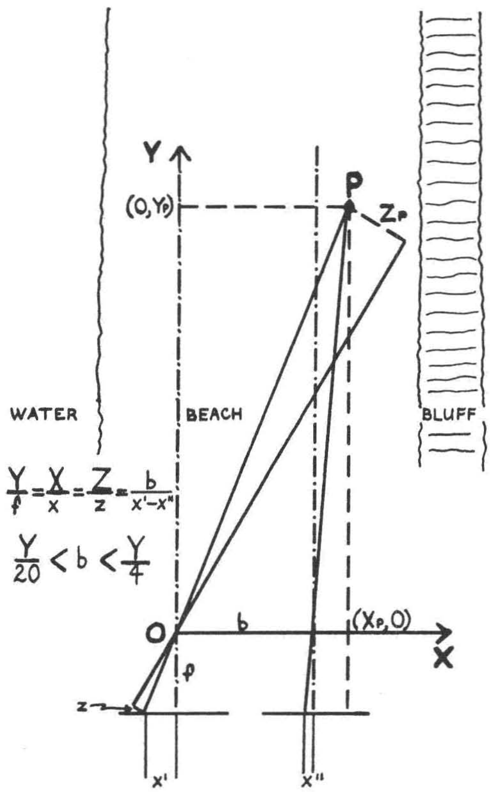

FIG. 1. Normal horizontal terrestrial photogrammetry applied to a beach situation.

stereometric camera, with 40 cm. base.

In the field operations conducted by Kelley (8), the median distance in the photographic field was typically 100 meters, with a base-length of 10 meters. The maximum working distance was about 200 meters, with a base-length of approximately 20 meters. His set-up was that of the normal case of terrestrial photogrammetry, i.e., the camera axes were parallel to each other and perpendicular to the base-line; the camera axes were pointed parallel to the shoreline (Figure 1). He used Gevaert arti-halo, rapid ortho plates having a film speed equivalent to A.S.A. 10, with yellow filter; the nominal value of the photo-theodolite's fixed aperture is $f/12$. Control for location and elevation of the photo-theodolite was established in the field (Figure 2); the focal-length of the camera was determined from the available field photography, and its accuracy was improved to the required level with an iterative plotting procedure.

The photo-theodolite's negative plates were introduced directly into the A-7 Autograph for plotting. Some difficulties arose

FIG. 2. View of beach on Lake Erie west of Fairport, Ohio (August 1955) showing control targets and general aspect of photographs used in this project.

in plotting because of blind spots behind dunes, and because of the almost uniform tone of large stretches of beach surface (Figure 2).

To provide a basis for calculating volumetric changes in the beaches, sets of synoptic profiles may be plotted. To plot a profile, one establishes first the midpoint of the plotted base; a perpendicular is then drawn through this midpoint. At specified intervals along the perpendicular, lines are drawn parallel to the base. On these lines, elevations are determined for points whose locations are also determined (Figure 3).

An Application of Terrestrial Photogrammetry to the Laboratory Study of Shore Processes

In the laboratory operations conducted by Kelley (8), the median distance in the photographic field of the stereometric camera was typically about 4 meters, with the camera base length fixed at 0.40 meter. Photographing a model beach set in a wave tank which was 12 feet long and 4 feet wide, he was able to cover the field from either side or from one end, using normal oblique terrestrial photogrammetry; for exposures from one end, he depressed the cameras 15 g.

Each of the two cameras in the stereometric unit has both diaphragm and shutter. Apertures range from $f/12$ through $f/36$ in three steps; shutter-speeds range from time and bulb through 1/300 second.

The surface slopes of the model beaches ranged from 1:6.5 to 1:10. Following in general a scale factor of 1:10, several types of beach configurations were produced. A simple but effective wave generator provided the means for modifying beaches as observed in certain field situations; in this way, it was possible to produce sets of "before-and-after" maps, and from them to calculate volumetric changes (Figures 4a and b). It was quite a simple matter to produce maps of the offshore bottom by pumping the water out of the wave tank and

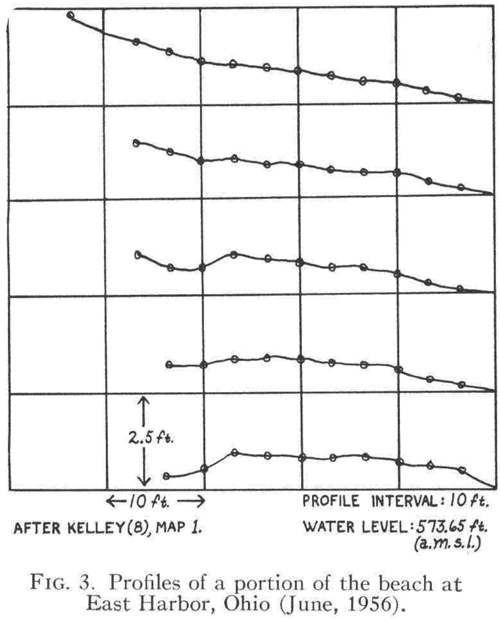

FIG. 3. Profiles of a portion of the beach at East Harbor, Ohio (June, 1956).

photographing sub-aerial and sub-aqueous surfaces in the same pairs of pictures.

In order to plot with the A-7 from the stereometric camera's plates, it was necessary to enlarge them to provide an apparent principal distance lying within the A-7's range. Kelley chose an enlargement of 2×, changing the nominal principal distance to 180 mm.; an iterative procedure was used to adjust the value of the principal distance.

The plotting scale was 1:10, and the relation of scales of the instrument and the plotting was 2:3; hence the instrument (model) scale was 1:15. Each model beach was mapped with a contour interval of 0.05 ft. The floor of the tank was taken as the horizontal datum.

In the laboratory case, the plotting operation was relatively simple. The coordinates of control points were obtained with ease, and direct measurements could be made of features in the model; even stereophotography of water waves could be checked against data obtained from wave meters. Here, there was less difficulty in placing the floating mark in contact with the beach surface than in the horizontal case using the photo-theodolite.

The residual position and elevation errors computed by Kelley are as follows:

	Standard Error	
	Horizontal	*Elevation*
1. *Photo-theodolite*, scale 1:100 (10 control points) (*Profiles*)	±.31 ft.	±.02 ft.
2. *Laboratory model*, scale 1:10 (4 control points) (*Map*) (*Before wave action*)	±.03 ft.	±.02 ft.
3. *Laboratory model*, scale 1:10 (4 control points) (*Map*) (*After wave action*)	±.05 ft.	±.02 ft.

For the field situation involving the photo-theodolite, the tolerances of 1 ft. (Horizontal) and 0.1 ft. (Elevation) were not exceeded. In the laboratory model (scaled 1:10), with fewer control points, the tolerance of 0.1 ft. (Horizontal) is met, but that of 0.01 ft. (Elevation) is not quite met. Assuming the errors to be distributed according to the Gaussian law, the maximum errors to be expected can be estimated as approximately three times the standard error. Hence half of the values tabulated above yield a maximum error which also falls within the prescribed limits.

For future work, Kelley (8) recommends that the base-line be parallel to the waterline, and that the elevation of the photo-theodolite be increased; these modifications would simplify plotting and eliminate some of the blind spots. He suggests that the pictures be taken from the water, i.e., directed landward, and that photography be restricted to the middle three or four hours of daylight to minimize shadows. The author does not believe that his proposal that the photo-theodolites be mounted on towers in shallow water is operationally feasible, since this arrangement would usually involve wave-induced vibrations, and the problem of recovering camera stations for sequences of maps and profiles. Kelley also suggests using shallow draft ships carrying one or two photo-theodolites, and low-attitude aerial photography.

Experiments with a Non-Photogrammetric Camera

In the early days of the project prior to the work described by Kelley (8), he and the author experimented with a 3″×4″ Speed Graphic, equipped with plates, to obtain stereo photography. Although this camera is an excellent photographic instrument, it was not designed for the kind of work that was being attempted; consequently the quality of the plotted results led to turning to the photo-theodolite and stereometric camera. It is entirely possible that with more skill, better results might have been obtained with the Speed Graphic; Burkhardt (3) has described the use of a 35 mm. camera for photogrammetric work on architectural objects.

Regardless of how inexpensive a method may be devised for obtaining the photography, the plotting must still be run through expensive equipment; hence economy of this type is almost always bound to be more apparent than real.

The Speed Graphic has been used effectively, however, in a rapid beach profiling technique which may be quite useful in studies requiring only rough estimates of volumetric changes; or where the mere

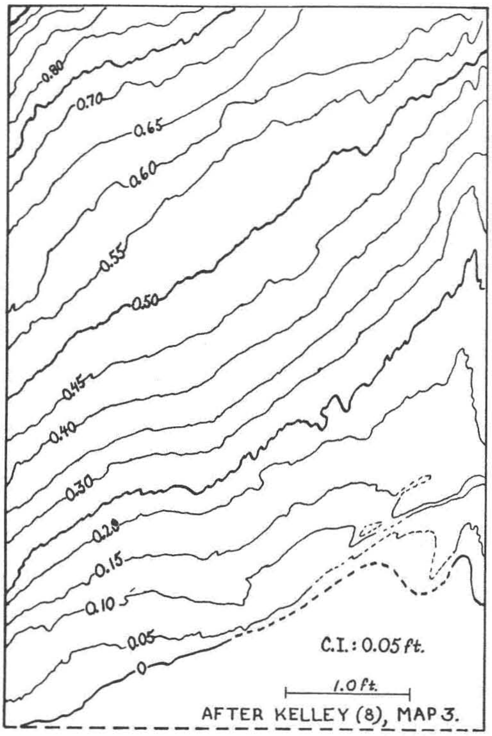

FIG. 4(a). Map of model beach.

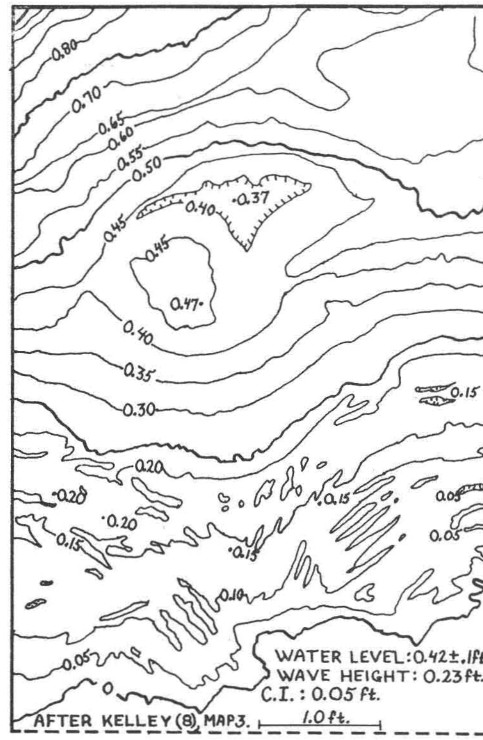

FIG. 4(b). Map of same beach as shown in Fig. 4(a), after an additional 45 minutes of wave action.

change in shape or vertical position of the profile is significant. By moving a light along the desired line of profile at night, and using a camera with open shutter as the recording instrument, a profile can be drawn rather quickly (Figure 5). Obviously, sequences of such profiles can be made by reoccupying the same stations at different times.

This procedure has been carried out quite easily. An ordinary, two-cell flashlight served as the light source, with the flashlight and camera pointing toward each other along a line approximately perpendicular to the profile to be drawn. The light was clamped to a two-foot long pointed plank, or sled, which one man drew along a prearranged line of profile, from the water's edge to the top of the bluff or the inner edge of the beach. Apertures of $f/4.5$ and $f/6.3$, and XX Film yielded satisfactory tracks.

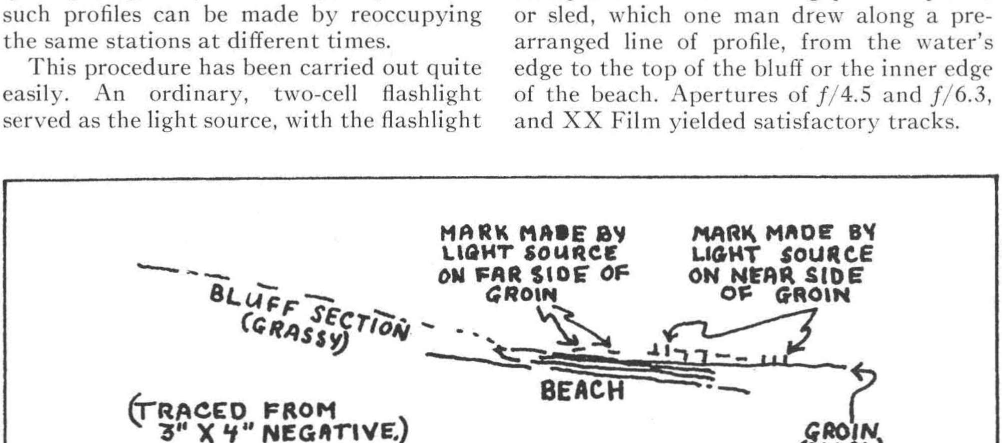

FIG. 5. Profiles of beach at Lakeview Park, Ohio (July 1954), drawn by dragging a light across the beach along predetermined lines. Scale: from 1 to 2: 100 ft.; from 2 to 3: 75 ft.

For a scale check, the man pulling the sled concluded some of the profiles by sliding the light vertically across a marked one-foot interval on the sled.

Where a number of profiles are to be recorded on one exposure, each profile can be numbered on the exposure by the sled operator. The assistant merely removed the light from the sled, and facing away from the camera, with the light pointing over his shoulder toward the camera, he wrote the number in space, as he would on a large blackboard.

By using previously established horizontal control the map positions of the profile and the camera were located. One may, of course, apply stereoscopic methods here, and photogrammetric cameras may be used, but we have not carried our work beyond the one-camera, Speed Graphic step.

For mapping inshore lake-bottom topography (water less than six feet deep), a discontinuous but well-defined profile has been drawn in the following manner. The rodman lowered a stadia rod, or some other marked rod, to the lake-bottom at selected points along the profile; he worked from a small boat, or from a structure like a groin. By flashing a light held against the rod at a known distance above the bottom, the rodman placed a dot or dash on the film at each rod station. It is easy to splice such offshore dot profiles to their continuations above water level, by adjusting for the distance of the light above the bottom. Profiles on opposite sides of a groin can be coded by using dots or vertical dashes on one side and horizontal dashes on the other (Figure 5).

The initial attempts to profile nearshore, beach, and bluff zones by this method have been very encouraging. The negatives obtained show all of the markings as black lines or dots, bearing a striking resemblance to the inked profiles which are part of the standard diet of the coastal engineer and geologist.

Similar methods are applicable to the study of currents. Current floats have been constructed and topped with miniature electric lamps, their dry cells serving a second function as ballast at the bottom of the vertical rod. The simulated movement of these floats has been tracked satisfactorily, using *f*/6.3 and *f*/4.5 apertures, and XX film. Here one may close the shutter for a fixed time at the end of a fixed interval, in order to place time breaks on the float paths.

Dr. Bertil Hallert, in a personal communication, reported that a comparable method utilizing stereophotography has been used successfully for mapping currents in waters off southern Sweden.

The disadvantages of the moving light method are as follows:

1) Stray light sources and reflections from the water's surface may be troublesome.
2) The work is restricted to night hours.
3) People in the area of the study invariably congregate around the camera and the light sled; many feel impelled to stare into the lens, despite pleas from the phtographer.
4) As used in this project, it is at best only a type of reconnaissance method.

Suggestions for Future Work

Many possibilities for future work have been implied in this paper, and need not be spelled out.

One possibility not implied involves the mapping of the inshore bottom by terrestrial photogrammetry. A method proposed by the author and described by Kelley (8) utilizes photographs of nearly vertical graduated rods of known length which touch bottom. The rods are supported at the water's surface by floats, and are long enough to present suitable targets above the water's surface. By photographing the rods simultaneously from two stations, the coordinates of points on the rods can be determined. Since the tilt of the rods can be calculated from the available photography, the elevation of the bottom can also be calculated. By properly distributing the rods and camera stations, synoptic elevations of the inshore bottom can be obtained in any desired horizontal pattern.

If the water's surface is not disturbed by waves and if the bottom materials are stiff but easily penetrated, pointed graduated rods carrying bearing plates at fixed points can be forced downward until the bearing plates rest on the bottom. In this way the rods can be placed in attitudes which are so close to vertical that the errors introduced by tilt (cosine of the angle of tilt) may be so small that they can be ignored.

Concluding Remarks

The methods of photogrammetry have much to contribute to the study of shorelines. Terrestrial photogrammetry meets many of the needs of shoreline studies, particularly if discrete strips of shoreline are to be mapped repeatedly or if maps of bluffs adjacent to the beach are required.

The development of suitable photogrammetic methods for the wide variety of situations encountered in shoreline studies will very likely depend more on new techniques than on new equipment; the equipment now available appears to be quite adequate for the levels of accuracy required.

The experience gained in this project underscores the need for acquiring skill in obtaining the photography. A knowledge of both the elements of photogrammetry and the essence of the problem which the photogrammetry is to serve is necessary for effective field operations.

Acknowledgments

Mr. Robert A. Kelley's tireless efforts have contributed materially to the substance of this paper; it is regretted that he has been unable to participate as a co-author. The reader interested in details of his work not mentioned herein are referred to his unpublished report (8).

The assistance of Professors Arthur Brandenberger and Frederick Doyle of the Ohio State University is gratefully acknowledged. The former served also as principal adviser to Mr. Kelley in the preparation of his thesis.

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