# SESQUICENTENNIAL OF THE U.S. COAST AND GEODETIC SURVEY

## SYMPOSIUM

*As announced in the preceding issue of the* International Hydrographic Review, *the publication of extracts from articles appearing under the above title in Volume XXIII, No. 2, of the April 1957 edition of* Photogrammetric Engineering *on the occasion of the one-hundred-and-fiftieth anniversary of the U. S. Coast and Geodetic Survey is being continued below.*

## II. — CONTROL FOR PHOTOGRAMMETRIC MAPPING

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Horizontal and vertical control surveys conducted by the Geodesy Division of the Coast and Geodetic Survey provide the basic framework for photogrammetric mapping. Any considerable extension or breakdown of the basic network that is necessary to control a mapping project is accomplished by photogrammetric field parties using second-order triangulation, traverse or leveling methods. Additional unmonumented, lower-accuracy surveys are then made to provide control points in designated places for the photogrammetric plot and for stereoscopic contouring. Instruments generally used for these control surveys are the Wild Theodolite T-2 and the Zeiss Opton Level. The accuracy standards established and followed by the Bureau in the location of geodetic control provide a strong foundation for all subsequent mapping and charting operations.

The mapping operations of the Photogrammetry Division are designed to meet the National Map Accuracy Standards at manuscript scales of 1/5 000, 1/10 000, 1/12 000 and 1/20 000. Furthermore, selected points for the control of hydrography or aids to navigation must be located within 0.25 millimeter at the mapping scale. To insure meeting the prescribed standards, particular emphasis has been placed on the careful selection and identification of control.

The ideal method of control identification, namely marking the stations with targets before photography so that the image is visible, has generally proved to be impractical. The extra work involved in marking the stations prior to photography and maintaining these targets until after the completion of photography is prohibitively expensive. Marks have been set and are maintained in the Ohio test area for use in the calibration of the nine-lens camera and in this case, the results warrant the cost. In practice, the control stations are visited after the photographs are available, and the image of the station is identified either directly or by the substitute station method.

Direct identification is used exclusively for prominent objects, such as church spires, tanks or stacks, whose images can be easily seen on the photographs. The substitute station method is most commonly used and provides a high degree of accuracy although the image of the basic control station cannot be identified.

One or more well-defined image points near the station, such as road intersections, forks in streams, or small trees that can be positively identified on the photographs are stereoscopically examined in the field and marked with fine points pricked with a needle. (Figure 1). The distance from the control station to the substitute station is measured in feet and in meters and the azimuth is determined by measuring the angle to another control station or azimuth mark, or by a solar observation. Two independent pointings are made in determining the azimuth to provide a check. All the information plus a large-scale sketch at the vicinity of the station is recorded on a special form provided for this purpose. (Figure 2.) A geographic position is later computed for the substitute station by the compiler and this is plotted on the manuscript in lieu of the control station.

Bridges by stereoplanigraph or multiplex can then be triangulated and adjusted graphically to fit the plotted control, and the models reset for detailing. Similarly, nine-lens radial plots are laid to fit the plotted stations after which detail points are located by intersection. The accuracy of these methods depends on the ability of the compiler to plot control points accurately. Other important factors are the possibility of mechanical error introduced by the coordinatograph of the plotting instruments, ability of the instrument operator to see the exact image identified, or the skill of the compiler in the preparation of templets used in radial plotting.

Recent improvements in the techniques of stereoscopic instrument bridging and adjustment have tended to eliminate these sources of possible error. Most of our horizontal bridging is being done on Zeiss Stereoplanigraphs, C-5 and C-8, and a Wild Autograph, A-5. Adjustments of the observed coordinate values are accomplished mathematically on the IBM Electronic Computer, No. 604 and also graphically. Instrument coordinates are read and recorded for all points to be located along with a minimum of three control stations in any single strip. All points can be read within 0,03 mm at the model scale. These coordinates are then mathematically scaled and rotated, based on the geodetic-coordinates of stations that were identified at each end of the strip. Residual systematic errors at all control stations along the strip are then removed graphically.

Instrument departure from true coordinate positions results in smooth curves so that the magnitude of discrepancies at centrally located control enable the adjuster to apply a systematic correction to all points. Four elements involved in this adjustment are azimuth, scale along the flight line, and their secondary effects of swing of the individual models and scale normal to the flight line. Corrected instrument-coordinates are then converted to true ground-coordinates. (The accompanying paper by Mr. G.C. Tewinkel presents a detailed explanation of this adjustment method.)

Currently, a greater effort is being made in this Bureau to improve the accuracy of the photogrammetric location of nautical and aeronautical aids to navigation, obstructions, dangers to air and sea travel, and control for hydrographic or airport surveys. Economic factors demand that these locations be determined by bridging relatively long distances, with high altitude photography, with a minimum

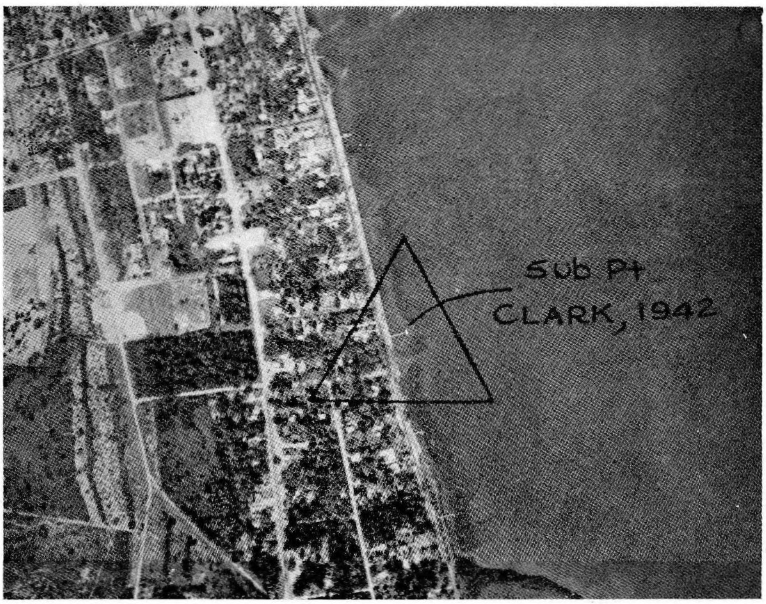
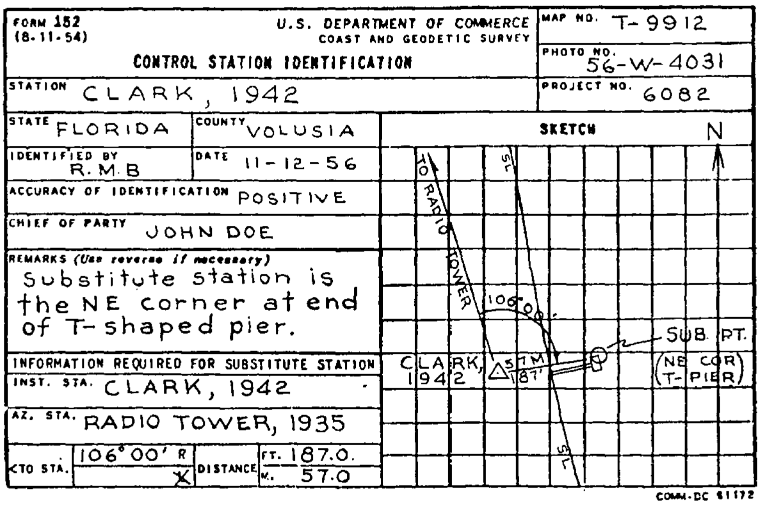



*Fig.* 1.
Part of an aerial photograph illustrating the identification of substitute horizontal control station.

of additional field control surveys. The potential accuracy of positions determined by modern bridging methods has necessitated a re-assessment of tolerances which have been allowed field men in the identification of control. Until recently he was allowed an error of 0,15 mm at the scale of the photography, in the identification and measurements for position of the substitute control station. This tolerance was realistic as it approached plotting accuracy, but the highly magnified image afforded by a first-order plotting instrument displays the 0,15 mm error as being more than five times the observational discrepancy. Inasmuch as a chain is only as strong as its weakest link, new instructions are being issued to reduce this possible source of error.


FORM 152 (8-11-54)
U.S. DEPARTMENT OF COMMERCE
COAST AND GEODETIC SURVEY
CONTROL STATION IDENTIFICATION
MAP NO. T-9912
PHOTO NO. 56-W-4031
STATION CLARK, 1942
PROJECT NO. 6082
STATE FLORIDA
COUNTY VOLUSIA
IDENTIFIED BY R. M. B
DATE 11-12-56
ACCURACY OF IDENTIFICATION POSITIVE
CHIEF OF PARTY JOHN DOE
REMARKS (Use reverse if necessary)
Substitute station is the NE corner at end of T-shaped pier.
INFORMATION REQUIRED FOR SUBSTITUTE STATION
INST. STA. CLARK, 1942
AZ. STA. RADIO TOWER, 1935
∠TO STA. 106°00′ R
DISTANCE FT. 187.0 M. 57.0
SKETCH
N

COMM-DC 41172

*Fig. 2.*

A control station identification card showing how a substitute station is identified and how it is referenced to a monumented triangulation station.

Wherever practical, the personnel of photogrammetric field parties are trained in the techniques of aerotriangulation, and are given the opportunity to view and study the stereoscopic model in the bridging instrument. This demonstrates to them the necessity for care in the selection of substitute stations and the type of image that is most useful for accurate results. Until recently, the identification of the center of a road intersection or a small tree would suffice. New instructions specify the use of points such as corners of fence lines and piers, sidewalk and small ditch intersections, small bushes, and other suitable images that the stereoplanigraph operator can positively identify within 0,05 mm at the model scale. The selection of more than one substitute station at each control station eliminates the possibility of gross misidentification. Because of a scarcity of suitable images near the station, the field man must often select points further removed than was previously the case. He must, however, employ methods that will insure an accuracy within one foot for the computed position of the substitute station. As it is impossible to actually prick the image point on field prints of the photographs within the prescribed accuracy, the approximate area is indicated. A detailed sketch on the Control Identification Card is submitted so that the instrument operator can obtain a reading on the exact point. An approximate north arrow is included to eliminate doubt and to assure the correct orientation of card and photograph.

Experiments are underway in the Coast and Geodetic Survey to adapt a mathematic adjustment bridging procedure to the nine-lens photograph system instead of the radial plot in current use. As precise measurements with a comparator are needed, the refined method of control identification mentioned above is essential.

Experience with mathematic solutions of large-scale, horizontal-bridging problems under minimum control conditions is limited. Few tests have been conducted to determine the number and spacing of control stations needed to achieve specified results. As the accuracy of our basic control is known, it is believed that the possible error of control identification has been reduced to a minimum. Excellent results have been obtained with three short bridges approximately twenty models long. The flights were bridged in the vicinity of three different airports, and positions were obtained photogrammetrically for points previously located by field methods. Three control stations approximately ten miles apart were used in each adjustment. The results showed that the standard error in the positions of the test points relative to the national datum was under five feet or within 0.05 mm on the 1/30 000 scale photography.

Experiments to provide additional information on horizontal-bridging, that is, on the practicable lengths of such bridges, the control requirements, and the consistency and accuracy of results are now being planned.

An experimental strip has been flown and tests of various horizontal-bridging procedures and adjustments are contemplated in the spring of 1957. This strip is eighty miles long consisting of approximately thirty-five models. Horizontal-control is spaced five to ten miles apart along the flight line. The problem consists of determining photogrammetric positions of points previously located by second-order field methods near the center and along the strip. Several methods are to be employed in the adjustment. Different combinations of control stations spaced at varying intervals are to be used to adjust a single instrument run. Another test will determine the magnitude of instrument deviation at the center using two geodetic-control stations 40 to 80 miles apart, together with an intermediate taped distance and a known azimuth. Experiments are being scheduled in an effort to cancel the bow effect by triangulating the strip in opposite directions with the diapositives set in opposite instrument cones. It is hoped that the results of these tests will establish a criterion by which control requirements to meet specifications under special conditions can be predetermined.

Vertical-control for the contouring of coastal areas is provided by usual methods and requires little discussion here. In Alaska most of this contouring is done with nine-lens photographs. The tidal water surface provides a considerable amount of vertical-control information and additional elevations are established back from the shore as needed, usually by trigonometric methods. Vertical-bridging is generally limited to two and occasionally three nine-lens models. In the United States stereoscopic contouring is done with both nine-lens and single-lens instruments, and control is provided in practically every model. This vertical-control is usually established by spirit leveling, sometimes by trigonometric leveling from bench marks of the basic network.