THE VARIABLE ELEVATION WEDGE

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IN THE April–May–June, 1945 issue of PHOTOGRAMMETRIC ENGINEERING Stephen H. Spurr of Harvard Forest described an elevation wedge which had been developed at Harvard Forest primarily for the measurement of tree heights from stereoscopic pairs of aerial photographs. Prior to the publication of that description Mr. Spurr gave permission to the organization in which the author of this paper was at that time employed to use or adapt the elevation wedge to any purposes which it might fulfil satisfactorily.* It is the purpose of this paper to describe an adaptation of the original elevation wedge, and in so doing, it is desired to accord to Mr. Spurr and his associates due credit for conceiving a method of measuring elevation differences on stereoscopic pairs of aerial photographs by means of two rows of dots on a transparent sheet as described in the paper referred to above.

The original method developed at Harvard Forest involved two rows of small dots reproduced on a transparent sheet. These rows of dots were inclined slightly toward each other. Figure 1 illustrates one of the Harvard Elevation Wedges. The dots were equally spaced along the rows, and hence the transverse distances

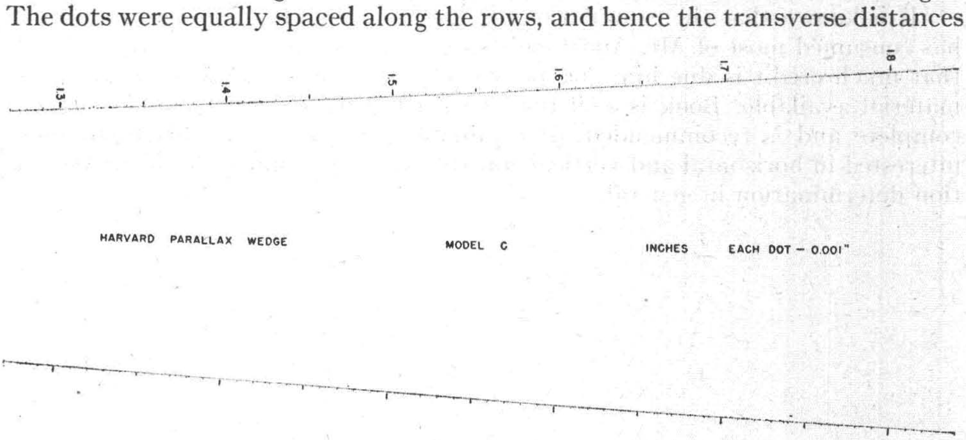

FIG. 1

between successive pairs of dots varied by equal increments. When used as a parallax measuring device, the parallax increment for each successive pair of dots was a constant quantity. This constant parallax increment was then converted into terms of elevation difference by the application of mathematical expressions which were derived from the flying height, the air base, and the focal length of lens in the aerial camera. On the wedge illustrated in Figure 1 the parallax increment for each successive pair of dots was .001 inch. For operation, the transparent overlay was laid on two overlapping photographs which had been carefully oriented under a stereoscope. Then, using the floating dot principle, differences in parallax were measured from which elevation differences were calculated.

The variable elevation wedge employs the same basic principles as the fixed elevation wedge but has incorporated in it certain provisions which permit adjustments to be made so that readings can be taken directly in terms of feet difference of elevation between selected points. Since the relationship between

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elevation difference and parallax difference is not a straight-line relationship, the dots are placed at gradually increased spacings along the rows to compensate for this fact. Furthermore, the variable wedge can be adjusted for use with con-

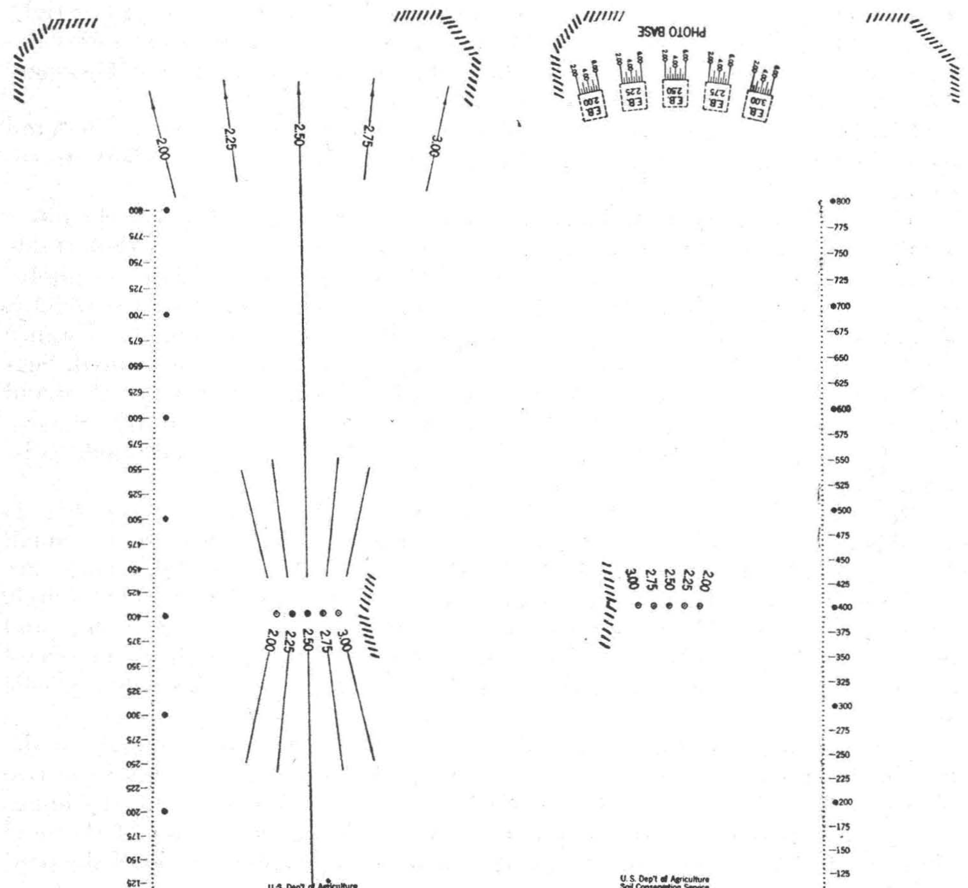

FIG. 2. Pointer sheet shown on left, the scale sheet on right.

tact prints, reductions, or enlargements made from any aerial negatives which were exposed from an approximate height of 13,750 feet above average terrain. That altitude is generally required by several Government agencies. Aerial photographs taken with any focal length lens can be used; the flight altitude is the governing consideration. Normal overlap in line of flight is necessary. The wedge which will be described is for use with a simple lens stereoscope. A wedge of the same type could be made for use with mirror stereoscopes. Also, wedges could be made for flying heights other than 13,750.

The variable elevation wedge consists of two transparent sheets of topographic base film which are illustrated in Figure 2.

The left sheet will hereafter be referred to as the pointer sheet; the right sheet will be called the scale sheet. The rows of dots and the pointers and scales are photographically reproduced on the under surfaces of the sheets. The spacings, along the rows, between successive dots, are not equal.

It is believed that the best way to describe this device is to outline in detail the procedure for using it in conjunction with any common type of lens stereoscope.

The distance between stereoscope lenses should be adjusted to suit the interpupillary distance of the observer, so that he can experience comfortable stereoscopic vision without any eyestrain. Then, a pair of overlapping photographs should be oriented under the steroscope so that a good sharp model is seen. While the photographs remain temporarily in this position, the distance between any two like images on the two photographs should be measured. Several such measurements between successive pairs of points should be taken and the average figure obtained. This distance will hereafter be referred to as the eye base. Let it be assumed for illustration that the distance has been found to be approximately 2.60 inches.

Referring to the illustration of the scale sheet and the pointer sheet (Fig. 2) it will be noted that each sheet has a horizontal axis on which there are five small dots surrounded by circles and labelled 2.00, 2.25, 2.50, 2.75, 3.00. These are eye-base distances. The operator should select, on the pointer sheet, the circle whose labeled value is nearest to the actual measured eye-base distance, and place it exactly on top of the similarly labelled circle on the scale sheet. The exact center of the two coinciding circles should now be pierced with a fine needle point

Next, a distance which is arbitrarily termed photo-base should be determined. This may be found by measuring, with a scale, on each of the two photographs to be used, the distance between the photo-center and the image on the same photograph of the point which appears at the center of the next photograph. This measurement should be made on each photograph of the pair, and the two figures averaged.

Next, the transparent sheets are to be adjusted for photo-base. With the two eye-base circles marked 2.50 in perfect coincidence, a fine needle should be placed in the needle holes. The pointer sheet should now be rotated with respect to the scale sheet, using the needle hole as a pivot, until the pointer marked 2.50 rests on a reading corresponding to the photo-base measurement in the small photo scale box labelled E. B. 2.50. The graduations of the E. B. scale box are in terms of inches of photo-base. The smallest graduation equals .5 inch of photo-base and a total range from 2.00 inches to 6.0 inches is provided. It is believed that by careful manipulation the pointer can be set to the nearest .10 inch of photo-base on the scale. For a check on the accuracy of the setting, the opposite side of the scale sheet and pointer sheet have duplicate scales and pointers. When the sheets are correctly adjusted opposite pointers for a particular eye-base should rest on identical settings on opposite photo-base scales, and those particular eye-base circles at the center should be in exact coincidence. The two sheets should now be fastened together with several inch-long pieces of scotch cellulose tape along the overlapping edges at the top and bottom. It is also well to apply tape near the center. After the two sheets have been securely taped together, the eye-base circles should be re-examined for coincidence and the pointer readings on the photo-base scales should be checked for perfect agreement. The needle may then be removed. Figure 3 shows a wedge which has been adjusted for an eye-base of 2.50 inches and a photo-base of 4.50 inches.

The two overlapping photographs should now be very carefully mounted on some table top or other flat surface for use under the lens stereoscope. Centers and conjugate centers should be carefully marked on each of the two photographs with a fine needle point. The photographs should be placed so that those four points are in exact line along the edge of a scale, and the photographs should be separated so that the distance between the center of one photograph and its marked position on the other photograph is equal to the eye-base setting of the variable elevation wedge, viz., in the case of this illustration, 2.50 inches. The photographs should then be fastened down with scotch tape. The stereoscope should now be placed over the photographs, and oriented, and the lens separation slightly adjusted until a clear, sharp model is perceived without any eyestrain.

Now place the elevation wedge on the surface of the photographs so that the two rows of dots are at approximate right angles to the line joining photo centers. Then, for more exact orientation, the operator should look through the stereoscope, and while clearly seeing the photo model, rotate the wedge slightly in either direction until the auxiliary rows of nine large target dots spaced about $\frac{3}{4}$ inch apart are *perfectly* fused into a single row of dots which point directly toward the observer. The transparent sheets should, of course be held down flat during this step. When the target dots are in sharp fusion the rows of small elevation dots will also be in sharp fusion. When the foregoing steps are completed the wedge is oriented in correct relation to the stereoscopic model.

For finding the difference of elevation between two points, the stereoscope should be moved and re-oriented until the two selected points are in the approximate center of the stereoscopic field. Bringing the variable elevation wedge into correct relative orientation with respect to the visible photo-model, and holding it down flat on the surface of the pictures, the operator should move it toward or away from him until some one of the small fused dots in the row numbered 0 to 800 rests on the ground at the first point. The two adjacent dots, which are respectively five feet higher and five feet lower should be checked to note if one appears slightly above the ground and the other slightly below the ground. Checking adjacent dots is an aid only on level spots of ground; on slopes it is obviously of no value. However, where the ground does slope, a good check can be afforded by turning the elevation wedge completely around to the opposite direction and then taking a check reading on the point. The two readings should agree within five feet. For close work, the readings may be averaged. The reading for the point should be recorded. Each floating dot represents an elevation increment of five feet from the adjacent dot. Every fifth dot is numbered on the wedge. The total range of this particular wedge is 800 feet, there being 160 dots. A reading should be similarly taken for the second point. The difference between the two readings then represents the difference in elevation between the two points. Successive readings on other points will likewise yield differences in elevation.

The two photographs must remain in the same relative positions while any series of points are being read. Likewise, the adjustment of the variable elevation wedge and the adjustment of the stereoscope lenses must not be disturbed during a series of readings. If it becomes necessary to "flip" the photographs to reach points hidden under the overlap, the readings taken after "flipping" is done will not be in correct relation to those taken before. In this connection, it might be mentioned that on photographs taken at 13,750 feet with an $8\frac{1}{4}$ inch

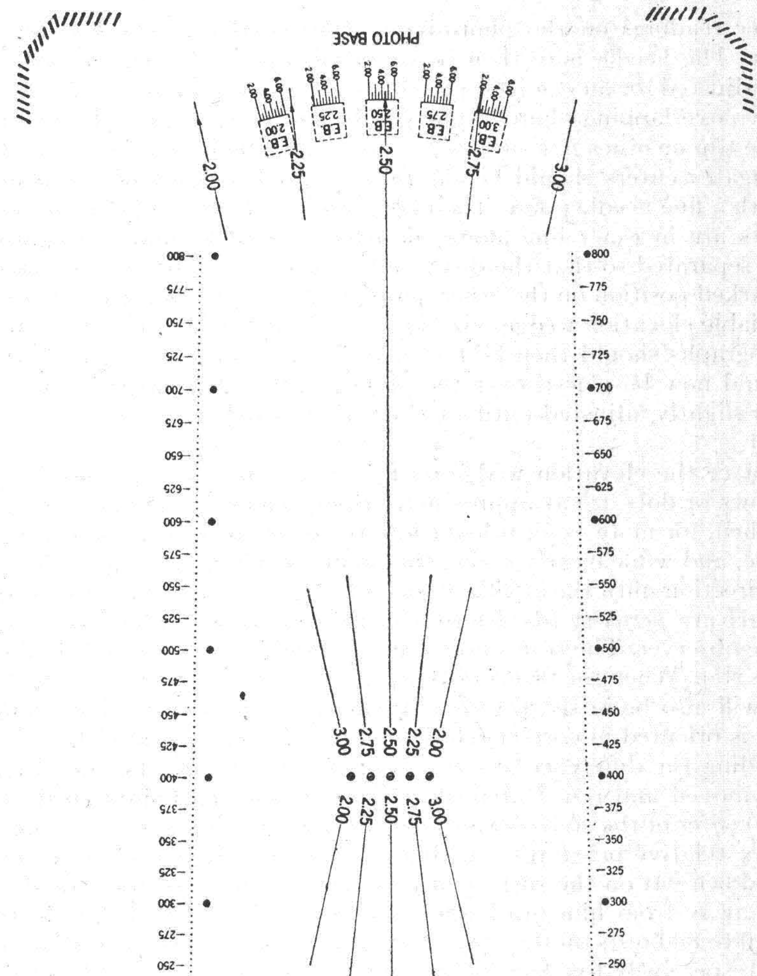

FIG. 3. Assembled Variable Elevation Wedge.

lens a parallax difference of .001 inch corresponds to an elevation difference of about four feet. An inordinate distortion of .01 inch could easily be caused in "flipping" the photographs which would amount to about 40 feet in elevation.

The procedure given above should be followed through for each separate pair of photographs, because one can expect photo-base variations on successive pairs which would cause excessive errors if the variable elevation wedge was not adjusted for each new average photo-base. However, as long as the same observer uses the same adjusted stereoscope the eye-base adjustment of the variable wedge need not be changed. The photo-base adjustment for any pair of photographs can be easily made and checked following the sequence of steps as previously outlined. To accommodate different observers' eye-bases adjustments varying from 2.00 inches to 3.00 inches by steps of .25 inch each are provided.

It will be noted that the photo-base adjustment scales cover the interval from 2.00 inches to 6.00 inches. This fact determines the types of reproductions from aerial negatives that may be used with the variable elevation wedge. Any pair of photos having a photo-base of not less than 2.00 and not more than 6.00 inches may be used regardless of the focal length of the lens in the original aerial camera provided that the aerial camera was about 13,750 feet above the ground when the exposures were made. For the standard aerial negatives at the scale of 1:20,000 exposed with an $8\frac{1}{4}$ inch lens this range of use covers everything from a $7'' \times 9''$ exposure reduced to .8 diameter to a $9'' = 9''$ exposure enlarged to 1.50 diameter. Any reproductions within those limits may be used. It is, of course, highly preferable that any prints used be on low-shrink paper.

It is stressed that readings obtained through use of the variable elevation wedge are relative figures which yield differences in elevations. The accuracy of the reading is mainly dependent on the ability of the observer to detect when a "floating dot" rests on the surface of the ground. There are, however, other factors which will each contribute an increment of error to the measurements. The shrinkage and distortion of paper and film are unavoidable sources of small errors. Tilt in either or both of the two aerial photographs used will cause inaccuracies which will become greater as the outer edges of the stereoscopic model are approached. However, for photographs which comply with the standard specifications with respect to tilt, elevation differences between points which are fairly close to each other should not be too seriously in error. Unequal elevations of the aerial camera at successive exposure stations will also cause small unavoidable errors.

As a matter of general interest it may be mentioned that the two component parts of the variable wedge are one-fifth of the size of the original drawing, which was prepared on a constant size base sheet. On the original five-diameter drawing great care was exercised to secure precision, the objective being to have all dots within .002 inch of their correct position. This of course entailed accurate beam compass measurements taken from a standard meter-bar. The final drawing was photographically reduced using the best precision lens available.

As to the accuracy of results obtainable with the variable elevation wedge, the possibilities can only be stated after assuming certain basic conditions. If the aerial film is in good condition and the reproductions are on low-shrink paper, and if there is no tilt in either of the two photographs, it is believed that an experienced technician should obtain elevation differences for points fairly close together within an average error of about 1/4000 times the denominator of the fractional scale of the photographs. For photographs at the scale of 1:20,000 the average error should not exceed five feet. The presence of tilt would, of course, commensurately increase the average error.