also indicated a greater need for uniformity rather than an increase in the resolution of aerial photography to be used for mapping.

XI. EVALUATION

The merit of this study lies in the great care that was exercised in eliminating differences in the conditions within each experiment-differences which might detract from the reliability of the measurements. The great number of measurements that were made strengthen the validity of small differences in stereo acuity that were found. There are many more variables of stereoscopic viewing which should be studied; however it is hoped that the information in this paper will be useful in the future development of stereo measuring equipment.

*Photogrammetric Measurements in Structural Research**

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ABSTRACT: *The photogrammetric method can be used as a measuring tool for different testing programs in structural research. This paper deals with the advantages, disadvantages, measuring accuracy, and limitations of photogrammetry. Practical applications to test specimens are illustrated.*

INTRODUCTION

DURING recent years, non-topographic photogrammetry has been widely discussed by photogrammetrists and engineers. At the same time, several illustrations of photogrammetric deformation measurements for structural members have been performed in the United States and foreign countries. Photogrammetric methods among other advantages for structural research provide answers rapidly; but, currently, such methods are not widely used as a measuring tool. The reasons for this under-development in applications to structural research are that the required instruments are difficult to obtain and are too expensive. These difficulties might be overcome by the production of standareized instruments which are versatile enought to be used for different purposes but are as simple, rugged, and economical as possible.

HISTORIC BACKGROUND

In 1937, Dr. Max Zeller had measured the interior roughness of waterpipes by the photogrammetric method,[1] with a special camera designed to photograph objects at close distances.

Professor K. B. Jackson of Toronto University of Canada presented his paper, "An Application of Photogrammetry in Structural Research," at the semi-annual meeting of the American Society of Photogrammetry in 1954.[2] His work dealt with the deformation of curved thin plates under axial loads.[3]

Dr. Bertil Hallert described the test of model airplane wings by a photogrammetric method[4] in PHOTOGRAMMETRIC ENGINEERING, December, 1954.

Around 1955, students at Ohio State University measured the deflections of simple supported beams and slabs photogrammetrically.[5]

At the semi-annual meeting of the American Society of Photogrammetry in March, 1958, Dr. R. D. Turpin presented his research on deflection measurements of highway pavement and soil movements.[6]

BASIC PRINCIPLE

The principle of photogrammetric measurement used in structural research is much

* This paper was awarded Second Prize in the 1958 competition for the Bausch & Lomb Photogrammetric Award. Photo of author is on page 314 of 1959 YEARBOOK.

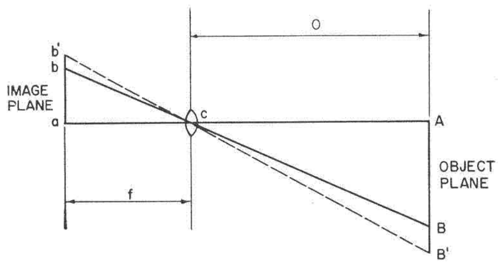

FIG. 1. Basic relationship between object and image planes.

simpler than the principle used for mapping and military purposes.

Figure 1 shows the relationship between object and image planes. By trigonometry.

$$bb' = BB' \times \frac{f}{O}$$

or

$$BB' = bb' \times \frac{O}{f} \quad (1)$$

where

BB' = Displacement of point B in object plane
bb' = Displacement of point b in image plane
O = Object distance
f = Focal-length

In Eq. (1) the distance in object plane, BB', is equal to the photo distance, bb', times the scale of the photography, O/f.

In the photogrammetric method, an initial photograph is usually taken before applying the load; then at subsequent stages photographs are taken under specific loading conditions. The deformation of the structural members can be computed by means of the deviations shown in the photographs and the scale of photography.

Advantages of Photogrammetric Method

The advantages of using a photogrammetric method to measure deformations can be summarized as follows:

(a) Photogrammetric method provides results rapidly without touching the test specimens.
(b) A single photograph registers the positions of all points simultaneously.
(c) Any part of the specimen can be used for measurement, whereas for the conventional testing method only a few points are investigated.
(d) Measurements are free from inertia or friction, and the mechanical errors can be neglected.
(e) The measurement can be repeated and checked at any time because the original photographs are available.
(f) Test can be conducted at higher speeds photogrammetrically than can be done by present mechanical methods.
(g) The photographs can be taken, and deformations measured, without interrupting the application of the load.
(h) Results can be obtained throughout the test clear to and even including destruction of the specimen.

Disadvantages of Photogrammetric Method

The disadvantages of using a photogrammetric method to measure deformations are:

(a) A special camera has to be designed for the photogrammetric method because a fixed-focus camera will not yield satisfactory photographs when the object distance is less than about 50 feet.
(b) The cost of designing a particular camera for a particular test may be too high.
(c) The larger the specimen, the less accurate the results are likely to be.
(d) Specialized lighting may be required for the photography.

Application to Structural Testing

I. TESTING OF BEAMS

A. *Vertical Deflection of a Beam Specimen.* The main purpose of this testing is to investigate vertical deflection of steel, reinforced concrete, or other types of beams subjected to uniform, concentrated or any other loads.

Generally, the initial photograph taken before the load is applied provides the basic information. Other photographs are then taken under specific loads. As shown in Figure 2, when these two photographs are rotated ninety degrees (90°), the deflections of the beam appear as x-parallaxes which may be measured by a stereo-comparator or by a mirror stereoscope with a parallax bar. The deflection can easily be computed by using Eq. (1). In the testing program the dial gages may be used as checking instruments.

B. *Lateral Deformation of Beam Specimen.* Lateral stability is very important for long thin members. The apparatus for such testing is illustrated in Figure 3. The horizontal line-filament lamp is located in such a way that its

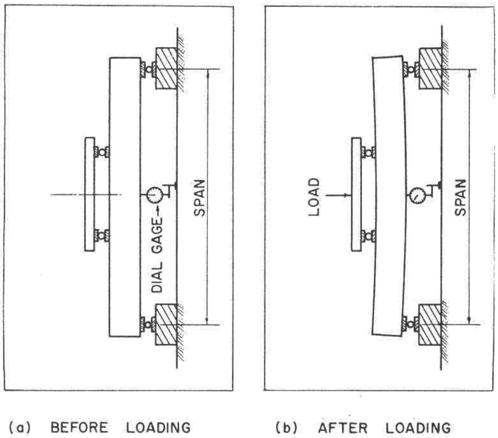

FIG. 2. Vertical deflection measuremnts.

light casts sharp shadows from a series of horizontal grid wires onto the surface of the specimen. The grid wires are fixed in a steel frame. In this example a $\frac{1}{2}$ inch spacing of wires is used. The angle between the line of light and the camera is 45°. If vertical grid wires are selected for measurement, a number of vertical line-filament lamps must be used.

A photograph of the grid wires and shadows show straight lines uniformly spaced on the surface of the specimen before loads are applied (Figure 4). After applying the loads to the beam, deflections in both the vertical and the horizontal directions are produced simultaneously. The deviations of shadows represent the combination of vertical and lateral deflections. The determination of such deflections can be summarized as follows:

(1) As stated in part A the deviation due to vertical deflection along the beam can be measured (Figure 2).

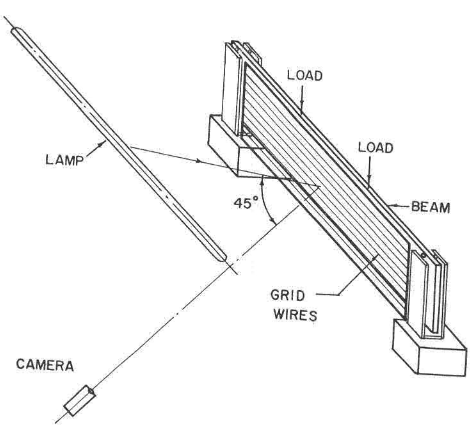

FIG. 3. Lateral deflection apparatus.

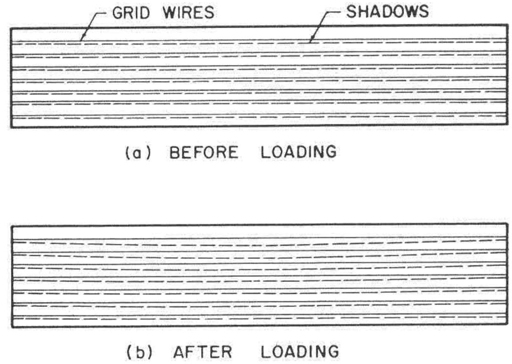

FIG. 4. Photographs of lateral buckling of beams.

(2) The difference between the total deviation and the deviation due to vertical deflection is the value caused by the lateral deformation and is equal to the deviation times the scale of the photography.

C. *Cracks of Reinforced Concrete Beams.* In the testing of reinforced concrete beams the number of cracks and the crack width become major points of investigation. The photographs taken for measurement also record the location and length of individual cracks. This information is pertinent to the theory of deflections. Some theories have been developed for determining the spacing of cracks. The photogrammetric method provides exact, permanent observations of such a test.

The widths of cracks are usually very small, and may be measured by using a microscope. After each increment of loading, the cracks are outlined with a heavy black crayon and a photograph of them is taken.

II. BUCKLING TEST OF THIN PLATES

The allowable stress of thin aluminum alloy plate used for airplanes is usually designed based on the buckling strength. Light-gage steel members used for construction are tested in the same manner. A considerable number of buckling-strength tests have been made using ordinary methods by aircraft companies and university research laboratories. Professor K. B. Jackson, Department of Applied Physics, University of Toronto, has developed an apparatus for testing curved, thin, aluminum alloy plates under axial loading. This work was carried out by the National Research Council, Ottawa, Canada, during World War II.[3]

The photographic apparatus used by Professor Jackson is described as follows:

The aluminum curved plates (18 inches long, 4 to 8 inches wide, 0.018 to 0.036 inches thick, with radii of curvatures between 24 inches, and 48 inches) are subjected to loading by a Southwark-Tate-Emery Testing Machine.

A 17 cm. Zeiss Tessar Camera, $3\frac{1}{4}\times 4\frac{1}{4}$ inches format, was used for photography.

A vertical line-filament lamp used as a light source cast sharp shadows of grid wires on the surface of the specimen. The position of the lamp, the wire grid, and the scale of the photographs are arranged in such a way that images of shadows are formed in straight lines and keep a constant distance, 0.5 mm., from the adjacent images of the wires. Under axial loading the plate deforms and the shadow of the wire grid will bend to the right if the vertical section of the specimen is bent backwards.

On the photographs, measurements were made by Zeiss Stereo-comparator over the whole area on 0.5 inch centers. The contours of initial deformation and deflection and specific loading were plotted.

For other kinds of thin plates, the same grid wire system can also be used to measure deformations. The geometry of the photographic method used in this project was shown in the report of the National Research Council of Canada, 1947.[3]

Using the simplified photographic method, the deflection of the specimen at the nominal position of the shadow may be assumed equal to the measured displacement of the shadow times the scale.

III. SHEAR RESISTANCE TEST ON LIGHT-GAGE STEEL CONSTRUCTION

In 1958, many tests for lateral resistance on light-gage steel construction were carried out in the Structural Research Laboratory of Cornell University. The framework for testing is illustrated in Figure 5a. When the load was applied by jacks, the frame was distorted. The process continued until the assembly reached the maximum lateral resistance, at which time failure of the welding and buckling of the elements occurred.

The photogrammetric method can also be used as a tool in measuring the deformation of this frame. The buckling deformation can be measured by means of grid wires as stated previously.

CAMERA ORIENTATIONS

For the ideal case there is no movement of the camera since both the inner and outer orientation of the camera are constant from exposure to exposure.

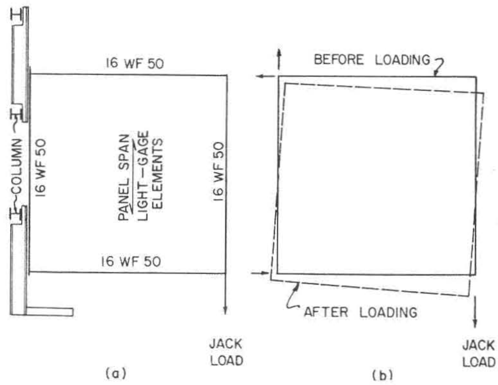

FIG. 5. Shear resistance testing for light-gage steel construction.

In practice, however, some corrections may be needed for unavoidable movement of the camera. Usually fixed marks can be located on the background outside of the specimen, as reference points. If parallax appears in such points, the orientation has been changed; furthermore, the error in orientation can easily be corrected.

MEASURING ACCURACY IN PHOTOGRAPHS

The error in measuring a photograph is one of the principal errors in the photogrammetric method.

By using a stereo-comparator the typical standard error is 3 to 5 microns (0.003 to 0.005 mm.). When the stereoscope and parallax bar are used in measuring photographs, the standard error is in the range of 10 to 30 microns (0.01 to 0.03 mm.). The size of this error depends, mainly, on the experience and natural aptitude of the operator. When accurate measurements are required, a stereo comparator should be used as a measuring tool.

In the usual method of testing, the dial gage is used for measuring deflections of specimen members. The accuracy of the dial gage is 0.001 inch. To achieve the same accuracy as the dial gage, in the photogrammetric method using a stereo comparator, the scale of photography should be less than 6.35. This maximum can be derived as follows:

Required measuring accuracy of deflection $=0.001$ inch

Standard error in measuring photograph $=0.004$ mm.

$0.001\times 25.4=0.004\times$ scale of photography

Scale of photography $=6.35$

The scale of photography used in Professor Jackson's project was 5.08. This may be considered as one of the limitations of using the photogrammetric method, because some specimens may range in size from ten to thirty feet. Photogrammetric inaccuracies can result in photographs taken of such subjects. Consequently, the inability to photograph accurately at certain distances, from the subject, is a definite limitation of this method.

Conclusion

For relatively smaller specimens, the photogrammetric method can provide great accuracy and complete information in measuring deformations of the specimens. Under good lighting conditions the photographs can be taken without stopping the load application, and, as a result, rapid records can be continuously obtained. But for larger specimens, the scale of the photography (O/f) usually may be greater than the limiting value (6.35 to produce values comparable to a 0.001 in. dial gage). For large specimens it is more difficult to obtain better accuracy.

Care must be taken that a precise lens is used in the camera for photogrammetric measuring. The focal-length, angular field, and depth of focus of the lens must form a compatible system for each test set up. Different structural tests may require different lenses and obtaining these lenses may become expensive.

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*A New Portable Reflectance Spectrophotometer for the Selection of Film and Filters for Aerial Photography**

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ABSTRACT: *The paper will consist of (1) illustrations and description of the Reflectance Spectrophotometer built by Perkin-Elmer Corporation for the U. S. Army Engineer Research and Development Laboratories (2) the operating characteristics of the instrument and (3) examples of the first field data obtained and how it applies to the problem of film-filter selection.*

BROADVIEW, as well as many other groups and individuals, has long felt the need for a logical and systematic approach to the use of films and/or filters for the best delineation of aerial photographic subjects. Because the images on a photo represent so many hues that no one film-filter combination will separate all the objects, the few objects which are of primary interest usually determine the film-filter combination used. A choice of a film-filter combination all too often has had to depend on guesswork as to the spectral

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