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A. J. Peterka

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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HYDRAULIC LABORATORY REPORT NO. 164

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THE FLUID POLARISCOPE

by

FRED LOCHER, ASSOCIATE ENGINEER
and
J. N. BRADLEY, ENGINEER

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Denver, Colorado
Dec. 12, 1944

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SUBJECT: THE FLUID POLARISCOPE

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DEPARTMENT OF THE INTERIOR
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Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
December 12, 1944

Laboratory Report No. 164
Hydraulic Laboratory
Compiled by: Fred Locher and
J. N. Bradley
Reviewed by: J. E. Warnock

Subject: The fluid polariscope.

1. General description. The diverse responses of a flowing fluid to variously shaped forms is a fascinating study but not an exact one unless the directions of the flow can be made visible. A new method of study developed during recent years at Massachusetts Institute of Technology promises a real advance in this branch of hydrodynamics. Much of the following information was obtained through contact with Mr. Walter Leaf of the Denver and Rio Grande Western Railroad who has made practical use of the fluid polariscope in the investigation of the design of locomotive fireboxes and other similar problems. The method is analogous to that wherein polarized light is used to render visible the strains in plastic models of solid structures. When stressed, these models deform slightly and in so doing bend and twist the polarized light passing through them in a manner such that visible color bands or fringes show at the points of strain. These fringes photograph well in black and white (figure 1-A); but in most cases involving fluid motion, color photography is preferred. In the analysis of fluid flow, a suspension of bentonite in the fluid modifies the polarized light in a manner similar to that which occurs in a stressed plastic model.

The bentonite particles consist of platelets so small that there is no tendency to settle out of the suspension and so light that they move with the fluid, apparently having no appreciable inertia of their own. These physical properties, as well as its optical properties, make bentonite superior to other substances used to follow fluid flow, such as ink, smoke streams in gases, or fine bubbles. The latter materials cannot follow the paths of fine eddy motion where streamline flow is disrupted.

In the analysis of fluid stream flow the bentonite so modifies the light passing through the stream that colored bands or fringes are visible, connecting points where a particular rate of change in speed of the fluid prevails. High-speed photography by the use of the Strobolux and the Stroboscope, obtainable from the General Radio Company of Cambridge, Massachusetts, has enabled the observation of highly turbulent flow as well as more nearly streamline flow.

The method can be used qualitatively to observe how a moving or a stationary object affects the flow, or quantatively to calculate the necessary data. It is even possible by polarization of fluid flow to calculate the rate at which heat will be transferred from a solid to a liquid.

Within limits, the information obtained with fluid flow is applicable to gases; so the method is useful in aviation and many other fields.

2. Details of model and related equipment. A two-dimensional model usually consists of a thin section of the structure or device to be tested, approximately 1/2 inch to 1 inch thick, mounted between two plates of glass or clear plastic. A plane polarized lens and a quarter-wave plate are placed between one face of the model and a diffused light source such that circularly polarized light will pass through the portion of the model to be studied. A second polarizer and a quarter-wave plate are placed on the opposite or viewing side of the model. This second pair of plates serves to return the circularly polarized light to its original state. The polaroid and the quarter-wave plates are obtainable in sizes ranging from 1 inch to 12 inches in diameter, from the Polaroid Corporation, Cambridge, Mass., or the Photoelastic Company, 55 West 42nd Street, New York City, N. Y.

The bentonite is of a special type which must be optically active or double refracting. The Colorado, the Utah, and the Wyoming types are, in general, not optically active. The most satisfactory bentonite comes from California desposits and may be purchased from the Baroid Sales Division of the National Lead Company, 830 Ducommun Street, Los Angeles, California, attention of Mr. D. H. Larson. The raw bentonite should be dissolved in distilled water making not over a 5-percent solution, by weight, to allow the grit and other foreign material to settle to the bottom. The solution should be stirred occasionally during the first few days and then allowed to stand for a month or more, undisturbed. After the settling period, the clearer portion of the liquid at the top of the container can be removed by siphoning and the milky material at the bottom of the container can be discarded. The water can then be evaporated and the dry material stored in nonferrous containers, or the bentonite mixture can be stored in Pyrex bottles. Separation of the foreign material can also be accomplished with a Sharples supercentrifuge. This method will require much less time and probably will result in a superior product.

The bentonite and water mixture should contain approximately 1.5 percent of bentonite, by weight, and 0.01 percent of sodium pyrophosphate. The fluid should be stored in Pyrex bottles and not be allowed to contact ferrous metals, as the bentonite reacts chemically with these metals, partially destroying the optical effect.

A suitable pump for small models may be obtained from the Eastern Engineering Company of New Haven, Connecticut. This is a small, centrifugal pump, called the model B, direct-connected to a rheostat-controlled motor, making it possible to regulate flow. The capacity is 7 gallons per minute at zero pressure, or zero gallons per minute at 17 lbs. pressure.

A photograph of a model with necessary equipment is shown on figure 1B. The model to be tested is located between the two quarter-wave plates. A reservoir capable of holding several times the amount of solution actually required for operation of the model is located beneath the model. The small laboratory pump on the left circulates the liquid through the model and back to the reservoir. The speed of the pumping can be controlled by the rheostat mounted above the pump; thus it is possible to view laminar flow as well as turbulent flow. Operation could be improved by mounting the reservoir so that the water surface would be above the high point of the model at all times. This would eliminate certain difficulties that have been experienced with entrainment of air in the model, as shown on figure 1B.

3. Method of adjusting polarizers. To adjust the optical system, introduce the two polaroid polarizers and rotate one of these around its axis until extinction of light is obtained. Make one of the polarizing axes of the polarizers vertical and the other horizontal with the aid of a thin, polished, circular, transparent bakelite disk loaded at each end of a diametrical vertical line. If a perfect cross appears as a black band in the field of multicolor stress fringes, then the polarizing axes are vertical and horizontal. If not, then rotate the two polarizers in the same direction by the same amount (thus keeping the extinction of light unaltered) until the cross is formed. The result is plane polarized light.

To eliminate the isoclinics from the field of stress fringes, introduce one quarter-wave retardation plate between the two polarizers, described above, and rotate it until extinction of light is restored. Pass this position by 45 degrees, at which point maximum illumination is obtained. Put the second quarter-wave plate between the first and the remaining polarizer and rotate this plate until extinction of light is restored. The axes of the two mica plates are now at right angles to each other and each is at a 45-degree angle with the axes of the polarizers. The light between the mica plates is then circularly polarized. This is the type of light generally used in photoelastic work.

4. References. The first reference applies to two-dimensional flow.

(1) "Visible Strain," The Engineer, November 12, 1943, p. 385, vol. CLXXVI, No. 4583.

The following references apply to three-dimensional analysis by the scattered-light method. There are definite possibilities for obtaining results with this method in an hydraulic model when the flow is three-dimensional.

(2) R. Weller and J. K. Bussey, "Photoelastic Analysis of Three-Dimensional Stress Systems Using Scattered Light." N.A.C.A., Technical Note No. 737 (1939).

(3) R. Weller, "The Analysis of Three-Dimensional Stress Problems by Photoelasticity." Presented at the joint session of the Civil Engineering, Mechanics, and Research Divisions of the S.P.E.E. at Berkeley, California, June 1940.

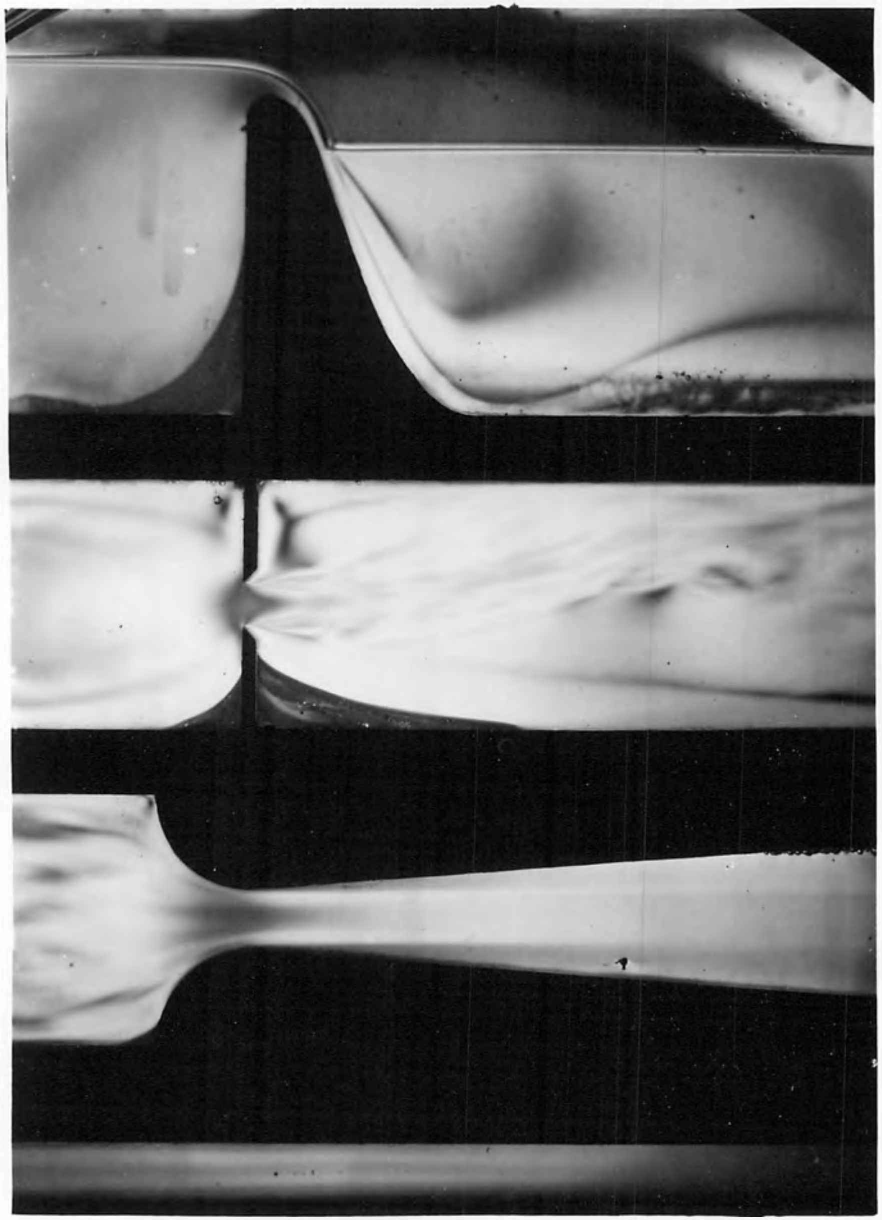
(4) D. C. Drucker and R. A. Mindlin, "Stress Analysis by Three-Dimensional Methods." Journal of Applied Physics, vol. 11, No. 11, November 1940, pp. 724-732.

(5) R. A. Mindlin, "A Review of the Photoelastic Method of Stress Analysis." Journal of Applied Physics, vol. 10, No. 4, April 1931, pp. 222-241; vol. 10, No. 5, May 1939, pp. 273-294 (parts I and II).

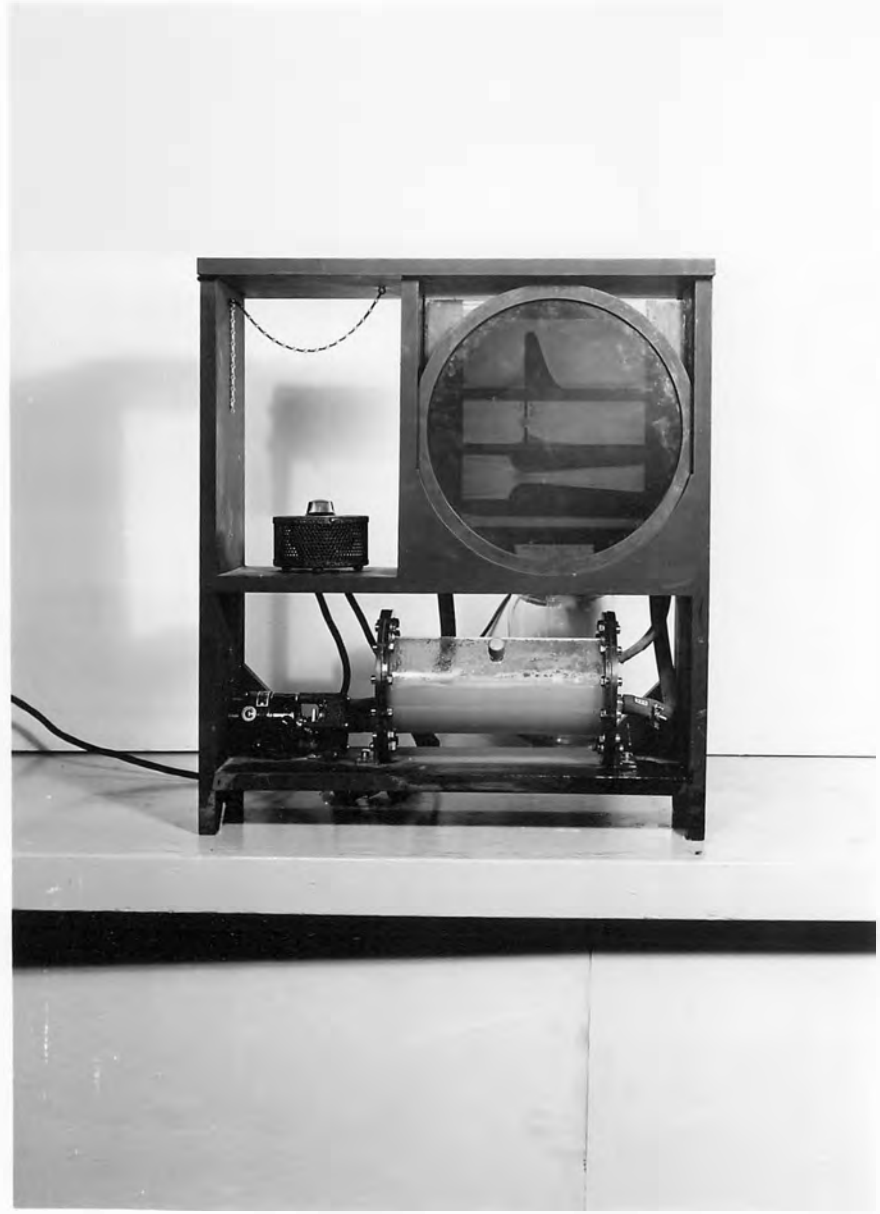
(6) P. R. Rosenberg, "Study of a Shrink Fit Model by the Scattered-Light Method." Proceedings of the Thirteenth Semi-Annual Eastern Photoelasticity Conference, June 12, 13, and 14, 1941, pp. 99-103.

The following article refers to a method for obtaining instantaneous pictures of hydrodynamics which would make it possible to analyze the results more accurately.

(7) F. S. Wyle, "Some Photoelastic Studies in Dynamics." Proceedings of the Thirteenth Semi-Annual Eastern Photoelasticity Conference, June 12, 13, and 14, 1941, pp. 13-16.



A - Photograph of flow through model showing fringes.



B - Front view of model and accompanying equipment.

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