

# INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



*This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:*

<https://www.issmge.org/publications/online-library>

*This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.*

# SUB-SECTION II 9

## MISCELLANEOUS

II 9 14

### A STUDY OF PHOTOELASTIC MODELS OF FOUNDATIONS

ROBERT R. PHILIPPE

Head Engineer Ohio River Division Laboratories, Corps of Engineers, Mariemont, Ohio

FRANK M. MELLINGER

Senior Engineer Ohio River Division Laboratories

#### I. INTRODUCTION

Stress analysis by means of photoelastic models presents two problems to the investigator. The first problem involves the application of the model analysis to design; the second involves technique, such as the selection of model materials, preparation of the model, methods of loading, and examination and recording of results. The objective of this paper is to present only a model technique for investigating stress distribution in foundations beneath wall structures and earth embankments. The photoelastic medium used is gelatin, which has the advantage of allowing loadings of the same scale as the dimensional scale of the model. Since the use of gelatin for two-dimensional photoelastic model studies requires special treatment in model construction and calibration, the greater portion of this paper will deal with that phase. Only a minimum of theoretical background will appear, supplemented by references to the extensive published works on theoretical treatment of photoelasticity and elasticity. To illustrate the techniques, the solution to the specific problem of evaluating the boundary stresses for a flood wall with a sloping base and vertical key is presented.

#### II. SCOPE

The preparation and examination of photoelastic models of foundations has been developed by the Corps of Engineers 4), 5), over a period of about 10 years. The present method of examining foundation stress distribution has proved to be an excellent tool of investigation, particularly where boundary conditions and loadings are complicated. This is true even though the assumption of elasticity is necessary and for the particular case illustrated, uplift forces due to seepage beneath the wall are not simulated by the model.

The illustrative example used in this paper is a part of a study to compare quantitatively the effect of varying base to height ratios and key depths of six different flood wall designs, on the distribution and magnitude of foundation stresses.

Flood walls are used by the Corps of Engineers for local flood protection works instead of levees or dikes in areas congested by buildings and utilities to the extent that the acquisition of the additional right of way necessary for an earth levee is uneconomical and impractical.

#### III. PREPARATION OF MODEL

The first consideration in the preparation of the model is the selection of a model scale. This is controlled by the size of the tank. The tank shown on Fig. 1a is about the largest

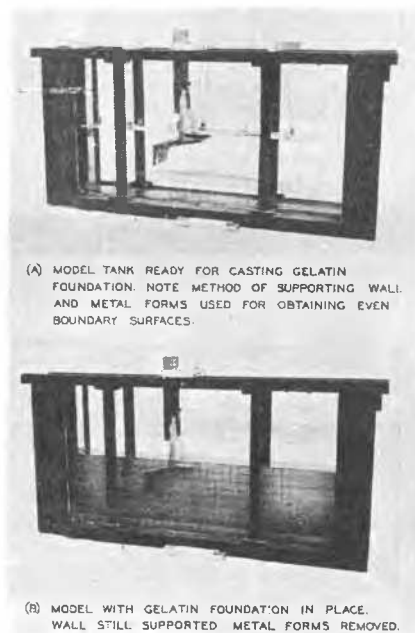


FIG. 1

practical size in consideration of the amount of gelatin required and the observation of the finished assembly in the polariscope. The inside dimensions of this tank are 41 x 18 x 4-inches. The other controlling features are the depth of overburden to a rigid boundary and the maximum wall heights. In the present case the maximum wall height was 32 feet above the ground surface and the depth of overburden to a rigid boundary about 40 feet. For these conditions a model scale of 1 to 60 was best suited.

The model of the flood wall was constructed to the 1 to 60 scale using a form of 24-gauge galvanized metal, and filling it with cement mortar. The model wall section was 3-7/8-inches wide. The combination of the metal form and mortar gave about the same unit weight per unit length of wall as that of the prototype, and therefore, only the dimensional scale reduction controlled.

Next, the model wall was set in the tank in its proper position with reference to the foundation, allowing as much free length landward from the wall as possible to avoid end effects, and to provide space for calibration of the gelatin foundation. This arrangement is illustrated by Fig. 1a which also shows horizontal metal forms in place to provide an even boundary surface. The bottoms of the forms are

greased lightly with vaseline.

The next step is to prepare the gelatin for casting the foundation. For these tests a mixture of 15% gelatin and 85% distilled water by weight was used. Any reasonably well refined brand of commercial gelatin will yield a sufficiently clear model, providing this procedure is followed. (1) Soak the gelatin in water for three to four hours or until it is well saturated. (2) Heat the gelatin in a double boiler arrangement until it is melted completely; this can be done without getting the gelatin solution above 50° C. (3) After melting, impurities such as hair and dirt are removed from the gelatin by straining it through a clean cloth or a 250 mesh sieve. It is also important that all containers used be thoroughly cleaned and that a cover be kept over the pans while soaking and heating. (4) The gelatin solution is allowed to cool to about 35° C. before it is poured in the 4-inch-wide glass sided tank, prepared as shown on Fig. 1a, for casting the foundation with the wall in place. (5) The gelatin is poured to about 1/4-inch above the horizontal metal forms. The gelatin will solidify and cool to room temperature in about 10 hours. Room temperature should be constant and controlled at about 21° C., particularly during photoelastic examination of the model. (6) After the gelatin is solidified, the horizontal spacers or forms and the excess gelatin are removed, thus establishing an even, free boundary surface. This is necessary for the reason that as the gelatin cools its surface dries and shrinks. Such shrinking forms a meniscus which adheres to the sides of the tank and produces a slightly concave surface.

Just before the model is loaded and examined for its stress optical properties in the polariscope, Fig. 1b, the gelatin is freed from the glass sides of the tank by means of a long bladed knife; the space behind the knife being filled with water at room temperature. The knife should be kept warm and greased with vaseline to avoid tearing the gelatin. When the gelatin is freed from the glass sides these boundaries are practically frictionless; simulating a condition of two-dimensional strain for the foundation when load is applied.

In the case of the flood wall model the following two loadings are applied to the foundation: - Load 1, that due to the weight of the wall less the effect of submergence; Load 2, the water load. This latter loading is applied by filling a dental rubber sack contained by the wall and the sides of the tank as shown by Fig. 4b. The effect of submergence applies to both the foundation and wall. In the case of the foundation, the weight of the gelatin is 62.5 lbs. per cubic foot, about the weight of submerged earth in most cases. For the wall section, the submerged portion is buoyed up by a force equal to the weight of the displaced gelatin. This force is present in the gelatin foundation as an isotropic stress condition and does not appear in the stress pattern produced by the weight of the wall, and the water load. Therefore, the stresses from the photoelastic pattern bear a direct relationship to the prototype of 1 to 60, the linear model scale, since the unit weights of the model components are approximately those of the prototype.

#### IV. CALIBRATION OF THE FOUNDATION

After being freed from the glass sides of the tank, the gelatin is calibrated to obtain the stress fringe relationship for the foundation. This is accomplished by applying a uniformly distributed load to the surface of the

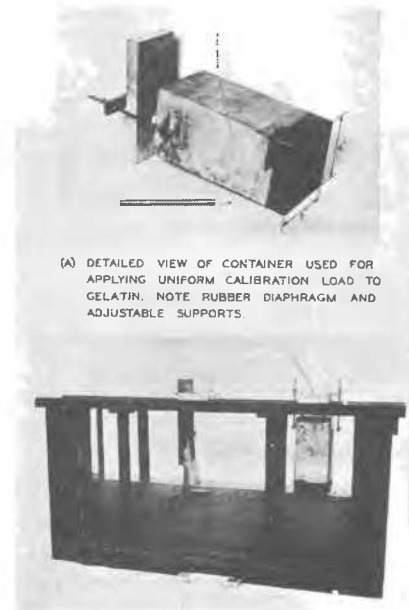


FIG. 2

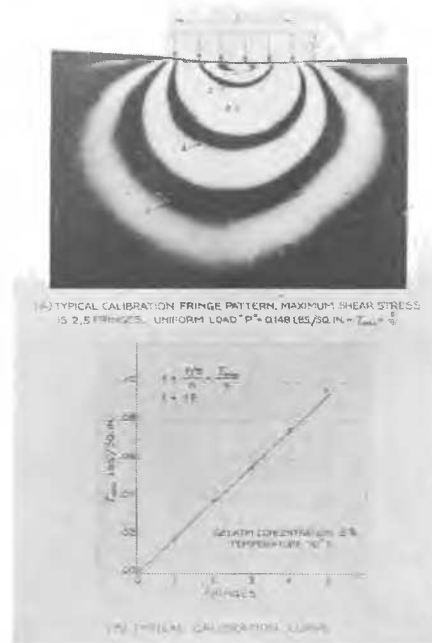


FIG. 3

gelatin. Uniform pressures are obtained by a water column acting on the gelatin through a rubber membrane as shown on Figs. 2a and 2b. In Fig. 3a the uniform pressure "p" acting on the gelatin is 0.148 psi. It can be shown that the maximum shear stress " $\tau_{max}$ " in such a case is given by the expression

$$\tau_{max} = \frac{p}{\pi} = \frac{0.148}{3.1416} = 0.047 \text{ psi}$$

Since the thickness "t" of the model is 4 inches and the maximum fringe order n is 2.5 the material fringe value "f", 1) page 161 is,

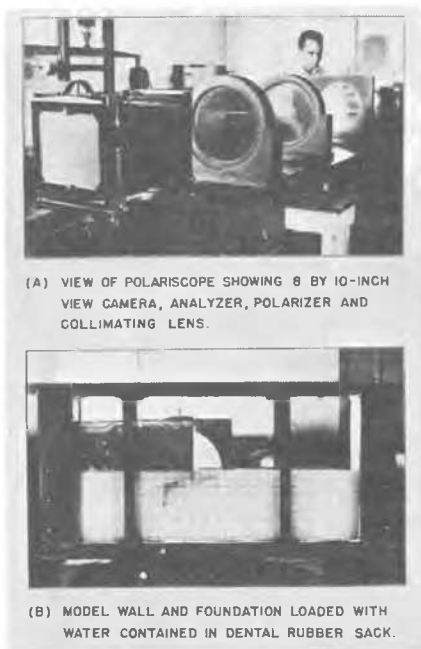
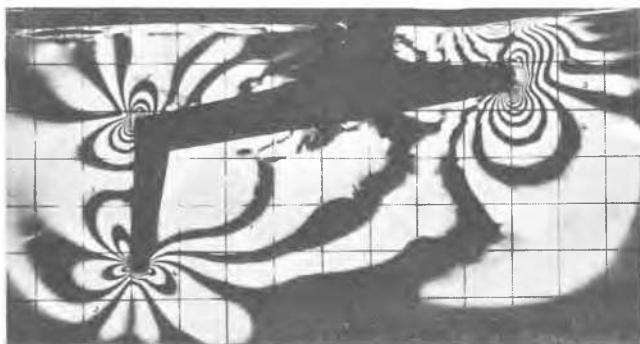


FIG. 4



Isochromatic pattern for model 4.0  
 $F = 0.0188$  Lbs. per sq. in.

FIG. 5

$$f = \frac{\tau_{\max} t}{n} = \frac{0.047}{2.5} \times 4.0 = 0.0752 \text{ psi. shear stress}$$

and the fringe value of the model "F" is,

$$F = \frac{\tau_{\max}}{n} = \frac{0.047}{2.5} = 0.0188 \text{ psi. shear stress}$$

Fig. 3b. shows the complete results of the calibration tests for the gelatin foundation.

#### V. LOADING THE MODEL

The next step is to load the model and obtain the isochromatic fringe pattern and the isoclinic pattern of the foundation as shown by Figs. 5 and 6 respectively. Loading is accomplished by releasing the wall and filling a dental rubber sack with water as shown by Fig. 4b. The resultant horizontal and vertical forces applied are shown in prototype dimensions (sixty times the model loading) by Fig. 7.

#### VI. POLARISCOPE

After applying the load to the foundation, the stress optically sensitive gelatin is examined in a polariscope by means of both white light and monochromatic light. The polariscope used, Fig. 4a, consists of a suitable lens system, with 12-in. diameter polaroid discs and quarter wave plates for the polarizer and analyzer. The model is viewed directly through the analyzer, or when pictures are required, an 8 by 1-in. view camera is used. Two overlapping photographs were necessary to obtain the monochromatic fringe pattern of Fig. 5. The monochromatic light source was a 100 watt lamp of the type A - H - 4 (Westinghouse) with a suitable ballast transformer. The white light source was a 400-watt Mazda spot light.

#### VII. RECORDING THE ISOCHROMATIC FRINGE PATTERN AND THE ISOCLINIC PATTERN

The isochromatic fringe patterns shown on Figs. 3a and 5 were obtained using monochromatic light. The black and white fringes shown thereon are loci of equal maximum shear stress for which the value is fixed by the calibration of the model and the order "n" of the fringe. The order for the key fringes are shown by the arabic numbers on the patterns. To determine the order of the black fringes, it is necessary to examine the model visually with white light which yields a colored fringe pattern of yellow, red, and green bands. The progression from yellow to red to green repeated indicates that the stress is building up while the reverse indicate reduction in stress. For both the foregoing operations the quarter wave plates are used in what is termed a standard or crossed circular polariscope, Frocht 1) p. 126. The next step is to determine the isoclinics or the loci of equal angularity of the principal stresses. In this case the polariscope arrangement is the same as above, except that the quarter wave plates are removed. The isoclinics show up as dark bands and for this reason a white light source is used, as the dark bands will show up better over the colored stress pattern than over a monochromatic or black and white pattern. The isoclinics shown on Fig. 6 were sketched using the 1-in. grid system inked on the glass sides of the tank, see Fig. 1a. Each isoclinic represents a separate setting of the analyzer and polarizer which were revolved synchronously through  $90^\circ$ . Frocht 1) p. 181.

#### VIII. REDUCTION OF BOUNDARY STRESSES

It is now possible to evaluate the maximum shear stress ( $\frac{p-q}{2}$ ), where p and q are the major and minor principal stresses) at any point in the foundation by means of the isochromatic pattern of Fig. 5. Also the shearing stress on the X and Y planes is obtaining at any point in the foundation by the relationship:

$$\tau_{xy} = \frac{p-q}{2} \sin 2\theta$$

Where " $\theta$ " the angularity of the principal stresses is obtained from Fig. 6. Furthermore the values of the normal stresses are determined at the free boundaries. For example, on the landside free surface:

$$q = \sigma_y = 0$$

and

$$p = 2 \tau_{\max} = \sigma_x$$



ing advantages and limitations.

- a) It has greater optical sensitivity than any other known material from the point of view of double refraction, thereby permitting true scale loading.
- b) It can be cast to any required shape, and is sensitive enough to allow the evaluation of stresses due to body forces. 2)
- c) Normal and shear stress determinations are within the requirements of engineering accuracy.
- d) The assumption of elasticity for the foundation is made necessary by the method of test.
- e) For the case illustrated, uplift forces on the wall section due to seepage are not simulated, although they can be determined separately and superimposed on the results.
- f) Due to the rigid confinement of the glass sides of the tank, the gelatin foundation simulates a condition of true two dimensional

strain.

#### BIBLIOGRAPHY

- 1) Frocht Max. M., Photoelasticity, Volume 1 John Wiley and Sons, Inc., New York, 1941.
- 2) Farquharson, F.B. and Hennes, R.G., "Gelatin Models for Photoelastic Analysis of Stress in Earth Masses", Civil Engineering, Vol. 10, No. 4, April 1940.
- 3) Nadai, A., Plasticity, p. 247, McGraw Hill Book Co., 1931.
- 4) Knappen and Philippe, Soil Mechanics at Muskingum III, Engineering News Record, April 23, 1936.
- 5) Middlebrooks, T.A., Foundation Investigation of Fort Peck Dam Closure Section, Paper G-3, Proceedings of the International Conference on Soil Mechanics and Foundation Engineering June 22 to 26, 1936, Vol. 1